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Chapter 1.1: Energy Scenario

Part–I: Objective type Questions and Answers

1.	The highest consumed primary fuel in the world is: a) Coal b) **Oil** c) Natural Gas d) Renewables
2.	The fossil fuel which has seen highest growth internationally is: a) **Natural Gas** b) Oil c) Coal d) Nuclear
3.	The largest contributor to Pakistan's primary energy mix is: a) Coal b) Oil c) **Natural Gas** d) Nuclear
4.	In 2017-18, the province with highest natural gas production was: a) Baluchistan b) **Sindh** c) Punjab d) KPK
5.	The sector consuming major share of primary energy in Pakistan is: a) Agriculture b) **Industrial** c) Transport d) Domestic
6.	Wind energy potential for Pakistan at 50m height is: a) 40GW b) 48GW c) 46GW d) **50GW**
7.	The global Reserve/Production ratio shows that oil reserves in 2018 accounted for ____ years of current production a) 30 b) 46 c) **50** d) 58
8.	The global Reserve/Production ratio shows that coal reserves in 2018 accounted for ____ years of current production a) 100 b) **132** c) 154 d) 58
9.	In 2017, Pakistan imported major share of refined petroleum from: a) Qatar b) **UAE** c)Kuwait d) Oman
10.	The sector consuming major share of electricity in Pakistan is: a) Agriculture b) Industrial c) Transport d) **Domestic**
11.	One component of Paris agreement is to hold the increase in global average temperature below 1.5°C. State True or **False**
12.	The Global Climate Risk Index 3 has categorized Pakistan in top ten severely climate-

	affected countries in the world, with imminent adverse impacts. State True or False
13.	Natural gas consumption in 2017-18 was highest in a) Power plant b) Industry c) Transport sector d) Domestic sector
14.	LPG consumption in 2017-18 was highest in a) Transport sector b) Domestic sector c) Industrial sector d) Commercial sector
15.	In 2017-18, highest crude production was in the province of: a) Sindh b)KPK c) Baluchistan d) Punjab
16.	Renewables constituted ____ percentage of the total electricity generation mix in 2017-18. a) 5 b) 8 c) 2 d) 3
17.	As of 2018, total installed solar PV capacity in Pakistan is: a) 430 MW b) 450 MW c) 330 MW d) 550 MW
18.	By 2030, the GHG emission is expected to be highest from the electricity generation sector. State True or False
19.	Bagasse based generation contributed to ___ percentage of Pakistan's renewable energy generation in 2017-18. a) 26.2% b) 28.4% c) 25.6% d)33.5%
20.	Estimated solar power generation potential of Pakistan is: a) 3000 GW b) 2500 GW c) 3300 GW d) 2900 GW

Part–II: Short Questions and Answers

S1.	Mention any 5 powers vested on NEECA by the National Energy Efficiency and Conservation Act 2016. Ans. Five powers vested in NEECA by the National Energy Efficiency and Conservation Act 2016 are: • initiating demonstration and research and development programs • taking up capacity building and institutional development initiatives • establishing accredited laboratories for carrying out testing and analysis • recommending to Federal or Provincial Government, fiscal and financial incentives for achieving energy conservation objectives

	• carrying out energy audits either by itself or through certified individuals for factories, building premises etc. for identifying energy conservation measures
S2.	Mention few powers vested in Provincial Agencies by the National Energy Efficiency and Conservation Act 2016. Ans. Few powers vested in Provincial Agencies by the National Energy Efficiency and Conservation Act 2016 are: • amend energy conservation building codes to suit regional and local conditions • direct all owners/occupiers of building complexes being designated consumers to comply with provisions of energy conservation building codes • direct such designated consumers (building owners) to conduct energy audits through accredited energy auditor • establish and designate laboratories duly certified by Federal Government.
S3.	Mention the key energy efficiency policies in Pakistan Vision 2025. Ans. The key energy efficiency policies in Pakistan Vision 2025 are: • Maximize distribution efficiency and cut wasteful losses through investment in transmission and distribution infrastructure and effective enforcement of controls; • Focus on demand management and conservation to ensure prioritization in allocation, elimination of wasteful use, incentives to use more energy efficient equipment and appliances and achieve better balance between peak and off-peak hours

Chapter 1.2 Energy management & audit

Part – I: Objective type questions and answers

1.	"The judicious and effective use of energy to maximise profits and enhance competitive positions". This can be the definition of: a) Energy conservation b) Energy management c) Energy policy d) Energy Audit
2.	The objective of energy management includes a) Minimising energy costs b) minimising waste c) Minimising environmental degradation d) all the above
3.	Replacement of steam based hot water generation by solar system is an example of a) Matching energy usage to the requirement b) Maximising system efficiency c) Energy substitution d) Performance improvement
4.	1 kWh = ……. Kcal a) 800 b) 860 c) 400 d) 680
5.	The benchmarking parameter for air conditioning equipment is a) kW/Ton of Refrigeration b) kW/ kg of refrigerant handled c) kcal/m^3 of chilled water d) Differential temperature across chiller
6.	The percentage of energy saved at the current rate of use, compared to the reference year rate of use, is called a) Energy Utilization b) Energy Performance c) Energy Efficiency d) None
7.	Which instrument is used to monitor O_2, CO in flue gas? a) Combustion analyser b) Power analyser c) Pyrometer d) Fyrite
8.	Lux meter is used to measure…… a) Illumination level b) Sound intensity and illumination level c) Harmonics d) Speed
9.	For a cement plant the parameter, "kWh/MT of clinker "indicates a) Energy Index parameter b) Utility factor c) Production factor d) load factor
10.	Energy manger should be well versed with a) Manufacturing and processing skills b) Managerial and technical skills c) Technical and marketing skills d) Managerial and commercial

	skills
11.	An energy policy does not include a) Target energy consumption reduction b) Time period for reduction c) Declaration of top management commitment d) Future production projection
12.	CO_2 measurement of Fyrite kit is based on a) Weight basis (dry) b) Volume basis (dry) c) Weight basis (wet) d) Volume basis (wet)
13.	Non-contact speed measurements can be carried out by a) Tachometer b) Stroboscope c) Oscilloscope d) Speedometer
14.	The tool used for performance assessment and logical evaluation of avenues for improvement in Energy management and audit is a) Fuel substitution b) Monitoring and verification c) Energy pricing d) Bench marking
15.	Infrared thermometer is used to measure a) Surface temperature b) Flame temperature c) Flue gas temperature d) Hot water temperature
16.	Having an energy policy a. Shows commitment b. Satisfies regulations c. Indicates energy audit skills d. Adds to the list of policies
17.	Air velocity in ducts can be measured by using ___ and manometer a) Orifice meter b) Borden gauge c) Pitot tube d) Anemometer

Part – II: Short questions and answers

S1.	List any four important factors involved in deciding final cost of purchased electricity. The factors which are involved in deciding final cost of purchased electricity are • Maximum demand charges, kVA • Energy Charges, kWh • TOD Charges, Peak/Non-peak period • Power factor Charge, P.F
S2.	What are the principles of energy management? Ans. The principles of energy management involve the following:

	i) Procure all the energy needed at the lowest possible price ii) Manage energy use at highest energy efficiency iii) Reusing and recycling energy by cascading (waste heat recovery) iv) Use the most appropriate technology v) Reduce the avoidable losses
S3.	What is the need for managerial skills in energy management? Ans: Managerial skills include bringing about awareness, motivating people at all levels, changing the structure & procedure, monitoring the energy consumption, norms target setting, etc. Both the organizational and people changes are required. For example, a mere awareness campaign in an industry on switching off lights, fans and air conditioners brought about a significant reduction in energy consumption.
S4.	What do you mean by energy audit? Ans. Energy Audit is defined as "examination of any energy consuming project about the way the energy is generated, transmitted and distributed or used there and identification of areas where energy waste can occur for improving energy efficiency and where scope for improving energy use efficiency may be possible".
S5.	Explain how matching energy usage to requirement can enhance energy efficiency Ans. Mismatch between equipment capacity and user requirement often leads to inefficiencies due to part load operations, wastages etc. Worst case design, is a designer's characteristic, while optimization is the energy manager's mandate and many situations present themselves towards an exercise involving graceful matching of energy equipment capacity to end-use needs. **Example:** • Eliminate throttling of a pump by impeller trimming, resizing pump, installing variable speed drives
S6.	Give any four bench marking parameters followed in equipment/utility related in Industries. Ans. i) kWh/ton of refrigeration (on Air conditioning plant) ii) % thermal efficiency of a boiler plant iii) kWh/NM^3 of compressed air generated iv) kWh /litre in a diesel power generation plant.

S7.	List any one energy audit instrument used for power measurement and one for flue gas measurement along with parameters to be measured? Ans. <table><tr><th>Instrument</th><th>Parameters measured</th></tr><tr><td>**Portable power analyser used for power measurement**</td><td>**Measure, record the V, A. pf, Frequency, kVA, kVAr, kW, KWh, KVA, harmonics etc.**</td></tr><tr><td>**Combustion analyser used for flue gas measurement (zinconia cell board or electro mechanical cell board)**</td><td>**O_2, CO, NO_x, SO_x, CO_2 (calculated), temperature** ♦ **Some instrument will also give excess air, efficiency, draft, etc.**</td></tr></table>
S8.	What is the significance of an energy policy? Ans. A written energy management policy will guide efforts to improve energy efficiency, and represents a commitment to saving energy. It will also help to ensure that the success of the program is not dependent on particular individuals in the organization. An energy management policy statement includes a declaration of commitment from senior management, as well as general aims and specific targets relating to: ➢ Energy consumption reduction (electricity, fuel oil, gas, petrol etc.) ➢ Energy cost reduction (by lowering consumption and negotiating lower unit rates) ➢ Timetables ➢ Budgetary limits ➢ Energy cost centres ➢ Organisation of management resources.
S9.	How do you classify energy conservation measures? Ans. Based on energy audit and analyses of the plant, a number of potential energy saving projects may be identified. These may be classified into three categories: 1. Low cost – high return; 2. Medium cost – medium return; 3. High cost – high return
S10.	Define energy management Ans. The judicious and effective use of energy to maximize profits (minimize the costs) and enhance competitive positions.
S11.	List steps involved in pre-audit phase. Ans. Pre-audit phase: ♦ Plan and organise ♦ Walk through audit ♦ Informal interview with plant personnel
S12.	What are the factors to be considered before procuring fuels for energy efficiency and economics?

	Ans. The following factors should be considered before procurement of fuel for energy efficiency and economics: • Price at source, transport charge, type of transport • Quality of fuel • Energy content
S13.	What are the few comparative factors need to be looked in to for external benchmarking used for inter-unit comparison and group of similar units? Ans. Few comparative factors, which need to be looked into while benchmarking externally are: • Scale of operation • Vintage of technology • Raw material specifications and quality • Product specifications and quality
S14.	What is the objective of energy management? Ans. The objectives of energy management is to achieve and maintain optimum energy procurement, utilisation throughout the organisation and a) To minimise energy costs/ waste without affecting production & quality b) To minimise environmental effects
S15.	What are the few important technical feasibility parameters that one should consider during analysis of energy conservation opportunities? Ans. The technical feasibility should address the following issues: • Technology availability, space, skilled manpower, reliability, service etc • The impact of energy efficiency measure on safety, quality, production or process. • The maintenance requirements and spares availability
S16.	What do you understand by plant energy performance? Ans. Plant energy performance (PEP) is the measure of whether a plant is now using more or less energy to manufacture its products than it did in the past: a measure of how well the energy management programme is doing. It compares the change in energy consumption from one year to the other considering production output. Plant energy performance monitoring compares plant energy use at a reference year with the subsequent years to determine the improvement that has been made.
S17.	What is fuel substitution and list one example of fuel substitution? Ans. Fuel substitution is substituting existing fossil fuel with more efficient and less cost / less polluting fuels such as natural gas, biogas, and locally available agro residues. E.g. Natural gas is increasingly the fuel of choice as fuel and feedstock in fertilizers, petrochemicals, power and sponge iron industries.
S18.	What are the base line data that an audit team should collect while conducting detailed energy audit?

	Ans. The audit team should collect the following baseline data: - Technology, processes used and equipment details - Capacity utilisation - Amount & type of input materials used - Water consumption - Fuel Consumption - Electrical energy consumption - Steam consumption - Other inputs such as compressed air, cooling water etc - Quantity & type of wastes generated - Percentage rejection / reprocessing - Efficiencies / yield
S19.	List at least four examples falling under "optimising the input energy requirements" while maximizing system efficiency? Ans. • Shuffling of compressors to match needs. • Periodic review of insulation thickness • Identify potential for heat exchanger networking and process integration. • Optimisation of transformer operation with respect to load.

Part – III: Long questions and answers

L1.	Briefly explain with examples on fuel and energy substitution Ans. **Fuel substitution:** Substituting existing fossil fuel with more efficient and less cost/less polluting fuel such as natural gas, biogas and locally available agro-residues. Energy is an important input in the production. There are two ways to reduce energy dependency; energy conservation and substitution. Few examples of fuel substitution ▪ Natural gas is increasingly the fuel of choice as fuel and feedstock in the fertilizer, petrochemicals, power and sponge iron industries. ▪ Replacement of coal by coconut shells, rice husk etc. ▪ Replacement of LDO by LSHS Few examples of energy substitution ✓ Replacement of electric heaters by steam heaters ✓ Replacement of steam based hot water by solar systems
L2.	Distinguish between preliminary energy audit and detailed energy audit? **Preliminary energy audit** is a relatively quick exercise to:

	▪ Establish energy consumption in the organization ▪ Estimate the scope for saving ▪ Identify the most likely (and the easiest areas for attention ▪ Identify immediate (especially no-/low-cost) improvements/ savings ▪ Set a ‘reference point’ ▪ Identify areas for more detailed study/measurement ▪ Preliminary energy audit uses existing, or easily obtained data Whereas, **detailed energy audit** • Provides a detailed energy project implementation plan for a facility, since it evaluates all major energy using systems. • Offers the most accurate estimate of energy savings and cost. • Considers the interactive effects of all projects, accounts for the energy use of all major equipment, and • Includes detailed energy cost saving calculations and project cost. • Arrives energy balance based on an inventory of energy using systems, assumptions of current operating conditions and calculations of energy use. This estimated use is then compared to utility bill charges.
L3.	Give a typical energy audit reporting format. Ans. After successfully carried out energy audit energy manager/energy auditor should report to the top management for effective communication and implementation. A typical energy audit reporting contents and format are given below. The following format is applicable for most of the industries. However the format can be suitably modified for specific requirement applicable for a particular type of industry. ♦ Acknowledgement ♦ Executive summary - Energy audit options at a glance and recommendations ♦ Introduction about the plant ♦ Production process description ♦ Energy and utility system description - List of utilities - Brief description of each utility ♦ Detailed process flow diagram and energy and material balance ♦ Energy efficiency in utility and process systems ♦ Energy conservation options and recommendations - List of options in terms of no cost / low cost, medium cost, and high investment cost, annual energy and cost savings, and pay back - Implementation plan for energy saving measures / projects ♦ Annexures
L4.	Write down the steps involved in Energy management Strategy? Ans: 1. Identify a strategic corporate approach 2. Appoint energy manager 3. Set up an energy monitoring and reporting system 4. Conduct energy audit 5. Prepare an energy management policy statement 6. Prepare and undertake a detailed project implementation plan

	7. Implement a staff awareness and training program 8. Annual review
L5.	List steps involved in detailed energy audit. Ans. Pre-audit phase: ♦ Plan and organise ♦ Walk through audit ♦ Informal interview with plant personnel Audit phase: ♦ Primary data collection ♦ Conduct survey and monitoring ♦ Conduct detailed trials and experiments ♦ Analysis of energy use ♦ Identification and development of energy conservation opportunities ♦ Cost benefit analysis ♦ Report preparation and presentation to the plant personnel and management Post audit phase: ♦ Implementation and follow-ups

Chapter 1.3 Energy Management System (EnMS): ISO 50001:2018

Long Questions

L1.	**What is ISO 50001?** ISO 50001 is a voluntary International Standard developed by the International Organization for Standardization (ISO) to provide organizations an internationally recognized framework to manage and improve their energy performance. The standard addresses the following: Energy use and consumption Measurement, documentation, and reporting of energy use and consumption Design and procurement practices for energy-using equipment, systems, and processes Development of an energy management plan and other factors affecting energy performance that can be monitored and influenced by the organization. ISO 50001 does require continual energy performance improvement but it does not include prescriptive energy performance improvement goals. Rather, it provides a framework through which each organization can set and pursue its own goals for improving energy performance.
L2.	**What is an energy management system?** An energy management system is a series of processes that enables people of varied responsibilities across an organization to use data and information to maintain and improve energy performance, while improving operational efficiencies, decreasing energy intensity, and reducing environmental impacts.
L3.	**What is the value of ISO 50001?** In the business world, a popular adage states that you can't manage what you don't measure. This principle applies to the world of energy management—an area of growing interest and concern to enterprises around the world due to its potential to help control costs, boost energy efficiency, improve environmental quality and enhance competitiveness. Until now, the absence of an internationally recognized energy management standard has inhibited widespread adoption of best energy management practices. The new ISO 50001 international energy management system standard overcomes this barrier and offers organizations a proven approach to develop an energy management plan addressing critical aspects of energy performance—including energy use, measurement, documentation, reporting, design and procurement practices, and other variables affecting energy management that can be measured and monitored. Adoption of ISO 50001 is important to establish a more systematic and sustainable approach

	to managing energy within a facility. Conformance to the standard provides proof that a facility has implemented sustainable energy management systems, completed a baseline of its energy use, and committed to continual improvement in energy performance. The value of certification will be driven by market forces within supply chains, potential utility incentive programs requiring ISO 50001, and the standard's relation to future carbon mitigation policies.
L4.	**Who partnered in the development of ISO 50001?** ISO created Project Committee (PC) 242 to carry out the development of ISO 50001, which includes participation from 59 nations (14 of which are observing). DOE supported the American National Standards Institute's (ANSI) role as Secretariat of PC 242 (serving jointly with Brazil), to lead the international development ISO 50001. In addition, DOE contributed actively to the U.S. Technical Advisory Group (TAG), the U.S. delegation to ISO PC 242. The U.S. TAG led international efforts to ensure that ISO 50001 preserves the United States' focus on data-driven energy performance and emphasis on management support. Following publication of ISO 50001, PC 242 transitioned to a Technical Committee (TC) 301, which will update ISO 50001 as needed and develop a family of related standards, such as ISO 50004 (guidance for ISO 50001), ISO 50003 (auditing of ISO 50001 by certification bodies), ISO 50006 (energy performance indicators and energy baselines), etc. DOE support will help ensure that the new standards will be consistent with U.S. energy policy and strategy. Learn more about **ISO/TC 301** and its activities.
L5.	**Who are the intended users of ISO 50001?** ISO 50001 applies to industrial plants; commercial, institutional, or governmental facilities; and entire organizations. ISO 50001 provides benefits for organizations large and small, in both public and private sectors, in manufacturing and services, in all regions of the world.
L6.	**1) Why should my company care about ISO 50001?** Energy is a critical component of an organization's operations and can be one of the largest controllable costs, depending on the activities. Improved energy performance helps organizations maximize the use of their energy sources and energy-related assets, thus reducing both energy cost and consumption. ISO 50001 provides a framework for organizations to make positive contributions toward reducing depletion of energy resources and mitigating worldwide effects of energy use, such as global warming, while improving the efficiency of organizational operations related to energy.
L7.	**How does ISO 50001 fit with existing Management Systems (e.g., ISO 9001, ISO 14001)?** ISO 50001 is based on the same management system model of continual improvement used for ISO 9001 and 14001. This compatibility makes it easier for organizations to integrate energy management into their quality and environmental management efforts. However, ISO 50001 adds new data-driven sections related to energy planning, operational control, and measuring and monitoring.
L8.	**What initial steps can my company take to prepare for adopting ISO 50001?** **Purchase ISO 50001**. Take preparatory steps toward establishing an energy management system (EnMS): Develop an energy policy that includes commitment to the EnMS from top management Identify a management representative to lead implementation of the EnMS Establish a team of representatives from major functional areas of the organization Decide on the boundaries of the EnMS

	Once prepared, get started with implementing an EnMS: Undertake an energy review to identify significant energy uses, their energy consumption, and opportunities for improvement Establish an energy baseline Identify energy performance indicators for tracking energy performance improvement against the baseline Access energy management **tools, expertise, and training**. Get started with ISO 50001 by getting recognized through the **50001 Ready** programme for self-attested implementation of energy management business practices.

Chapter 1.4 Financial Management

Part – I: Objective type questions and answers

1.	Simple payback period is equal to: a) Ratio of First cost/net yearly savings b) Ratio of Annual gross cash flow/capital cost c) $\sum_{t=0}^{n} \frac{CF_t}{(1+k)^t}$ d) All the above
2.	Simple payback period for an energy efficient motor that costs PKR. 1.5 Million to purchase and install and is expected to save PKR. 0.75 million per annum is__________ a) 1.1 years b) 2 years c) 0.75 years d) 2.25 years
3.	Which of the following equation used to calculate the future value of the cash flow_______? a) NPV $(1 - i)^n$ b) NPV $(1 + i)^n$ c) NPV + $(1 - i)^n$ b) NPV/ $(1 + i)^n$
4.	The NPV of equipment is PKR. 10000 and interest on discount rate is 10%. The future value of the cash flow at the end of 2 years is ______? a) PKR. 10000 b) PKR. 12,100 c) PKR. 8100 d) PKR. 8264
5.	The cost of replacement of inefficient compressor with an energy efficient compressor in a p was PKR 5 Million. The net annual cash flow is PKR 1.25 Million. The return on investment is: a) 15% b) 20% c) 25% d) 19.35%

6.	The ratio of annual net cash flow to capital cost is ___________ a) Net present value b) Internal rate of return c) <u>Return on investment</u> d) Discount factor
7.	The broad indicator of the annual return expected from initial capital investment is __ a) NPV b) IRR c) <u>ROI</u> d) Discount factor
8.	The sum of present values of all the cash flows associated with it is called __________ a) Return on Investment b) Internal Rate of Return c) <u>Net Present Value</u> d) None of the above
9.	The factor that reflects the risk of the project while evaluating the present value of the expec future cash flow is ______________ a) Life of the project b) <u>Discount rate</u> c) Capital cost d) All the above
10.	IRR stands for________ a) Integration rate of return b) Interest return rate c) <u>Internal rate of return</u> d) Investment return rate
11.	For all the expenditures in the plant, the value of cash flow at the end of the year will be ____ a) Positive b) <u>Negative</u> c) Nil d) None of the above
12.	The set net present value to determine internal rate of return is ______ a) 1 b) <u>0</u> c) 10 d) 2
13.	The internal rate of return cannot distinguish between ___________ a) Lending b) Borrowing c) <u>Both a & b</u> d) None
14.	Sensitivity analysis is an assessment of ______________ a) Profits b) Losses c) <u>Risk</u> d) all
15.	The present value of a PKR. 1000 cost in year "0" projected to 10 years at an escalation rate 5% and a 10% interest rate is _________ a) PKR. 4225 b) <u>PKR. 628</u> c) PKR. 1 d) PKR. 2.33
16.	The present value of PKR. 1000 in 10 years time at an interest rate of 10% is _________ a) PKR. 2594 b) <u>PKR. 386</u> c) PKR. 349 d) PKR. 10000

Part – II: Short type questions and answers

S1.	List out different costs involved in the process of implementing energy management? Ans. Different costs involved in the process of implementing energy management are: i) Direct project cost ii) Additional operations and maintenance cost iii) Training of personnel
S2.	What circumstances need investments for energy conservation in any plant? Ans. The need for investments in energy conservation can arise under following circumstances: i. For new equipment, process improvements etc. ii. To provide staff training iii. To implement or upgrade the energy information system iv. And other priorities
S3.	What criteria need to be considered while listing down the investment opportunities for any energy conservation project? Ans. When listing investment opportunities the following criteria need to be considered: i) Energy consumption per unit of production of a plant or process ii) Current state of repair and energy efficiency iii) Quality of the indoor environment iv) Effect of any proposed measure on staff attitudes and behaviour
S4.	Why organizations hesitant to invest money on energy conservation projects? Ans. i. Organization typically gives priority to investing in what they see as their core or profit-making activities in preference to energy efficiency ii. Even when they do invest in saving energy, they tend to demand faster rates of return than they require from other kinds of investment.
S5.	What are the basic criteria for financial investment appraisal? Ans. The basic criteria for financial investment appraisal include • Simple payback period, • Return on investment and internal rate of return • Net present value and cash flow
S6.	Why short term payback is an inadequate yardstick for assessing longer term benefits? Ans. The benefits arising from some energy saving measures may continue long after their payback periods. Such measures do not need to be written off using fast discounting rates but can be regarded as adding to the long term value of the assets. For this reason, short term payback is an inadequate yardstick for assessing longer term benefits
S7.	How do you relate plant maintenance to achieve energy efficiency in a plant?

	Ans.	There is a clear dependence relationship between energy efficiency and maintenance. This operates at two levels: ❖ Initially, improving energy efficiency is most cost-effectively done in existing facilities through normal maintenance procedures ❖ Subsequently, unless maintenance is regularly undertaken, savings from installed technical measure, whether in new-build or existing facilities, may not be realized.

S8.	List down the advantages with 'Simple Payback period' technique Ans. A widely used investment criterion, the simple payback period offers the following advantages: • It is simple, both in concept and application. Obviously a shorter payback generally indicates a more attractive investment. It does not use tedious calculations. • It favours projects, which generate substantial cash inflows in earlier years, and discriminates against projects, which bring substantial cash inflows in later years but not in earlier years.
S9.	What are the limitations with Return on Investment technique? Ans. The limitations with ROI technique are: ▪ It does not take into account the time value of money. ▪ It does not account for the variable nature of annual net cash inflows.
S10.	Calculate net present value for an investment towards a Compact Fluorescent Lamp (CFL). The following table gives investment and cash flow. (Assume discount rate is 10% and life of the CFL is 2 years). Investment PKR.400/- Savings in year — Cash flow, PKR Year # 1 — 1000 Year # 2 — 1000 Ans. Investment : PKR 400/- Discount rate (k) : 10% (i.e. 0.1) Life of the CFL (t) : 2 years NPV : $\sum_{t=0}^{n} \frac{CF_t}{(1+k)^t}$ NPV $= \frac{CF_0}{(1+k)^0} + \frac{CF_1}{(1+k)^1} + \frac{CF_2}{(1+k)^2}$ $= \frac{-400}{(1+0.1)^0} + \frac{1000}{(1+0.1)^1} + \frac{1000}{(1+0.1)^2}$ = -400 + 909 + 826 = PKR 1335/-
S11.	What are the main advantages with Net Present Value criterion? Ans. The net present value criterion has considerable merits. i. it takes in to account the time value of money

	ii. it considers the cash flow stream in its project life
S12.	What is the limitation with internal rate of return figure? Ans. The internal rate of return figure cannot distinguish between lending and borrowing and hence a high internal rate of rerun need not necessarily be a desirable feature.
S13.	What are different kinds of cash flows in any energy management project? Ans. Generally there are two kinds of cash flow; the initial investment as one or more instalments, and the savings arising from the investment.
S14.	List down the factors need to be considered in calculating annual cash flows. Ans. Taxes, Asset depreciation and intermittent cash flows
S15.	Under what circumstances sensitivity analysis is required? Ans. Sensitivity analysis is an assessment of risk. Sensitivity analysis is carried out particularly on projects where the feasibility is marginal.
S16.	Calculate the present value of tax cash flow from a PKR 10,000 investment towards 5 hp energy efficient motor with 30% declining balance depreciation rate, 50% tax rate and 10% interest rate. Ans. Present Value = P x d x t / (i + d) = (10000 x 0.3 x 0.5)/ (0.1 + 0.3) = PKR. 3750
S17.	List down any three options available for financing in-house energy management? Ans. i. From a capital budget ii. From a specific department or section budget iii. By obtaining bank loan iv. By raising money from stock market
S18.	How to make energy management self financing? Ans. One way to make energy management self financing is to split savings to provide identifiable returns to each interested party.
S19.	How an energy manager utilises if he has access to a proportion of the revenue savings arising from staff activities? Ans. if, an energy manager has access to a proportion of the revenue savings arising from staff's activities, then these can be reinvested in: ❖ Further energy efficiency measures ❖ Activities necessary to create the right climate for successful energy management which do not, of themselves, directly generate savings ❖ Maintaining or up-grading the management information system.

Part – III: Long type questions and answers

L1.	An energy auditor recommended to replace an old air fan and incompetently designed air delivery duct system causing PKR 23 million a year in electricity cost by changing the system with a modern backward curved fan with adequately designed duct system for total investment costs of PKR 2.2 million. Expected electricity cost reduction is 5%. Considering over 15 years sustained savings, calculate 'IRR' Ans. Life of the modified system : 15 years Expected annual savings : 5% : 0.05 x 2300000 PKR. 1,15,000 / year Investment : PKR 2,20,000/- $S = \frac{(1+i)^n \ xi}{(1+i)^n - 1} xI$ S = annual energy savings I = Investment N = years i = Internal rate of return $\frac{115000}{220000} = \frac{(1+i)^{15} xi}{(1+i)^{15} - 1}$ By trial and error method, I = 52%
L2.	Annual savings after replacement of boiler for three years is PKR. 5, 00,000, PKR. 5, 50,000, PKR. 6, 50,000. Total project cost is PKR 13.5 lakh. Considering cost of capital as 12%, what is the net present value of the proposal? Ans. Cash flow stream of project Investment PKR 13,50,000 Annual savings Cashflow 1 5,00,000 2 5,50,000 3 6,50,000 Cost of capital to the plant is 12%. The net present value of the proposal is: $NPV = \frac{500000}{(1.12)^1} + \frac{550000}{(1.12)^2} + \frac{650000}{(1.12)^3}$ = 446428 + 438456 + 462657 = 13,47,541 NPV = 13,50,000-13,47,541 = 2459
L3.	Explain the limitations with 'Simple Payback Period' technique with an example. Ans. The limitations are • It fails to consider the time value of money. Cash inflows, in the payback calculation, are simply added without suitable discounting. This violates the most basic principle of financial analysis, which stipulates that cash flows occurring at different points of time can be added or subtracted only after suitable compounding/discounting. • It ignores cash flows beyond the payback period. This leads to discrimination

against projects that generate substantial cash inflows in later years.

To illustrate, consider the cash flows of two projects, A and B:

Investment	PKR. (100,000)	PKR.(100,000)
Savings in Year	Cash Flow of A	Cash flow of B
1	50,000	20,000
2	30,000	20,000
3	20,000	20,000
4	10,000	40,000
5	10,000	50,000
6	-	60,000

The payback criterion prefers A, which has a payback period of 3 years, in comparison to B, which has a payback period of 4 years, even though B has very substantial cash inflows in years 5 and 6.

- It is a measure of a project's capital recovery, not profitability.
- Despite its limitations, the simple payback period has advantages in that it may be useful for evaluating an investment.

L5.

Calculate the internal rate of return for the following cash flow of a project.

Year	0	1	2	3	4
Cash flow	(100,000)	30,000	30,000	40,000	45,000

Ans. The internal rate of return is the value of "r" which satisfies the following equation:

$$100{,}000 = \frac{30{,}000}{(1+\kappa)^1} + \frac{30{,}000}{(1+\kappa)^2} + \frac{40{,}000}{(1+\kappa)^3} + \frac{45{,}000}{(1+\kappa)^4}$$

The calculation of "κ" involves a process of trial and error. Try with different values of "κ" till the right-hand side of the above equation is equal to 100,000. To begin with, try κ = 15 per cent. This makes the right-hand side equal to:

$$\frac{30{,}000}{(1.15)} + \frac{30{,}000}{(1.15)^2} + \frac{40{,}000}{(1.15)^3} + \frac{45{,}000}{(1.15)^4} = 100{,}802$$

This value is slightly higher than our target value, 100,000. So increase the value of κ from 15 per cent to 16 per cent. (In general, a higher κ lowers and a smaller r increases the right-hand side value). The right-hand side becomes:

$$\frac{30{,}000}{(1.16)} + \frac{30{,}000}{(1.16)^2} + \frac{40{,}000}{(1.16)^3} + \frac{45{,}000}{(1.16)^4} = 98{,}641$$

Since this value is now less than 100,000, it can be concluded that the value of r lies between 15 per cent and 16 per cent. For most of the purposes this indication suffices.

Chapter 1.5 Financing Options

Part–I: Objective type Questions and Answers

1.	What is ESCO? a) Energy saving company b) Energy sourcing company c) Energy service company d) Energy section of company
2.	ROI must always be ___ than interest rate a) Lower b) Higher c) Equal d) No relation
3.	The key to the successful involvement of an ESCO in performance contracting is_____ a) Monitoring b) Verification c) Both a & b d) None
4.	Costs associated with the design, planning, installation and commissioning of a project are____ a) Variable costs b) Capital costs c) Salvage value d)None

Part–II: Short Questions and Answers

S1.	What do you understand about ESCOs? Ans. ESCOs are usually companies that provide a complete energy project service, from assessment to design to construction or installation, along with engineering and project management services, land financing.
S2.	What are performance contracts? Ans Performance contracting represents one of the ways to address some of the most frequently mentioned barriers to investment. Performance contracting through an ESCO transfers the technology and management risks away from the end-user to the ESCO.

Part–III: Long Questions and Answers

L1.	What is performance contracting? Ans. The core of performance contracting is an agreement involving a comprehensive

	package of services provided by an ESCO, including: ❖ An energy efficiency opportunity analysis ❖ Project development ❖ Engineering ❖ Financing ❖ Construction/Implementation ❖ Training ❖ Monitoring and verification Monitoring and verification, is key to the successful involvement of an ESCO in performance contracting where energy cost savings are being guaranteed. ESCOs are not "bankers" in the narrow sense. Their strength is in putting together a package of services that can provide guaranteed and measurable energy savings that serve as the basis for guaranteed cost savings. But, the energy savings must be measurable.
L2.	What are types ESCO primaries Business Models? Ans: Despite countless project-structuring options with Project Hosts for ESCOs, two performance based financing structures have emerged as the most common ones used by ESCOs, which are • Guaranteed Savings and • Shared Savings. Guaranteed Savings is the most commonly used structure employed in the United States and Shared Savings is mostly used in developing markets. Other less-frequently used schemes are the Deemed Savings and Outsourced Energy Management Services models
L3.	What is Guaranteed Savings Structure? Ans: Guaranteed Savings is an arrangement whereby the Project Host finances the EEP directly; typically with a third party entity (Lender), in exchange for the ESCO providing a guarantee to the Project Host that it will realize sufficient savings to cover its debt service payments to the Lender. If the realized savings fall short of the debt service payments, the ESCO will reimburse the Project Host for the shortfall. If the realized savings exceed debt service, the ESCO typically shares a portion of the excess, usually expressed as a percentage share with the amount depending on the risk taken and the extent of ongoing services provided by the ESCO. It should be noted that under the Guaranteed Savings approach the ESCO bears no direct contractual obligation to repay the Lender, but that the Project Host does. In other words, the ESCO's guarantee is not a guarantee of payment to the

	Lender, but is a guarantee of savings to the Project Host. The Guaranteed Savings structure is typically viable only in countries with a high degree of familiarity and confidence with EE technologies, local implementation expertise and the availability of commercially-attractive financing. The Guaranteed Savings concept is difficult to initiate in markets where EE is not well known or the ESCO concept is being introduced because it requires Project Hosts to assume investment repayment risk of the EEPs based on the savings performance of unknown EE technologies. This structure fosters the long-term growth of the ESCO and finance industries because it enables ESCOs, mostly SMEs, with limited credit history and capital resources, to develop and implement savings-based EEPs. Guaranteed Savings evolved in the U.S. from the initial Shared Savings structure in response to government Project Hosts, who could access low-cost, tax-exempt financing and desired to significantly reduce interest costs. It was embraced by smaller ESCOs and financial institutions to allow them to grow their respective industries. The primary benefit of this structure is that it reduces financing cost and enables a lot more investment in the EEPs to be made for the same debt service level. The public sector normally prefers this structure in order to maximize the amount of infrastructure investment made in its facilities that can be repaid from utility costs in its operating budget.
L4.	What is Shared Savings Structure? Ans.: Shared Savings is an arrangement whereby the ESCO (as opposed to the Project Host) finances the total upfront capital cost of the project and is totally responsible to repay the Lender. The Project Host pays a fixed percentage or amount of its realized savings from the project to the ESCO. This is sufficient for the ESCO to repay its debt service to the Lender (or equity IRR to an investor), to cover M&V costs, and to provide compensation to the ESCO for performing its ongoing services throughout the ESPC agreement term. Under this structure (as opposed to the Guaranteed Savings model), the Project Host has no contractual obligation to repay the Lender; but the ESCO does. It should be noted that this structure creates more risk for the ESCO because it requires ESCO to not only assume the project performance risk, but also Project Host credit risk. The Shared Savings approach typically requires an equity investment, which in combination with the higher risk assumed by the ESCO, carries a much higher finance cost than the Guaranteed Savings structure. The Shared Savings structure is a typical introductory structure for developing markets

Chapter 2.1 Fuels and Combustion

Part–I: Objective type Questions and Answers

1.	For complete combustion of every kg of FO firing, the theoretical quantity of air required is: a) 14 kg b) 5 kg c) 20 kg d) 10 kg
2.	Oxygen (O_2) percentage measurement by volume basis in flue gas helps in achieving finer air control and this is measured online by using: a) zirconium oxide probe b) potassium oxide probe c) copper tubes d) ultrasonic tester
3.	The knowledge of density of the liquid fuel is useful for quantity calculations and assessing ignition quality. Typical reference temperature at which density of fuel oil specified is at ___ °C . a) 0 b) 15 °C c) average ambient temperature d) temperature at the time of test
4.	The unit of density a) kg/m^3 b) cc/gm c) kg/m^2 d) as it is a ratio, it has no unit
5.	Name the instrument used for the measurement of specific gravity of liquid fuels a) Gravimeter b) Hydrometer c) Bomb calorimeter d) none of the above
6.	"In case of net calorific value (NCV) of any fuel, it assumes that water leaves with the combustion products with fully being condensed". State True or False
7.	The requirement of excess air for combustion and ash content in the fuel has one of the following relations: a) increases with increase in ash content in fuel b) decreases with increase in ash content in fuel c) ash does not affect the excess air d) none of the above
8.	The specific heat of oil is dependent on the specific gravity of oil. Tick correct relation between specific heat and specific gravity. a) lighter oil have higher specific heat b) heavier oil have lower specific heat c) lighter oil have lighter specific heat d) none of the above
9.	"Turndown ratio" for burners is the ratio of a) maximum fuel input over minimum fuel input b) maximum air input over minimum air input c) steam generated over the quantity of fuel burnt

	d) maximum amount of fuel fired over excess air input
10.	Which among the following fuels is having the highest specific gravity? a) furnace oil b) LSHS c) LDO d) HSD
11.	Viscosity of a liquid fluid is very much dependent on ___ . a) pressure b) pipe size c) temperature d) Is an independent fuel property
12.	Calorific value of any fuel is the measurement of heat or energy produced. State whether this is true or false. If false, indicate correct answer also. State True or False
13.	The compound of which of the elements is not present is ash generated in boiler using coal as fuel? a) sodium b) calcium c) iron d) nitrogen
14.	Which is the best pump for pumping LSHS? a) vertical turbine pump b) centrifugal pump c) diaphragm pump d) gear pump
15.	"Proximate analysis" of coal is an approximate analysis of coal, while the "Ultimate analysis" of coal is the accurate analysis. – True or False?
16.	While analysing the composition of coal in a laboratory, the solid left in the oven after volatile matter is distilled off is called as _____. a) ash content b) moisture content c) sulphur content d) fixed carbon and ash
17.	Large and irregular lumps of coal when fired in a boiler may lead to ____. a) poor combustion b) low excess air c) low unburnt fuel in the ash d) high thermal efficiency
18.	LPG is predominantly the mixture of Propane and ___ . a) methane b) ethane c) butane d) Isopropane
19.	LPG cylinders should be preferably stored in ____ . a) open spaces b) near to the user area c) in containers having a vent to remove out the uncondensed vapours d) in cellars or basements having no ventilation at ground level
20.	High percentage of carbon monoxide presence in the flue gas of boiler is an indicator of a) high excess air b) complete combustion c) good control of pollutants d) low excess air

Part–II: Short type Questions and Answers

S1.	What is excess air and why is it required for combustion in a boiler? For any fuel a fixed amount of theoretical air is required for stoichiometric combustion. In practice theoretical quantity of air is inadequate to mix with the entire quantity of fuel intimately. The problem is sought to be overcome by admitting some quantity of air in excess of the theoretical quantity. This is called excess air.
S2.	How to control excess air? Chemical analysis of the gases is an objective method that helps in achieving finer air control. By measuring carbon dioxide (CO_2) or oxygen (O_2) in flue gases by continuous recording instruments or Orsat apparatus or portable fyrite, the excess air level as well as stack losses can be estimated. The excess air to be supplied depends on the type of fuel and the firing system. For example, for optimum combustion of fuel oil, the CO_2 or O_2 in flue gases should be maintained at 14 -15% in case of CO_2 and 2-3% in case of O_2.
S3.	Define specific gravity. This is defined as the ratio of the weight of a given volume of oil to the weight of the same volume of water at a given temperature.
S4.	What are the advantages of blending different qualities of coal fed to the boiler? ▪ In case of coal lots having excessive fines, it is advisable to blend the predominantly lumped coal with lots containing excessive fines. Thus coal blending may limit the extent of fines in coal being fired. ▪ Blending of different qualities of coal may also help to supply a uniform coal feed to the boiler.
S5.	What is viscosity of fluid? The viscosity of a fluid is a measure of its internal resistance to flow.
S6.	What is the unit of viscosity? What is the instrument used for measurement of viscosity? Viscosity is measured in Stokes / Centistokes. Sometimes viscosity is also quoted in Engler, Saybolt or even Redwood. The measurement of viscosity is made with an instrument called as viscometer
S7.	Why is viscosity a very important parameter for any fuel oil? Viscosity is an important fuel property in the fuel oil specification. It influences the degree of pre-heat required for handling, storage and satisfactory atomization. If the oil is too viscous it may become difficult to pump, hard to light the burner and operation may become erratic. Poor atomization may result in the formation of carbon deposits on the burner tips or on the walls. Pre-heating is necessary for proper atomization.
S8.	Define specific heat of fuel oil and also mention its unit of measurement. Specific heat is the amount of Kcal needed to raise the temperature of 1 kg of fuel oil by $1^{o}C$. The unit of specific heat is kcal/kg ^{o}C.

S9.	What is the difference between Gross calorific value (GCV) and Net calorific value (NCV)? The difference between GCV and NCV is the latent heat of condensation of the water vapour generated by the combustion process. Gross calorific value assumes all vapour produced during the combustion process is fully condensed. Net calorific value assumes the water leaves with the combustion products without fully being condensed.
S10.	What is the main disadvantage of sulphur presence in any fuel? The main disadvantage of sulphur is the risk of corrosion by sulphuric acid formed during and after combustion, and condensing in cool parts of the chimney or stack, air pre heater and economiser.
S11.	What are the three main classifications of coal? • Anthracite • Bituminous • Lignite
S12.	How is moisture in coal determined in a laboratory? A sample of raw coal is crushed until it passes through a 20-mesh screen (20 meshes per linear inch). A definite amount is weighed, placed in a covered crucible, and dried in an oven at about 105^{o}C for 1 hr. Then the sample is cooled to room temperature and weighed again. The loss in weight represents moisture.
S13.	How is the measurement of Volatile matter for coal done in the laboratory? Fresh sample of crushed coal is weighed, placed in a covered crucible, and heat over a large Bunsen burner until all the voltaic gases are driven off. The sample is cooled and weighed. Loss of weight represents moisture and volatile matter. The remainder is coke (fixed carbon and ash).
S14.	Give the empirical relationship to convert proximate analysis to ultimate analysis of with regard to Indian coal. Relationship between ultimate analysis and proximate analysis %C = 0.97C+ 0.7(VM+0.1A) - M(0.6-0.01M) $\%H_2$ = 0.036C + 0.086 (VM -0.1xA) - 0.0035M^2 (1-0.02M) $\%N_2$ = 2.10 -0.020 VM Where C = % of fixed carbon A = % of ash VM = % of volatile matter M = % of moisture
S15.	What is the primary function of a burner used for liquid fuels? The primary function of burner is to atomise fuel to millions of small droplets so that the surface area of the fuel is increased enabling intimate contact with oxygen in air.
S16.	What is the important characteristic that distinctly highlights a good burner design? The good burner design will be one that is able to properly mix the air and fuel at the lowest possible excess air.

S17.	What are the two ways of preheating the storage tanks used for LSHS? • Bulk heating using steam coils placed at the bottom of the tank • Outflow heater
S18.	Define density of liquid fuel. Density is the ratio of the mass of the fuel to the volume of the fuel at a reference temperature typically at 15°C.
S19.	Arrange the following fuels in the ascending order of their calorific value. (HSD, coal, paddy husk) Paddy husk - 3,568 Kcal/kg Coal - 4,500 Kcal/kg HSD - 10,800 Kcal/kg
S20.	List out the effect of ash content in liquid fuels? Typically the ash value is in the range of 0.03-0.07% in liquid fuels. Ash has erosive effect on the burner tips, causes damage to the refractories at high temperatures and gives rise to high temperature corrosion and fouling of equipments.

Part–III: Long type Questions and Answers

L1.	Write short notes on combustion control for boiler. Also describe the different types combustion controls? Combustion controls assist the burner in regulation of fuel supply, air supply, (fuel to air ratio), and removal of gases of combustion to achieve optimum boiler efficiency. The amount of fuel supplied to the burner must be in proportion to the steam pressure and the quantity of steam required. The combustion controls are also necessary as safety device to ensure that the boiler operates safely. Various types of combustion controls in use are: *On/Off Control:* The simplest control, ON/OFF control means that either the burner is firing at full rate or it is OFF. This type of control is limited to small boilers. *High/Low/Off Control:* Slightly more complex is HIGH/LOW/OFF system where the burner has two firing rates. The burner operates at slower firing rate and then switches to full firing as needed. Burner can also revert to low firing position at reduced load. This control is fitted to medium sized boilers. *Modulating Control:* The modulating control operates on the principle of matching the steam pressure demand by altering the firing rate over the entire operating range of the boiler. Modulating motors use conventional mechanical linkage or electric valves to regulate the primary air, secondary air, and fuel supplied to the burner. Full modulation means that boiler keeps firing, and fuel and air are carefully matched over the whole firing range to maximize thermal efficiency.

L2.	Mention the means of storage of furnace oil in any industry. Also mention the safety precautions to be taken during storage. It can be potentially hazardous to store furnace oil in barrels. A better practice is to store it in cylindrical tanks, either above or below the ground. Furnace oil, that is delivered, may contain dust, water and other contaminants. The sizing of storage tank facility is very important. A recommended storage estimate is to provide for at least 10 days of normal consumption. Industrial heating fuel storage tanks are generally vertical mild steel tanks mounted above ground. It is prudent for safety and environmental reasons to build bund walls around tanks to contain accidental spillages. As a certain amount of settlement of solids and sludge will occur in tanks over time, cleaning should be carried out at regular intervals-annually for heavy fuels and every two years for light fuels. A little care should be taken when oil is decanted from the tanker to storage tank. All leaks from joints, flanges and pipelines must be attended at the earliest. Fuel oil should be free from possible contaminants such as dirt, sludge and water before it is fed to the combustion system.
L3.	Calculate the Stoichiometric (kg) amount of air required for the following liquid fuel.

Constituents	% By weight
Carbon	85.9
Hydrogen	12
Oxygen	0.7
Nitrogen	0.5
Sulphur	0.5
H_2O	0.35
Ash	0.05

GCV of fuel : 10880 kcal/kg

Calculation for Requirement of Theoretical Amount of Air

Consider a sample of 100 kg of fuel. The chemical reactions are:

Element	Molecular Weight kg / kg mole
C	12
O_2	32
H_2	2
S	32
N_2	28
CO_2	44
SO_2	64
H_2O	18

$C + O_2 \rightarrow CO_2$

$H2 + O \rightarrow H_2O$

$S + O_2 \rightarrow SO_2$

Constituents of fuel

$C + O_2 \rightarrow CO_2$

$12 + 32 \rightarrow 44$

12 kg of carbon requires 32 kg of oxygen to form 44 kg of carbon dioxide therefore 1 kg of carbon requires 32/12 kg i.e. 2.67 kg of oxygen

$(85.9)\ C + (85.9 \times 2.67)\ O_2 \rightarrow 314.97\ CO_2$

$2H2 + O_2 \rightarrow 2H_2O$

$4 + 32 \rightarrow 36$

4 kg of hydrogen requires 32 kg of oxygen to form 36 kg of water, therefore 1 kg of hydrogen requires 32/4 kg i.e. 8 kg of oxygen

$(12)\ H2 + (12 \times 8)\ O \rightarrow 108\ H_2O$

$S + O_2 \rightarrow SO_2$

$32 + 32 \rightarrow 64$

32 kg of sulphur requires 32 kg of oxygen to form 64 kg of sulphur dioxide, therefore 1 kg of sulphur requires 32/32 kg i.e. 1 kg of oxygen

$(0.5)\ S + (0.5 \times 1)\ O_2 \rightarrow 1.0\ SO2$

Total Oxygen required = 325.57 kg

(229.07+96+0.5)

Oxygen already present in

100 kg fuel (given) = 0.7 kg

Additional Oxygen Required = 325.57 – 0.7

= 324.87 kg

Therefore quantity of dry air required = (324.87) / 0.23

(air contains 23% oxygen by wt.)

= 1412.45 kg of air

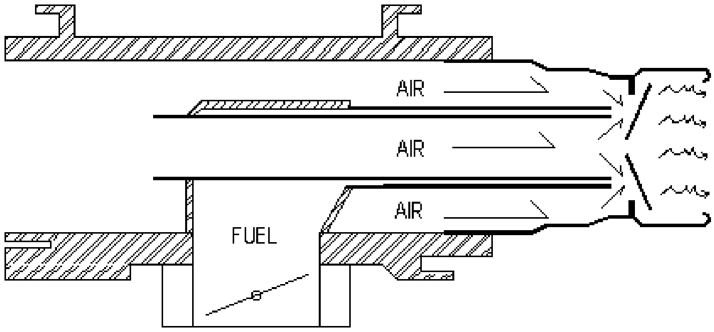
Theoretical Air required = (1412.45) / 100

= 14.12 kg of air / kg of fuel

L4. What is the function of draft in a boiler? Enumerate the different types of draft available for a boiler?

The function of draft in a combustion system is to exhaust the products of combustion into the atmosphere. The draft can be classified into two types namely Natural and Mechanical Draft.

	Natural Draft: It is the draft produced by a chimney alone. It is caused by the difference in weight between the column of hot gas inside the chimney and column of outside air of the same height and cross section. Being much lighter than outside air, chimney flue gas tends to rise, and the heavier outside air flows in through the ash pit to take its place. It is usually controlled by hand-operated dampers in the chimney and breeching connecting the boiler to the chimney. Here no fans or blowers are used. The products of combustion are discharged at such a height that it will not be a nuisance to the surrounding community. *Mechanical Draft:* It is draft artificially produced by fans. Three basic types of drafts that are applied are: *Balanced Draft:* Forced-draft (F-D) fan (blower) pushes air into the furnace and an induced-draft (I-D) fan draws gases into the chimney thereby providing draft to remove the gases from the boiler. Here the furnace is maintained at from 0.05 to 0.10 in. of water gauge below atmospheric pressure. *Induced Draft:* An induced-draft fan draws enough draft for flow into the furnace, causing the products of combustion to discharge to atmosphere. Here the furnace is kept at a slight negative pressure below the atmospheric pressure so that combustion air flows through the system. *Forced Draft:* The Forced draft system uses a fan to deliver the air to the furnace, forcing combustion products to flow through the unit and up the stack.
L5.	Describe the working of an oil fired burner with a simple sketch covering the following points. a) atomization of fuel b) primary and secondary air circuit c) burner turndown ratio The burner is the principal device for the firing of fuel. The primary function of burner is to atomize fuel to millions of small droplets so that the surface area of the fuel is increased enabling intimate contact with oxygen in air. The finer the fuel droplets are atomized, more readily will the particles come in contact with the oxygen in the air and burn. Normally, atomization is carried out by primary air and completion of combustion is ensured by secondary air. Burners for fuel oil can be classified on the basis of the technique to prepare the fuel for burning i.e. atomization. The air is brought into the head by means of a forced draft blower or fan. The fuel is metered into the head through a series of valves. In order to get proper combustion, the air molecules must be thoroughly mixed with the fuel molecules before they actually burn. The air in the center is the primary air which is sued for atomization and the one surrounding is the secondary air which ensures complete combustion.



The mixing is achieved by burner parts designed to create high turbulence. If insufficient turbulence is produced by the burner, the combustion will be incomplete and samples taken at the stack will reveal carbon monoxide as evidence.

Since the velocity of air affects the turbulence, it becomes harder and harder to get good fuel and air mixing at higher turndown ratios since the air amount is reduced. Towards the highest turndown ratios of any burner, it becomes necessary to increase the excess air amounts to obtain enough turbulence to get proper mixing. The better burner design will be one that is able to properly mix the air and fuel at the lowest possible air flow or excess air.

An important aspect to be considered in selection of burner is **turndown ratio**. Turndown ratio is the relationship between the maximum and minimum fuel input without affecting the excess air level.

For example, a burner whose maximum input is 250,000 Kcal and minimum rate is 50,000 Kcal, has a 'Turn-Down Ratio' of 5 to 1.

Chapter 2.2 Boilers

Part – I: Objective type Questions and Answers

1.	For a pulverised coal fired boiler the type of firing followed is: a) over firing b) tangential firing c) vertical firing d) mixed firing for effective heat transfer
2.	The recommended TDS level in boiler drum, that can be safely maintained for the water tube boiler is: a) 3000 – 3500 ppm b) 2000 ppm c) 5000 ppm d) TDS is not a problem. It can be anything
3.	An efficient oil fired boiler can have an evaporation ratio of (steam to fuel ratio): a) 5 – 6 b) 13 - 16 c) 1 d) 7 - 9
4.	Considering efficiency parameters in mind, which of the boiler can be considered as most efficient? a) fluidised bed combustion boiler b) lanchashire boiler c) Stoker fired boiler d) chain grate boiler
5.	The excess air required for pulverised coal fired boiler is: a) 40 – 50% b) 15 – 20% c) 60 – 80% d) 30 – 40%
6.	Which one of the following loss is more predominant in boilers using furnace oil? a) radiation and convention losses b) loss due to hydrogen in fuel c) loss due to dry fuel gas d) loss due to moisture in fuel
7.	The elements of ultimate chemical analysis of fuel does not include: a) carbon b) oxygen c) volatile matter d) sulphur
8.	Controlled wetting of coal during the coal preparation leads to a) improper combustion b) reduction in flue gas exit temperature c) decrease in the percentage of unburnt carbon d) increase in the fines of coal
9.	The water supplied to the boiler that is converted into steam is called as: a) make-up water b) condensate water c) feed water d) blow-down water

10.	A rise in conductivity of boiler feed water indicates ____ . a) drop in the contamination of feed water b) greater purity of feed water c) rise in the contamination of feed water d) it has got no relation with the contamination of feed water
11.	Which one of the following is considered for boiler efficiency calculation if the moisture in the fuel is assumed to be useful for the process: a) net calorific value of fuel b) gross calorific value of fuel c) mixed calorific value d) average calorific value
12.	In a steam boiler, calcium and magnesium bicarbonates in boiler water dissolve in water to form: a) acidic solution b) alkaline solution c) neutral solution d) none of the above
13.	M14. For higher boiler efficiencies, the feed water is heated by ____ . a. air pre-heater b. convective heater c. super heater d. economiser
14.	In a three pass fire tube boiler, the term "pass" refers to ____ . a. number of times the hot water/steam circulates in the boiler b. number of burners in the boiler c. number of times the hot combustion gases pass through the boiler d. number of tubes in the boiler
15.	Internal water treatment for steam boiler is done to:. a) remove suspended soils b) prevent formation of scales c) help improve combustion efficiency d) reduce stack temperature
16.	The direct method of steam boiler efficiency calculates: a) energy gain by the working fluid over the energy content of the fuel b) energy content of the fuel over the energy gain of the working fluid c) quantity of steam generated to the quantity of fuel fired d) enthalpy of steam generated to the quantity of fuel fired
17.	The indirect method of evaluating boiler efficiency is also called as "Heat Loss" method. – True or False?
18.	Good opportunity for energy savings exists from boiler continuous blow down water: a) reusing the hot water so formed as make up water b) using the blow down steam to run steam turbine

	c) utilisation of flash steam in deaerator d) none of the above
19.	De-aeration of boiler feed water is referred to as: a) removal of dissolved gases b) removal of silica c) removal of scales by blow down d) phosphate treatment of feed water

Part - II: Short type questions and answers

S1.	What is the affect of sulphur in coal when used in boiler? Sulphur will get oxidised to SO_2 and fraction of SO_3 and will react with water to form sulphuric acid and this occurs at a temperature called the acid dew point which normally is about 120 ^{o}C. The sulphuric acid so formed corrodes this steel it comes in contact with.
S2.	Why boiler blow-down is required? As the feed water evaporate into steam, dissolved solids concentrate in the boiler. Above certain level of concentration, these solids encourage carryover of water into steam. This leads to scale formation inside the boiler, resulting in localised over heating and ending finally in tube failure. Hence blow-down is very much required for boilers.
S3.	What are the parameters required to estimate the boiler efficiency by direct method? a) Steam flow rate b) GCV of fuel c) Fuel flow rate d) Steam conditions (pressure and temperature) e) Feed water temperature
S4.	What is the principle of mechanical deaeration (pressure type) of boiler feed water? The pressure-type de-aerators operates by allowing steam into the feed water through a pressure control valve to maintain the desired operating pressure, and hence temperature at a minimum of 105 °C. The steam raises the water temperature causing the release of O_2 and CO_2 gases that are then vented from the system. This type can reduce the oxygen content to 0.005 mg/litre.
S5.	What is the effect of boiler loading on boiler efficiency? • The maximum efficiency of the boiler does not occur at full load, but at about two-thirds of the full load. If the load on the boiler decreases further, efficiency also tends to decrease. • As the load falls, so does the value of the mass flow rate of the flue gases through the tubes. This reduction in flow rate for the same heat transfer area, reduced the exit flue gas temperatures by a small extent, reducing the sensible heat loss.

	• Below half load, most combustion appliances need more excess air to burn the fuel completely. This increases the sensible heat loss.
S6.	What are the three main boiler systems present in any boiler? ▪ Feed water system ▪ Steam system ▪ Fuel system
S7.	What is the main difference between water tube boilers and fire tube boilers? In water tube boilers the water passes through the tubes and the hot gases passes out side the tubes where as in case of fire tube boiler the hot gases passes through the tubes and the water passes over the tubes.
S8.	What do you meant by tangential firing with respect to pulverized coal fired boiler? The method of firing used for coal firing in pulverized fuel fired boiler is the tangential firing. In this type of firing four burners are used at the corner to corner to create a fire ball at the center of the furnace.
S9.	What are the disadvantages of direct method of boiler efficiency evaluation over indirect method? Direct method a) Does not give clues to the operator as to why efficiency of system is lower b) Does not calculate various losses accountable for various efficiency levels
S10.	List out the data required for calculation of boiler efficiency using indirect method. Ans. The data required for calculation of boiler efficiency using indirect method are: • Ultimate analysis of fuel (H_2, O_2, S, C, moisture content, ash content) • Percentage of Oxygen or CO_2 in the flue gas • Flue gas temperature in ^0C (T_f) • Ambient temperature in ^0C (T_a) & humidity of air in kg/kg of dry air. • GCV of fuel in kcal/kg • Percentage combustible in ash (in case of solid fuels) • GCV of ash in kcal/kg (in case of solid fuels)
S11.	Explain the different external water treatment methods. External treatment is used to remove suspended solids, dissolved solids (particularly the Calcium and Magnesium ions which is a major cause of scale formation) and dissolved gases (oxygen and carbon dioxide). The techniques include: ○ Precipitation processes, in which chemicals are added to precipitate calcium and magnesium as compounds of low solubility. The lime-soda process is typical of this class, but other precipitating agents such as caustic soda and sodium phosphate can be used when the composition of the raw water permits. ○ Ion-exchange progresses, in which the hardness is removed as the water passes

	through bed of natural zeolite or synthetic resin and without the formation of any precipitate. Ion exchange processes can be used for almost total demineralization if required, as is the case in large electric power plant boilers. ○ De-aeration, in which gases are expelled by preheating the water before entering the boiler system. Water normally contains approximately 10 mg/1 of dissolved oxygen at ambient temperature ○ Filtration, to remove suspended solids
S12.	What are the salient features of a packaged boiler? The features of package boilers are: • Small combustion space and high heat release rate resulting in faster evaporation. • Large number of small diameter tubes leading to good convective heat transfer. • Forced or induced draft systems resulting in good combustion efficiency. • Number of passes resulting in better overall heat transfer. • Higher thermal efficiency levels compared with other boilers.
S13.	What are the parameters to be monitored for evaluating direct efficiency of boilers and what is the empirical relation used? Parameters to be monitored for the calculation of boiler efficiency by direct method are: • Quantity of steam generated per hour (Q) in kg/hr. • Quantity of fuel used per hour (q) in kg/hr. • The working pressure (in kg/cm^2(g)) and superheat temperature (^{o}C), if any • The temperature of feed water (^{o}C) • Type of fuel and gross calorific value of the fuel (GCV) in kcal/kg of fuel Boiler efficiency (η) = : $\frac{Q \times (hg - hf)}{q \times GCV} \times 100$ where, hg – Enthalpy of saturated steam in kcal/kg of steam hf - Enthalpy of feed water in kcal/kg of water
S14.	What are the two main classification of a stoker fired boiler? 1. Chain grate or travelling grate stoker 2. Spreader stoker
S15.	Calculate the blow down rate for a boiler with an evaporation rate of 3 tons/hr, if the maximum permissible TDS in boiler water is 3000 ppm and with 10 % make up water addition. The feed water TDS is around 300 ppm. Blow down (%) $= \frac{\text{Feed water TDS x \% Make up}}{\text{Permissible TDS in Boiler – Fee water TDS}}$ Percentage blow down $= \frac{300 \times 10}{3000 - 300} = 1.11\%$ If boiler evaporation rate is 3000 kg/hr then required blow down rate is: $= \frac{3000 \times 1.11}{100} = 3.33 \text{ kg/hr}$

S16.	Indicate the different methods of efficiency evaluation of Boiler and describe it. – i. Direct Method ii. Indirect Method Direct Method: $$Efficiency = \eta = \frac{E_{out}}{E_{in}}$$ where Adsorbed heat = E_{out} -The energy the feedwater has picked up Energy Input = E_{in} - The energy going into the boiler. Indirect Method: Most performance testing and commissioning of smaller and medium sized boilers is done by the indirect method measuring the losses and calculating the efficiency as $$\eta_{HHV} = 1 - \frac{\sum Losses}{E_{in}}$$
S17.	Give the empirical relation to determine the blow down quantity required in a water tube boiler. The following formula gives the quantity of blow down required: $$\text{Blow down (\%)} = \frac{\text{Feed water TDS x \% Make up}}{\text{Permissible TDS in Boiler – Fee water TDS}}$$
S18.	What are the various methods available to control the excess air in a boiler? Various methods are available to control the excess air: • Portable oxygen analysers and draft gauges can be used to make periodic readings to guide the operator to manually adjust the flow of air for optimum operation. Excess air reduction up to 20% is feasible. • The most common method is the continuous oxygen analyzer with a local readout mounted draft gauge, by which the operator can adjust air flow. A further reduction of 10-15% can be achieved over the previous system. • The same continuous oxygen analyzer can have a remote controlled pneumatic damper positioner, by which the readouts are available in a control room. This enables an operator to remotely control a number of firing systems simultaneously.

Part – III: Long type questions and answers

<table>
<tr><td>L1.</td><td>
a) What is the benefit of providing Economiser for a boiler?
b) Calculate the fuel oil savings by providing an Economiser for a boiler. The performance data of the boiler are given as below:
• Average quantity of steam generated : 5 T/h
• Average flue gas temperature : 315 ^{o}C (without economiser)
• Average steam generation / kg of fuel oil : 14 kg
• Feed water inlet temperature : 110^{o}C
• Fuel oil supply rate : 314 kg/h
• Flue gas quantity : 17.4 kg/kg of fuel
• Gross calorific value of fuel : 10,000 kCal/kg
• Rise in feed water temperature by providing economizer: 26 °C
• Annual operating hours : 8600

By providing Economiser the exit flue gas losses can be reduced and hence the boiler efficiency can be increased.
• Quantity of flue gases : 314 x 17.4 = 5463.6 kg/h
• Quantity of heat available in the : 5463.6 x0.23 x(315-200)
• : 144512 kCal/h flue gases
• Rise in the feed water temperature : 26 ^{o}C.
• Heat required for pre-heating the feed water : 5000 x 1 x 26 = 130000 kCal/h
• Saving in terms of furnace oil : 130000/10000 = 13 kg/h
• Annual operating hours : 8600
• Annual savings of fuel oil : 8600 x 13 = 111800 kg
</td></tr>
<tr><td>L2.</td><td>
Evaluate the boiler efficiency by indirect method from the following data.
a) Ultimate analysis of Oil
C : 84.0 % H_2 : 12.0 %
S : 3.0 % O_2 : 1.0 %
b) GCV of Oil : 10200 kcal/kg
c) Percentage of O2 and CO_2 in flue gas : 7 & 11
d) Flue gas temperature (T_f) : 220 ^{0}C
e) Ambient temperature (T_a) : 27 ^{0}C
f) Humidity of air : 0.018 kg/kg of dry air
g) Consider radiation loss as 5.0% of the total losses.
</td></tr>
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- Excess air supplied : $(O_2 \times 100)/(21-O_2)$

: $(7 \times 100)/(21-7)$

: 50%

Theoretical air requirement

$=[(11.43 \times C) + [\{34.5 \times (H_2 - O_2/8)\} + (4.32 \times S)]/100$ kg/kg of oil

$=[(11.43 \times 84) + [\{34.5 \times (12 - 1/8)\} + (4.32 \times 3)]/100$ kg/kg of oil

=13.82 kg of air/kg of oil

Actual mass of air supplied /Kg of fuel : [1 + EA/100] x Theo. Air (AAS)

: [1 + 50/100] x 13.82

: 1.5 x 13.82

: 20.74 kg of air/kg of oil

I % heat loss due to dry flue gas : $\frac{m \times C_p \times (T_f - T_a) \times 100}{GCV \text{ of fuel}}$

m : $\frac{0.84 \times 44}{12} + \frac{0.03 \times 64}{32} + \frac{20.74 \times 7}{100} + (0.07 \times 32)$

m : 21.35 kg/kg of oil

% Heat loss : $\frac{21.35 \times 0.23 \times (220 - 27) \times 100}{10200}$

: 9.29%

Percentage heat loss due to evaporation of water formed due to H_2 in fuel

$= \frac{9 \times H_2 \{584 + 0.45 (T_f - T_a)\}}{GCV \text{ of fuel}}$

Where, H_2 – percentage of H_2 in fuel $= \frac{9 \times 12 \{584 + 0.45 (220 - 27)\}}{10200}$

= 7.10%

Percentage heat loss due to moisture present in air

$= \frac{AAS \times humidity \times 0.45 \times (T_f - T_a)}{GCV \text{ of fuel}}$

$= \frac{20.74 \times 0.018 \times 0.45 \times (220 - 27)}{10200}$

= 0.317%

i. Heat loss due to dry flue gas : 9.29%

ii. Heat loss due to evaporation of water formed due to H_2 in fuel : 7.10 %

iii. Heat loss due to moisture

	present in air : 0.317 % iv. Heat loss due to radiation and other unaccounted loss(given) : 5% Boiler Efficiency = 100- [9.29+7.10+0.317+5] = 100 – 21.707 = 78.08 %
L3.	Describe chain grate and spreader stoker type boiler. Chain-Grate or Travelling-Grate Stoker Boiler Coal is fed onto one end of a moving steel grate. As grate moves along the length of the furnace, the coal burns before dropping off at the end as ash. Some degree of skill is required, particularly when setting up the grate, air dampers and baffles, to ensure clean combustion leaving the minimum of unburnt carbon in the ash. The coal-feed hopper runs along the entire coal-feed end of the furnace. A coal grate is used to control the rate at which coal is fed into the furnace by controlling the thickness of the fuel bed. Coal must be uniform in size as large lumps will not burn out completely by the time they reach the end of the grate Spreader Stoker Boiler Spreader stokers utilize a combination of suspension burning and grate burning. The coal is continually fed into the furnace above a burning bed of coal. The coal fines are burned in suspension; the larger particles fall to the grate, where they are burned in a thin, fast-burning coal bed. This method of firing provides good flexibility to meet load fluctuations, since ignition is almost instantaneous when firing rate is increased. Hence, the spreader stoker is favoured over other types of stokers in many industrial applications.
L4.	What do you mean by boiler blow down? The impurities found in boiler water depend on the untreated feed water quality, the treatment process used and the boiler operating procedures. As a general rule, the higher the boiler operating pressure, the greater will be the sensitivity to impurities. As the feed water materials evaporate into steam, dissolved solids concentrate in the boiler either in a dissolved or suspended state. Above a certain level of concentration, these solids encourage foaming and cause carryover of water into the steam. This leads to scale formation inside the boiler, resulting in localised overheating and ending finally in tube failure. It is therefore necessary to control the level of concentration of the solids and this is achieved by the process of 'blowing down', where a certain volume of water is blown off and is automatically replaced by feed water - thus maintaining the optimum level of total dissolved solids (TDS) in the water. Blow down is necessary to protect the surfaces of the heat exchanger in the boiler.
L5.	Write short notes on intermittent blow down and continuous blow down with respect to boilers. The intermittent blown down is given by manually operating a valve fitted to discharge pipe at the lowest point of boiler shell to reduce parameters (TDS or conductivity, pH, Silica and Phosphates concentration) within prescribed limits so that steam quality is not likely to be affected. In intermittent blowdown, a large diameter line is opened for a short period of time, the time being based on a thumb rule such as “once a shift for 2 minutes”. Intermittent blowdown requires l*arge* short-term increases in the amount of feed water put into the boiler, and hence may necessitate larger feed water pumps than if continuous blow

	down is used. Also, TDS level will be varying, thereby causing fluctuations of the water level in the boiler due to changes in steam bubble size and distribution which accompany changes in concentration of solids. Also substantial amount of heat energy is lost with intermittent blow down. Continuous Blowdown There is a steady and constant dispatch of small stream of concentrated boiler water, and replacement by steady and constant inflow of feed water. This ensures constant TDS and steam purity at given steam load. Once blow down valve is set for a given conditions, there is no need for regular operator intervention. Even though large quantities of heat are wasted, opportunity exits for recovering this heat by blowing into a flash tank and generating flash steam. This flash steam can be used for pre-heating boiler feed water or for any other purpose. This type of blow down is common in high-pressure boilers.

Chapter 2.3 Steam System

Part–I: Objective type Questions and Answers

1.	The best quality of steam for industrial process heating is: a) dry saturated steam b) superheated steam c) wet steam d) high pressure steam
2.	The normal velocities encountered in pipes for superheated steam is: a) 50-70 m/sec b) 30-40 m/sec c) 20-25 m/sec d) 15-20 m/sec
3.	The normal velocities encountered in pipes for saturated steam is: a) 60 to 80 m/sec b) 10-30 m/sec c) 5 to 10 m/sec d) 30 to 40 m/sec
4.	Which among the following steam traps has the principle of operation "Difference in temperature between steam and condensate" a) thermodynamic trap b) thermostatic trap c) orifice type trap d) float trap
5.	In industrial applications the type of trap used for main steam lines are: a) thermodynamic b) thermostatic c) bimetallic d) float
6.	Velocity of steam in steam pipe is directly proportional to: a) number of bends in pipe b) specific volume of steam c) length of pipe d) none of the above
7.	Heat transfer rate for drying application will be less if we heat with: a) saturated steam b) wet steam c) superheated steam d) high pressure steam
8.	Which type of insulation is more economic or energy efficient for steam pipelines carrying saturated steam? a) glass wool b) ceramic fibre c) calcium silicate d) fibre bricks
9.	For flash steam calculation, flash steam available% ___ . Where, x stands for a) x = Latent heat of flash steam b) x = Sensible heat of flash steam c) x = Steam enthalpy at atmospheric pressure d) Total heat of flash steam

10.	Superheat is the addition of heat to dry saturated steam without increase in pressure.
11.	Enthalpy of evaporation is also known as latent heat.
12.	As a thumb of rule, in case of efficiency issues for boiler, for every 6 °C rise in feed water temperature, there will be approximately 1% saving of fuel.
13.	Water hammer is common in: a) water pipes b) condensate pipes c) steam pipes with steam and condensate d) main steam lines with good traps
14.	Proper sizing of steam pipeline helps in minimising a) steam requirement b) condensate c) insulation thickness d) pressure drop
15.	The demand for flash steam should exceed its supply so that there is no build-up of pressure in the flash vessel and consequent loss of steam through safety valve.
16.	The equipment used to remove dirt from steam lines before steam trap is: a) vent b) drain c) strainer d) by pass line
17.	The problem of water hammer can be eliminated by positioning the pipes so that there is a continuous slope in the direction of flow.

Part- II: Short type questions and answers

S1.	Why dry saturated steam is preferred for heating applications? Dry steam does not contain moisture. The presence of moisture reduces the total heat in the steam. Hence dry saturated steam is preferred for process.
S2.	Name the characteristics of steam which makes it most popular and useful to industries? The following characteristics of steam make it so popular and useful to the industry: • Highest specific heat and latent heat • Highest heat transfer coefficient • Easy to control and distribute • Cheap and inert

S3.	State the principle of thermodynamic steam trap? Thermodynamic or disk traps are designed with a flat disk which moves between a cap and seat. On start-up, condensate flow raises the disk and opens the discharge port. When steam or very hot condensate arrives, it closes the disk, which stays closed as long as pressure is maintained above the disk. Heat radiates out through the cap, which diminishes the pressure over the disk, opening the trap to discharge condensate.
S4.	Why drain points are required in a steam system? The drain points help in removing water in pipes due to condensation of steam. Drains should be so arranged that the condensate can easily flow into the trap.
S5.	Explain why low pressure steam is more efficient? The low pressure steam has more latent heat compared with the high pressure steam. Indirect heating efficiency will be more for low pressure steam.
S6.	What is water hammer in a steam system? A water hammer in a steam system is caused by condensate collection in the plant or pipe work picked up by the fast moving steam and carried along with it.
S7.	Why steam condensate recovery is important? The condensate is very valuable not only because of its heat content but also because of its purity. It is already treated and any quantity of condensate recovered will also mean saving of treatment chemicals corresponding to that much of condensate.
S8.	What are the parameters to be considered while sizing a flash vessel in a flash steam recovery system from steam condensate? a) Pressure of condensate b) Pressure to be maintained in the flash vessel c) Quantity of condensate per hour entering the flash tank
S9.	Give any three functions of steam trap? a) To discharge condensate as soon as it is formed b) Not to allow steam to escape c) To be capable of discharging air and other incondensable gases
S10.	What is the principle of working of Float type steam trap? Difference in density between steam and condensate
S11.	What function a thermo compressor does in a steam system? Thermo compressor is a device used to recover flash from the process and generate low pressure steam with the help of medium pressure steam.

S12. What is flash steam?

Flash steam is produced when condensate at a high pressure is released to a lower pressure.

S13. Define sensible heat of a substance?

The heat required to change the temperature of a substance is called its sensible heat.

S14. Define latent heat of a fluid?

This quantity of heat required to change a chemical from the liquid to the gaseous state is called latent heat.

S15. Name the three types of classifications of steam traps and also give their principle of operation?

The steam traps are classified as follows:

Group	Principle	Sub-group
Mechanical trap	Difference in density between steam and condensate.	Bucket type a) Open bucket b) Inverted bucket, with lever, without lever c) Float type d) Float with lever e) Free float
Thermodynamic trap	Difference in thermodynamic properties between steam and condensate	a) Disc type b) Orifice type
Thermostatic trap	Difference in temperature between steam and condensate	a) Bimetallic type b) Metal expansion type.

S16. What are the two common causes of wet steam formation in a steam generation and distribution network?

The two most common causes of wet steam formation are:

- Generation of steam in a boiler without a super heater
- Effectiveness of lagging of steam distribution pipelines

The wetness in steam is removed by providing steam separators and steam trap at suitable locations.

S17. What are the advantages of direct injection of steam for heating of liquid?

- The equipment required is relatively simple, cheap and easy to maintain

	• No condensate recovery system is necessary • The heating is quick, and the sensible heat in the steam is also used up along with the latent heat, making the system thermally efficient
S18.	What are the important precautions to be addressed while designing a flash vessel for flash steam recovery system? • The diameter of the vessel should be such that a considerable drop in velocity allows the condensate to fall to the bottom of the vessel from where it is drained out by the steam trap • Flash steam itself rises to leave the vessel at the top • The height of the vessel should be sufficient enough to avoid water being carried over in the flash steam
S19.	What are the ways of reduction of steam usage? • Reduction in operating hours • Reduction in steam quantity required per hour • Use of more efficient technology • Minimizing wastage
S20.	Name the 4 most commonly used insulation material for steam pipes. • Cork • Glass wool • Rock wool • Asbestos

Part – III: Long type questions and answers

L1.	Explain "flash steam recovery" from steam condensate. Flash steam is produced when steam condensate at a high pressure is released to a lower pressure and can be used for low pressure heating. The higher the steam pressure and lower the flash steam pressure the greater the quantity of flash steam that can be generated. In many cases, flash steam from high pressure equipment is made use of directly on the low pressure equipment to reduce use of steam through pressure reducing valves. The flash steam quantity can be calculated by the following formula with the help of a steam table: Flash steam available % = $\frac{S_1 - S_2}{L_2}$ Where: S_1 is the sensible heat of higher pressure condensate. S_2 is the sensible heat of the steam at lower pressure (at which it has been flashed). L_2 is the latent heat of flash steam (at lower pressure). Flash steam can be used on low pressure applications like direct injection and can replace an equal quantity of live steam that would be otherwise required. The demand for flash steam should exceed its supply, so that there is no build- up of pressure in the flash vessel and the consequent loss of steam through the safety valve. Generally, the simplest method of using flash steam is to flash from a machine/equipment at a higher pressure to a machine/equipment at a lower pressure, thereby augmenting steam supply to the low pressure equipment. In general, a flash system should run at the lowest possible pressure so that the maximum amount of flash is available and the backpressure on the high pressure systems is kept as low as possible. Flash steam from the condensate can be separated in equipment called the 'flash vessel'. The diameter of the vessel is such that a considerable drop in velocity allows the condensate to fall to the bottom of the vessel from where it is drained out by a steam trap preferably a float trap. Flash steam itself rises to leave the vessel at the top. The height of the vessel should be sufficient enough to avoid water being carried over in the flash steam.
L2.	A process plant requires 200 kg/hr of saturated steam at 3.5 kg/cm^2.g. The management decided to utilise the blowdown water to generate flash steam. The pressure of blow down is 41 kg/cm^{2}g. Calculate what will be the cost savings per annum if the steam cost is PKR. 500 per tonne. Assume the annual operating hours of the equipment as 8000 hours.

	Pressure of blowdown water	=	41 kg/cm2.g
	Enthalpy of blow down water	=	251.2 kcal/kg
	Enthalpy of process steam	=	652.5 kcal/kg
	Sensible heat in process steam	=	139 kcal/kg
	Heat available in blowdown water for flashing	=	112.2 kcal /kg
	Latent heat in process steam	=	513.5 kcal /kg
	Flash steam generation	=	237 kg/hr
	Annual operating hours	=	8000
	Flash steam recovery	=	1896 ton/year
	Cost savings	=	PKR.9.48 lakh /year

L3. "Steam should always be utilised at the lowest possible pressure" – What are the important aspects to be considered before fixing up the steam pressure for a particular application?

A study of the steam tables would indicate that the latent heat in steam reduces as the steam pressure increases. It is only the latent heat of steam, which takes part in the heating process when applied to an indirect heating system. Thus, it is important that its value be kept as high as possible. This can only be achieved if we go in for lower steam pressures. As a guide, the steam should always be generated and distributed at the highest possible pressure, but utilized at as low a pressure as possible since it then has higher latent heat.

However, it may also be seen from the steam tables that the lower the steam pressure, the lower will be its temperature. Since temperature is the driving force for the transfer of heat at lower steam pressures, the rate of heat transfer will be slower and the processing time greater. In equipment where fixed losses are high (e.g. big drying cylinders), there may even be an increase in steam consumption at lower pressures due to increased processing time. There are however, several equipment in certain industries, where one can profitably go in for lower pressures and realize economy in steam consumption without materially affecting production time.

Therefore, there is a limit to the reduction of steam pressure. Depending on the equipment design, the lowest possible steam pressure with which the equipment can work should be selected without sacrificing either on production time or on steam consumption.

L4.	Write short notes on: (a) Thermodynamic steam traps (b) Thermostatic steam traps. a) Thermodynamic steam traps: Thermodynamic or disk traps are designed with a flat disk which moves between a cap and seat. On start-up, condensate flow raises the disk and opens the discharge port. When steam or very hot condensate arrives, it closes the disk, which stays closed as long as pressure is maintained above the disk. Heat radiates out through the cap, which diminishes the pressure over the disk, opening the trap to discharge condensate. Wear and dirt can be a problem with a disk trap because of the large, flat seating surfaces involved. If pressure is not maintained above the disk, the trap cycles frequently, wastes steam, and fails prematurely. Thermodynamic steam traps are relatively small and compact for the amount of condensate they are capable of discharging. Their advantage is that one unit can handle a wide range of pressures. The primary disadvantage is difficulty in discharging air and other non-condensable gases. b) Thermostatic traps: Thermal-element thermostatic traps are temperature actuated. On startup the thermal element is in a contracted position with the valve wide-open, purging condensate, air, and other non-condensable gases. As the system warms up, heat generates pressure in the thermal element, causing it to expand and throttle the flow of hot condensate through the discharge valve. When steam follows the hot condensate into the trap, the thermal element fully expands, closing the trap. If condensate enters the trap during system operation, it cools the element, contracting it off the seat, and quickly discharging condensate. Thermostatic traps are small, lightweight, and compact. One trap operates over extremely broad pressure and capacity ranges. Thermal elements can be selected to operate within a range of steam temperatures. In steam tracing applications it may be desirable to actually back up hot condensate in the lines to extract its thermal value.

L5.	What are the important guidelines for proper drainage and layout of steam lines? Guide for proper drainage and layout of steam lines: • The steam mains should be run with a falling slope of not less than 125 mm for every 30 metres length in the direction of the steam flow. • Drain points should be provided at intervals of 30-45 metres along the main. • Drain points should also be provided at low points in the mains and where the steam main rises. Ideal locations are the bottom of expansion joints and before reduction and stop valves. • Drain points in the main lines should be through an equal tee connection only. • It is preferable to choose open bucket or TD traps on account of their resilience. • The branch lines from the mains should always be connected at the top. Otherwise, the branch line itself will act as a drain for the condensate. • Insecure supports as well as an alteration in level can lead to formation of water pockets in steam, leading to wet steam delivery. Providing proper vertical and support hangers helps overcome such eventualities. • Expansion loops are required to accommodate the expansion of steam lines while starting from cold. To ensure dry steam in the process equipment and in branch lines, steam separators can be installed as required.

Chapter 2.4 Furnaces

Part-I: Objective type Questions and Answers

1.	In case of furnace performance, 'infiltration' is less harmful than 'exfiltration'. - True or false?
2.	If the furnace pressure is lower than outside pressure air infiltration takes place and which causes higher heat loss from flue gases.
3.	For optimum fuel consumption, furnaces should be operated at a) slightly negative b) slightly positive c) neutral d) any of the above
4.	Ceramic coatings when applied have a long life at temperatures upto ___ °C a) 1050 °C b)1150 °C c) 1250 °C d) 1350 °C
5.	Preheating of air temperature will be maximum in ___ with respect to furnaces waste heat recovery system. a) recuperative b) regenerative
6.	In large glass industries, the glass melting furnace is equipped with a) recuperators b) regenerators c) shell & tube heat exchanger d) heat wheels
7.	Pick up the wrong statement: The thermal efficiency of the furnace increases by a) increasing the furnace loading b) increasing the air flow rate c) reducing the surface heat loss d) minimising the CO loss
8.	Normally for billet reheating furnace, the type of pressure maintained inside is a) slightly positive pressure b) high negative pressure c) zero pressure d) none of the above
9.	For case of film burners the excess air level maintained is of the order of a) 20-25% b) 5 to 10% c) 15 to 20% d) none of the above
10.	Thermal efficiency of reheating furnace is of the order of a) 70 to 80% b) 65 to 70% c) 40 to 50% d) 20 to 40%

11.	The axis of the burner in a furnace should be kept: a. slightly inclined towards the roof b. more inclined towards roof c. slightly inclined towards the stock d. parallel to stock
12.	In connection with insulation material for furnaces, the heat storage losses in ceramic fibre insulation are minimum compared to other refractories.
13.	The emissivity of ceramic coatings used in furnace: a) decreases with increase in temperature b) Increases with increase in temperature c) remains constant d) decreases with increase in furnace pressure
14.	Higher excess air in an oil fired furnace would result in: a. increased furnace temperature b. increased heating rate c. reduced flame temperature d. none of the above
15.	Instrumentation used for measuring billet temperature in a reheating furnace a. flue gas analyser b. infrared pyrometer c. Pt/Pt-Rh thermocouple with indicator d. chrome alumnel thermocouple with indicator
16.	Normal operating temperature of rolling mill furnace a) 800 ^{o}C b) 900 ^{o}C c) 1000 ^{o}C 1200 °C
17.	Scale losses will: a. increase with excess air b. decrease with the excess air c. will have no relation with excess air d. will increase with nitrogen in air

Part-II: Short type questions and answers

S1.	Do you need excess air for combustion? If yes what should be the required excess air? Excess air is always required for complete combustion. The method of air supply should be such that there is intimate contact between oxygen and combustibles. This is achieved by creating turbulence in the combustion zone. Normally (in practice) the excess air should be about 10 to 15% more than the stoichiometric air requirement. However, there are burners which operate on 5 to 8% excess air also.
S2.	What is the significance of optimizing furnace temperature? Furnaces must be operated at an optimum temperature. Too high a temperature will cause overheating of the stock leading to excess oxidation high thermal stresses on refractories and higher fuel consumption. Too low temperature would lead to reduce quality of the product or difficult in metal forming etc.
S3.	What do you mean by turn down ratio? The ratio of maximum heat input rate to minimum. It is the range within which the burner operates satisfactory.
S4.	How do you determine excess air level in a furnace? Quantity of excess air can be determined by measuring the % O_2 or % CO_2 in the flue gas. With the measured volume of % CO_2, the excess air can be calculated by the following formula % excess air - $\left(\frac{TheoreticalCO_2 - ActualCO_2}{ActualCO_2}\right) x100$
S5.	What is the effect of furnace draft? It is important to operate furnace at a slightly positive pressure. Negative pressure lead to air infiltration affecting air fuel ratio and furnace temperature thus increasing fuel consumption. Excessive positive pressure leads to infiltration resulting in leaking out of flames, overheating of furnace refractories, reduced brick life and other associated problems.
S6.	What is a regenerative burner for furnace applications? Regenerative burner unit comprises of at least two burners, two regenerators or flow reversal system and associated controls. The burners and regenerators may be closely coupled or joined by a length of refractory lined duct to suit the space available in site. One burner fires using air fed to the base of regenerator, other burner acts as an exhaust post drawing off waste gas thereby heating its regenerator. When this regenerator is sufficiently charges the reversal valve operates to reverse the system. The regenerator previously cooled is reheated in turn by waste gas leaving the furnace via its associated burner post.
S7.	What is meant by combustion efficiency evaluation for a furnace? Combustion efficiency indicates the energy transferred from the fuel to the furnace. All the conventional fossil fuels basically contain carbon and hydrogen which when burnt react with oxygen of air forming carbon di oxide, carbon monoxide or water vapour.

S8.	Differentiate between furnace and oven? Furnace is an equipment to melt metals for costing or heat materials for change of shape (rolling, forging etc.) or change of properties (heat treatment). When the furnace is operated below 370 °C temperature then it is called as oven, and when it operates above 370 °C temperature then the operating equipment is called furnace.
S9.	List out different types of heat losses in furnaces. Different types of heat losses in furnaces are- a) Dry flue gas losses b) Heat distribution losses c) High temperature losses d) Heat loss through openings e) Draft losses f) Radiation and convection losses g) Heat carried by product carrying equipment (trolley, basket etc.)
S10.	What is the fuel saving rate evaluation formula for preheating of combustion air in furnaces? By using pre heat of combustion air in the furnaces fuel can be saved. The fuel saving rate is given by the following formula: $S = \left(\frac{P}{F + P - Q} \right) x100\%$ Where, s: fuel saving rate F: Calorific value of fuel (kcal/kg of fuel) P: quantity of heat brought in by pre heated air (kcal/kg fuel) Q: quantity of heat taken away by exhaust gas (kcal/kg fuel)
S11.	What is recuperator? Explain in brief? Recuperator is a heat exchanger installed to exchange heat between the waste gases and the air to be preheated. It usually consists of ducts and tubes, which carry air for combustion to be preheated.
S12.	Name three devices generally used as waste heat recovery for furnaces? 1) Metallic recuperators (2) Ceramic recuperators and (3) Regenerators
S13.	How do ceramic coatings help in reducing energy consumption in a furnace? Ceramic coatings in furnace chamber promote rapid and efficient transfer of heat, uniform heating and extended life of refractories. The emissivity of ceramic coated refractories increases with increase in temperature. Energy savings to an order of 8 to 10% can be achieved for high temperature applications.
S14.	How do you evaluate the furnace performance by direct method? $Thermal\ efficiency\ of\ the\ furnace = \frac{Heat\ in\ the\ stock}{Heat\ in\ the\ fuel\ consumed\ for\ heating\ the\ stock}$

	The quantity of heat to be imparted (Q) to the stock can be found from Q = m x C_p ($t_1 - t_2$), where Q = Quantity of heat of stock in Kcal m = Weight of the stock in Kg C_p = Mean specific heat of stock in kCal/kg°C t_1 = Final temperature of stock desired, °C t_2 = Initial temperature of the stock before it enters the furnace, °C

Part-III: Long type questions and answers

L1.	What are the advantages of using minimum excess air for combustion for a furnace application? How it can be achieved? The optimization of combustion air is the most attractive and economical measure for energy conservation. The impact of this measure is higher when the temperature of furnace is high. Air ratio is the value that is given by dividing the actual air amount by the theoretical combustion air amount, and it represents the extent of excess of air. By providing minimum excess air for combustion, the exhaust losses can be reduced and hence reduced fuel consumption. To obtain complete combustion of fuel with the minimum amount of air, it is necessary to control air infiltration, maintain pressure of combustion air, fuel quality and excess air monitoring. Higher excess air will reduce flame temperature, furnace temperature and heating rate. On the other hand, if the excess air is less, then unburnt components in flue gases will increase and would be carried away in the flue gases through stack. So correct excess air level keeping in a furnace saves fuel and also for some case reduces the scale losses.
L2.	Explain the importance of furnace draft and its control? If negative pressures exist in the furnace, air infiltration is liable to occur through the cracks and openings thereby affecting air-fuel ratio control. Tests conducted on apparently airtight furnaces have shown air infiltration up to the extent of 40%. Neglecting furnace pressure could mean problems of cold metal and non-uniform metal temperatures, which could affect subsequent operations like forging and rolling and result in increased fuel consumption. For optimum fuel consumption, slight positive pressure should be maintained in the furnace. Ex-filtration is less serious than infiltration. Some of the associated problems with ex filtration are leaping out of flames, overheating of the furnace refractories leading to reduced brick life, increased furnace maintenance, burning out of ducts and equipment attached to the furnace, etc. In addition to the proper control on furnace pressure, it is important to keep the openings as small as possible and to seal them in order to prevent the release of high temperature gas and intrusion of outside air through openings such as the charging inlet, extracting outlet and peephole on furnace walls or the ceiling.

L3.	In an industry one 30 kWh operating load, electrical furnace to be converted into furnace oil fired. Estimate the furnace oil (litre) requirement, considering the following: Calorific value of FO : 9200 Kcal/kg Density of FO (kg/litre at 15 °C) : 0.9 Efficiency of electrical furnace : 70% Efficiency of FO fired furnace : 55% Operating electrical load : 30 kWh Efficiency of electrical furnace : 70% Useful heat : 30 x 860 x 0.7 = 18060 kcal For meeting useful heat required FO : 18060/9200 = 1.96 kg Efficiency of FO fired furnace : 55% Net FO required to meet useful heat : 1.96/0.55 = 3.56 kg Estimated furnace oil quantity : 3.56 / 0.9 = 3.95 litres
L4.	In an engineering industry, resistance heating type furnace was used for heat treatment of the product. The power consumption of the furnace at 1/3 load and full load is 860 kWh and 1600 kWh per cycle respectively. The furnace heat treatment cycle and loading of the furnace was analysed. The details are as follows: Furnace capacity : 180 kW Loading capacity of furnace : 10 Tonnes Heat treatment cycle : Heating up to 650 °C – 6 hours : Soaking at 650 °C – 8 hours : Cooling in furnace – 4 hours Quantity of the stock to be treated : 1000T/year Evaluate the energy savings by optimum loading? Sp. Power consumption of stock: i) Load in furnace (1/3) : 10 x 1/3 = 3.3 MT Power consumption for 1/3rd load : 860 kWh/cycle Sp. Power consumption at 1/3rd load : 860/3.3 = 260.6 kWh/MT ii) Load in the furnace (full) : 10 MT Power consumption at full load : 1600 kWh/cycle Sp. Power consumption at full load : 1600/10 = 160 kWh/MT Reduction in power consumption at optimum load (full load) : 260.6 – 160 = 100.6 kWh/MT Annual stock production : 1000 T By operating furnace with each batch of 10T (full load) Reduction in power consumption : 1000 x 100.6 : 100600 kWh/year

L5.	Write few salient points about optimum capacity utilisation of furnaces. On e of the most vital factors affecting efficiency of furnace is loading. There is a particular loading at which the furnace will operate at maximum thermal efficiency. The best method of loading is generally obtained by trial-noting the weight of material put in at each charge, the time it takes to reach temperature and the amount of fuel used. The loading of the charge on the furnace hearth should be arranged, so that: 1. It receives the maximum amount of radiation from the hot surfaces of the heating chambers and the flames produced. 2. The hot gases are efficiently circulated around the heat receiving surfaces Stock should not be placed in the following portion. i) In the direct path of the burners or where flame impingement is likely to occur. ii) In an area which is likely to cause a blockage or restriction of the flue system of the furnace. iii) Close to any door openings where cold spots are likely to develop. Optimum utilization of furnace can be planned at design stage. In case of batch type furnaces, careful planning of the loads is important. Furnace should be recharged as soon as possible to enable use of residual furnace heat.

Chapter 2.5: Insulation & Refractories

Part-I: Objective type questions and answers

1.	'Ceramic fibre insulation' suitable up to ___ temperature. a) 540 °C b) 1050 °C c) 1325 °C d) 1850 °C
2.	Which Insulation material is suitable for low temperature application? a) Mineral fibre b) Fibre glass c) Silica d) polyurethane
3.	Match the following: Insulating material — Suitable temperature a) Rockwool — i) - 178 °C to 4 °C b) Fibre glass — ii) -167 °C to 82 °C c) Polystyrene — iii) Up to 820 °C d) Polyurethane — iv) Up to 540 °C Ans. a-iii); b-iv); c-ii); d-i)
4.	In insulation and refractories the unit for thermal coefficient is _____. a) K.cal/m-hr-°C b) K.cal/ m^2-hr-°C c) K.cal/m^2-°C d) K.cal/ m-°C
5.	The refractory material should have ____ heat conductivity. – a) low b) High c) Medium c) None
6.	By having lower density refractory, heat input will ____ . a) increase b) decrease c) remain constant d) none of the above
7.	Air acts as a bad insulator– (a) False or (b) True? –
8.	Name the Insulating material used in kilns for burning zone? a) silica bricks b) chrome magnesite c) high alumina refractories d) Calcium silicate blocks
9.	Make the best choice of insulation material for electric heat treatment furnace among the following group. a) glass wool b) calcium silicate c) fire bricks d) ceramic fibre

10.	For steam pipelines with temperature of 540 °C, select the best economic insulation? a) calcium silicate b) fibre glass c) rock wool d) Alumina
11.	While positioning the furnace wall using various type of insulation like, fire bricks, calcium silicate blocks and insulation bricks are used. Can you suggest the sequence of placement of their temperature tolerance for each of them? a) hot face, cold faces and intermediates b) cold face, intermediates and hot face c) hot face, intermediate and cold face d) All the above
12.	As an improvement of performance of furnace, _____ emissivity coating is applied for interior surfaces of furnaces. a)Low b) high c) medium
13.	Alumina is a ____ type of refractory. a)acid b) basic c) Neutral d) None of the above
14.	Polyurethane insulation material is suitable for: a. Temperatures up to 820 °C b. Low temperatures (-178 °C to 4 °C) c. Temperatures up to 540 °C d. Temperatures up to 1050 °C
15.	Calcium Silicate insulation material is suitable for: a. Low temperatures (-178 °C to 4 °C) b. Temperatures up to 820 °C c. Temperatures up to 540 °C **d.** Temperatures up to 1050 °C
16.	High emissivity coatings are applied on: a. Outer surface of furnace b. Refrigeration piping c. Inner surface of furnace **d.** None of the above
17.	Thermal resistance value decreases with increased thermal conductivity for a given turbine.
18.	In high temperature melting furnace hot liquid metal touches the refractory – True or false?
19.	Addition ZrO_2 to ceramic fibre will reduce shrinkage levels
20.	The insulation which can be used for lining furnaces operating up to 1850°C is: a) Alumina b) Zirconia c) Dolomite d) Calcium silicate

Part-II: Short type questions and answers

S1.	Why insulation is provided to flue gas ducts at chimney? Ans. To keep the flue gas temperature high, not to fall below the acid dew point temperature.
S2.	Why cold surfaces should be insulated? Ans. To prevent the flow of heat from the surroundings to the system, as in the case of cold surfaces which are used for air conditioning in summer?
S3.	Name any two insulating material used for steam pipelines Ans. Insulating materials used for steam pipelines are rock wool (mineral fibre) and fibreglass.
S4.	List any five parameters, which require to evaluate economic thickness of insulation. Ans. For determination of economic thickness following parameters are required: i) cost of fuel ii) Annual hours of operation iii) Heat content of fuelBoiler efficiency iv) Operating surface temperature v) Pipe diameter / thickness of surface vi) Estimated cost of insulation **vii)** Average exposure ambient still air temperature
S5.	Write the simple equation for heat loss calculation useful for up to 200 °C temperature. Ans. The surface heat loss can be computed with the help of a simple relation up to 200 °C surface temperature. S = [10 + (Ts-Ta) / 20] x [Ts-Ta] Where, S = Surface heat loss in kcal/hr m^2 Ts = Hot surface temperature in °C Ta = Ambient temperature in °C

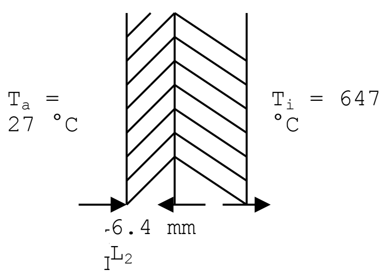
S6.	What are the other conditions to be looked while selecting the refractory for furnaces apart from furnace temperature? Ans. During the selection of refractory for furnaces following points considered apart from furnace temperatures: i) Ability to withstand action of molten metal slag, glass, hot gases etc. ii) Ability to withstand load and abrasive forces iii) Low coefficient of thermal expansion iv) Should be able to conserve heat **v)** Should not contaminate the material with which it comes into contact
S7.	In furnaces, apart from fuel savings, what are the other advantages by use of insulation? Ans. The advantages by use of insulation in furnaces, apart from fuel savings are: i) Offers better process control by maintaining process temperatures ii) Prevents corrosion by keeping higher flue gas temperatures above acid dew point. iii) Provides fire protection **iv)** Absorbs vibration
S8.	What is that initial survey for hot spots on surfaces of furnaces leads to? Ans. Initial survey could identify surface temperatures are above 60 °C, it requires insulation to reduce the losses. A judicious selection of proper insulation and the cost estimate plays a vital role in fixing the particular insulation for a defined surface.
S9.	What are the benefits of thermal insulation? Ans. Thermal insulation delivers the following benefits: – Reduces over-all energy consumption – Offers better process control by maintaining process temperature. – Prevents corrosion by keeping the exposed surface of a refrigerated system above dew point – Provides fire protection to equipment – Absorbs vibration
S10.	What is economic thickness of insulation? Ans. The effectiveness of insulation follows the law of decreasing returns. Hence, there is a definite economic limit to the amount of insulation, which is justified. An increased thickness is uneconomical and cannot be recovered through small heat savings. This limiting value is termed as economic thickness of insulation.
S11.	What is high emissivity coating? Ans. The high emissivity coating allows the surface emissivity of materials to be increased, with resultant benefits in heat transfer efficiency and in the service life of heat transfer components. High emissivity coatings are applied in the interior surface of furnaces.

S12.	Describe emissivity in refractory material. Ans. Emissivity is the measure of material's ability to both absorb and radiate heat. Higher emissivity characteristic has benefit of heat transfer efficiency and service life of material. High emissivity coatings are applied at the interior surface of the furnace
S13.	How do you reduce the heat loss through evaporation on a hot liquid tank? Ans. Open top tanks containing hot liquids lose energy through evaporation. Heat losses can be appreciably reduced by floating a layer of polypropylene (plastic) spheres on the surface of the liquid. Manufacturers claim a reduction of 70% heat losses by floating a layer of 45 mm diameter balls on the surface of liquids at 90°C.
S14.	What is the basis for classifications of refractories? Ans. Refractories can be classified on the basis of chemical composition and method of manufacturing.
S15.	What type of insulation used for furnace walls? Ans. Calcium silicate is used for furnace walls, which is reinforced with a non-asbestos binder. Has a simple air cell structure, has low thermal conductivity and will retain its size and shape in its variable temperature range.
S16.	What is a Ceramic-Fibre Insulating Lining? Ans. Ceramic fibres are produced by melting the same alumina-silica china (kaolin) clay used in conventional insulating firebrick and blowing air to form glass fibres. Ceramic-fibre linings, available for the temperature range of 650 to 1430°C (1200 to 2600°F) are more economical than brick in the 650 – to 1230°C- (1200 – to 2250°F) range. Savings come reduced first costs, lower installation labour, 90 to 95 percent less weight and a 25 percent reduction in fuel consumption.
S17.	Name the effect of thermal insulation on the equipment. Ans. Thermal insulation provided on equipment help to prevent either heat loss from the equipment or heat gain to the equipment.
S18.	List any four commonly used industrial applications of insulation. Ans. The insulation is commonly used for the following industrial purposes. i) Air conditioning system ii) Refrigeration and food preserving stores iii) Boilers and steam pipes **iv)** Insulating bricks in all types of furnaces
S19.	Define the insulation Ans. The insulation is defined as poor conductor of heat and has a low thermal conductivity.

S20.	Describe the refractory material. Ans. Any material, if it can withstand the action of abrasive or corrosive solids, liquids or gases at high temperatures are called 'refractory' material.

Part-III: Long type questions and answers

L1.	A furnace wall is made of 75 mm thick fire clay brick and 6.4 mm thick mid steel plate. The inside surface of brick temperature is 647 °C and outside air temperature is 27 °C. Determine: The heat loss per m² area of the furnace wall. Consider K1 (brick) = 1.1 W/m-°C K2 (steel) = 39 W/m-°C h_0 (outside heat transfer coefficient) = 68 W/m²-°C



Considering unit surface area

$$R_{brick} = \frac{L1}{K1} = \frac{0.075}{1.1} = 0.0682$$

$$R_{steel} = \frac{L2}{K2} = \frac{0.0064}{39} = 1.64 x 10^{-4}$$

$$R_{Conv.} = \frac{1}{h_0} = \frac{1}{68} = 0.0147$$

$R_{Total} = R_{brick} + R_{steel} + R_{cov} = 0.083$

i) Q (heat loss per m² area) = $\frac{T_i - T_a}{R_{Total}}$

$$= \frac{647 - 27}{0.083} = 7460 W / m^2$$

L2.	List out the general requirements of refractory? Ans. The general requirements of refractory before selecting for any furnace are: i) Area of application ii) Working temperatures iii) Extent of abrasion and impact iv) Structural load of the furnace v) Stress due to temperature gradient in the structures and temperatures fluctuations vi) Chemical compatibility with the furnace environment vii) Heat transfer and fuel conservation **viii)** Cost considerations
L3.	What do you mean by "Economic thickness of insulation"? Explain in details. Ans. The effectiveness of insulation follows the law of decreasing returns. Hence, there is a definite economic limit to the amount of insulation, which is justified. An increased thickness is uneconomical and cannot be recovered through small heat savings. This limiting value is termed as economic thickness of insulation. Each industry has different fuel cost and boiler efficiency. These values can be used for calculating economic thickness of insulation. This shows that thickness for a given set of circumstances results in the lowest overall cost of insulation and heat loss combined over a given period of time. The following figure shown below illustrates the principle of economic thickness of insulation.

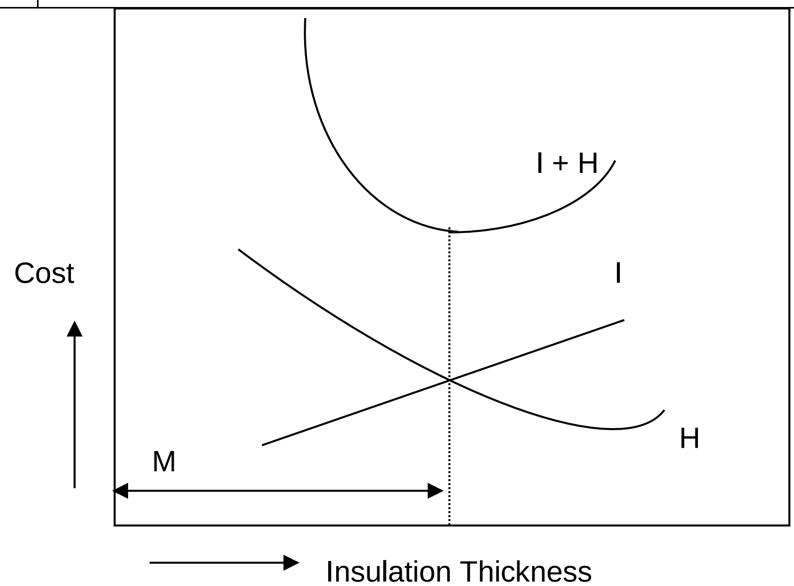


Figure Determination of economic thickness of insulation

I: Cost of Insulation H : Cost of Heat Loss
I + H : Total Cost M : Economic Thickness

The determination of economic thickness requires the attention to the following factors.

i. Alumina

ii. Pipe diameter/thickness of surface iii. Estimated cost of insulation. iv. Average exposure ambient still air temperature.	
L4.	Steam pipeline 100 mm diameter is not insulated for 100 metre length supplying steam at 10 kg/cm^2 to the equipment. Find out the fuel savings if it is properly insulated with 65 mm insulating material. *Given:* Boiler efficiency – 80% Fuel Oil cost - Rs.15000/tonne Surface temperature without insulation – 170°C Surface temperature after insulation – 65°C Ambient temperature – 25°C Ans. *Existing Heat Loss* S = [10+ (Ts-Ta)/20] x (Ts-Ta) Ts = 170°C Ta = 25°C S = [10+(170-25)/20] x (170-25) = 2500 Kcal/hr-m^2 S1 = S =Existing heat loss (2500 Kcal/hr-m^2) *Modified System* After insulating with 65 mm glass wool with aluminium cladding the hot face temperature will be 65°C Ts – 65°C Ta – 25°C Substituting these values S = [10+(65-25)/20] x (65-20) = 480 K.cal/hrM^2 S2 = S =Existing heat loss (480 Kcal/hr-m^2) **Fuel Savings Calculation** Pipe dimension = 100 mm ϕ & 100 m length Surface area existing (A1) = 3.14 x 0.1 x 100 = 31.4 m^2 Surface area after insulation (A2) = 3.14 x 0.23 x 100 = 72.2 m^2 Total heat loss in existing system (S1 x A1) = 2500 x 31.4 = 78500 Kcal/hr Total heat loss in Modified system (S2 x A2) = 480 x 72.2 = 34656 Kcal/hr Reduction in heat loss = 78500 – 34656 = 43844 Kcal/hr No. of hours operation in a year = 8400 hours Total heat loss (Kcal/yr) = 43844 x 8400 = 368289600

	Calorific value of fuel oil	=	10300 Kcal/kg
	Boiler efficiency	=	80%
	Price of fuel oil	=	PKD.15000/Tonne
	Yearly fuel oil savings	=	368289600/10300 x 0.8
		=	44695 kg//year
L5.	What are the factors involved in selecting a lagging material? Ans. The ultimate choice of a thermal insulating material is an engineering decision involving a number of factors, important among such are: 1. The operating temperature of the system 2. Thermal conductivity of the insulation 3. Capability of the insulation in application to hot surfaces readily and cheaply 4. Resistance to heat, weather and adverse atmospheric conditions 5. Ability to withstand vibration, noise, and accidental mechanical damage 6. Resistance to chemicals 7. Resistance to fire 8. No shrinkage or cracking during use 9. Jacketing the insulation 10. Total cost including maintenance costs		

Chapter 2.6: FBC Boilers

Part-I: Objective type questions and answers

1.	Fluidization in FBC boilers depends largely on the particle size and air velocity.
2.	FBC boilers offers the ability to burn high ash /sulphur coal.
3.	Lime stone ($CaCO^{3}$) is used in the FBC boiler bed to control SO_2 and NO_x
4.	In case of FBC boiler, the difference between mean solid and gas velocity is called Slip velocity
5.	AFBC is also known as bubbling bed boiler.
6.	FBC boiler has an advantage of: a) Burning high quality coal b) Burning only low grade coal c) Burning wide variety of coal d) None of the above
7.	The bed temperature for a FBC boiler ranges between? a) 750 – 800°C b) 840 – 950°C c) 950 - 1000°C d) 1000 - 1200°C
8.	The velocity of fluidizing air in atmospheric fluidized bed boiler is in the range of: a) Higher than 4.5 m/sec b) 1.2 – 3.7 m/sec c) Less than 1.2 m/sec d) 4-6 m/sec
9.	The coal particle size used for CFBC boiler is in the range of: a) 5 – 6 mm b) 6 – 12 mm c) 12 – 15 mm d) 15 – 25 mm
10.	In India commonly used power plant boilers are: a) PFBC boiler b) AFBC boilers c) Pulverized coal fired boilers d) Stoker fired boilers
11.	The boilers popularly used in sugar mills are: a) FBC with under feeding system b) FBC with over feeding c) Travelling grate stoker fired boilers d) PFBC boilers
12.	FBC boilers can operate with an overall boiler efficiency of: a) 84 ± 2% b) 78 ± 2% c) 88 ± 2% d) 94 ± 2%
13.	If the boiler bed temperature exceeds beyond 950°C results in: a) Over heating of in-bed tubes b) Ash fusion c) Melting of lime stones d) Ash carry over

14.	For air distribution in FBC boilers, which one of the following is used? a) Orifice plates b) Small parallel distributor pipes c) Compressed air through nozzles d) Secondary air from sides
15.	Objects can float or sink in a fluidised bed according to their a) velocities b) temperature c) density d) bed height
16.	In FBC the combustion is carried out at a temperature a) Below ignition temperature b) At adiabatic combustion temperature c) Above ash fusion temperature d) Below ash fusion temperature
17.	Residence time of combustion particles in FBC boiler is many times greater than conventional grate firing. – True or False
18.	For efficient sulphur retention, the temperature of the bed in a fluidized bed boiler should be a) 950°C b) 1100°C c) 850°C d) none of the above
19.	The amount of fly ash handled by FBC boiler is high due to elutriation of particles at high velocities.
20.	The following boilers can be retrofitted to FBC Technology a) Stoker fired water tube boiler only b) Oil fired water tube boiler only c) Both a & b are true d) Both a & b are false

Part-II: Short Type Questions and answers

S1.	What are the main advantages of FBC over conventional firing? Fluidised bed combustion has significant advantages over conventional firing systems and offers multiple benefits – namely fuel flexibility, reduced emission of noxious pollutants such as SOx and NOx, compact boiler design and higher combustion efficiency
S2.	What are the parameters which affect the performance of the heat transfer in FBC? (i)Bed temperature (ii) Bed pressure (iii) Superficial gas velocity (iv) particle size (v) Heat exchanger design and (vi) Gas distributor plate design
S3.	What is fluidizing velocity for a FBC boiler? The velocity required to make the particles in suspension in the air stream in a Fluidized Bed combustor is called fluidizing velocity.
S4.	In a FBC boiler, when bed is said to be fluidized? The bed of solid particles in a FBC exhibits the properties of a boiling liquid and assumes the

	appearance of a fluid. In this state the bed is said to be fluidized.
S5.	What is the principle of CFBC (circulating fluidized bed combustion) boiler? CFBC technology utilizes the fluidized bed principle in which crushed (6 –12 mm size) fuel and limestone are injected into the furnace or combustor. The particles are suspended in a stream of upwardly flowing air (60-70% of the total air), which enters the bottom of the furnace through air distribution nozzles. The balance of combustion air is admitted above the bottom of the furnace as secondary air. While combustion takes place at 840-900^{o}C, the fine particles (<450 microns) are elutriated out of the furnace with flue gas velocity of 4-6 m/s. The particles are then collected by the solids separators and circulated back into the furnace. This combustion process is called circulating fluidized bed (CFB).
S6.	State the important aspects to be considered in retrofitting conventional boilers with FBC? a) Water/steam circulation design b) Furnace bottom-grate clearance c) Type of particulate control device d) Fan capacity e) Availability of space
S7.	What is the significance of distributor plate in FBC system? An essential function of the distributor is to introduce the fluidizing air evenly through the bed cross section thereby keeping the solid particles in constant motion, and preventing the formation of defuidization zones within the bed.
S8.	List the three types of FBC boilers? 1. Atmospheric classic Fluidised Bed Combustion System (AFBC) 2. Atmospheric circulating (fast) Fluidised Bed Combustion system(CFBC) 3. Pressurised Fluidised Bed Combustion System (PFBC).
S9.	What are the features of bubbling bed boiler? (i) Distribution plate through which air is blown for fluidizing. (ii) Immersed steam-raising or water heating tubes which extract heat directly from the bed. (iii) Tubes above the bed which extract heat from hot combustion gas before it enters the flue duct.
S10.	What is the advantage of Pressurised Fluidised Bed Combustion System (PFBC) system over Atmospheric classic Fluidised Bed Combustion System (AFBC)AFBC? The PFBC system can be used for cogeneration or combined cycle power generation. By combining the gas and steam turbines in this way, electricity is generated more efficiently than in conventional system. The overall conversion efficiency is higher by 5% to 8%.

S11.	List the advantages of CFBC boilers over AFBC boilers. • Higher processing temperature because of high gas velocity through the system. • Lower combustion temperature of about 870 ^{o}C can be achieved constantly, which results in minimal NOx formation. • The combustion air is supplied at 1.5 to 2 psig rather than 3 to 5 psig as required by bubbling bed combustors. • Higher combustion efficiency. • Better turndown ratio. • Erosion of heat transfer surface in the combustion chamber is reduced, since the surface is parallel to the flow. In AFBC system, the surface is generally perpendicular to the flow.
S12.	Define minimum fluid velocity for a boiler? The minimum air/gas velocity which gives rise to bubble formation, vigorous turbulence and rapid mixing of the bed of solid particles which exhibits the properties of a boiling liquid and assumes the appearance of a fluid is called as minimum fluid velocity.
S13.	In the context of boiler issues, what is slip velocity? What are its advantages? The mean solids velocity increases at a slower rate than does the gas velocity. The difference between the solids velocity and the gas velocity is called as slip velocity.
S14.	List the factors that are important for efficient heat transfer in the bed. • Bed pressure • Bed temperature • Superficial gas velocity • Particle size • Heat exchanger design • Gas distribution plate design
S15.	Describe how pressurised fluidised bed boiler (PFBC) can be used in a cogeneration system. In PFBC, the bed vessel is operated at pressure upto 16 ata. The off-gas from the fluidized bed combustor drives the gas turbine. The steam turbine is driven by steam raised in tubes immersed in the fluidized bed. The condensate from the steam turbine is pre-heated using waste heat from gas turbine exhaust and is then taken as feed water for steam generation.
S16.	What are the advantages of using PFBC system for cogeneration or combined cycle power generation than the conventional system? • The overall efficiency is higher by 5% to 8%. • The potential reduction in boiler size is considerable due to increased amount of combustion in pressurized mode and high heat flux through in-bed tubes.

S17.	For FBC boiler, a statement is made to read as "A fluidised bed of solids behave in many ways like a liquid". Justify. The following points substantiate the statement: • Sand particles resting on a mesh become fluidized when air is blown through and take on the appearance and some of the properties of a boiling fluid. • Granular solids remain in layers when one is poured on to another. Rapid mixing occurs on fluidisation • A bed of stationary particles supports objects whatever their density. On fluidisation, an object of lower density floats and of higher density sinks • In a bed of stationary particles, heat is transferred slowly and there are big differences in temperature. In a fluidized bed, rapid mixing ensures uniformity of temperature
S18.	What modifications are required to retrofit a conventional stoker fired water tube boiler to fluidised bed combustion? Retrofitting of a fluidised bed combustor to a conventional stoker fired water tube boiler may involve: • The replacement of grate by a distributor plate with short stand pipes for admitting air from the wind box located underneath. • Installation of stand pipes to remove ash from the bed. • Provision of horizontal hair pin tubes in the bed with a pump for forced circulation from the boiler drum. • Modification of crusher to size the coal/limestone mixture for pneumatic under bed injection of the mixture.
S19.	What are the important aspects to be considered for retrofitting a conventional boiler to FBC technology? The important aspects to be considered in retrofit projects are: • Water/steam circulation design • Furnace bottom-grate clearance • Type of particulate control device • Fan capacity • Availability of space.
S20.	Define entrainment velocity for boilers? With higher air velocities, the bed particles leave the combustion with the flue gases so that solids recirculation is necessary to maintain circulating fluidized bed. The minimum velocity at which this phenomenon takes place is called as entrainment velocity.

Part-III: Long Type Questions and answers

L1.	Explain the main features with reference to fuel feeding system, air distribution, bed & in-bed heat transfer, surface and ash handling system for a FBC boiler. • Fuel Feeding For feeding fuel and sorbent like limestone or dolomite, usually two methods are followed as explained below: Under Bed Pneumatic Feeding If the fuel is coal, it is crushed to 1-6 mm size and pneumatically transported from feed hopper to the combustor through a feed pipe piercing the distributor. Based on the capacity of the boiler, the number of feed points increases as it is necessary to distribute the fuel into the bed uniformly. Over-Bed Feeding The crushed coal, 6-10 mm size is conveyed from coal bunker to a spreader by a screw conveyor. The spreader distributes the coal over the surface of the bed uniformly. This type of fuel feeding system accepts over size fuel also and eliminates transport lines, when compared to under-bed feeding system. • Air Distributor An essential function of the distributor is to introduce the fluidizing air evenly through the bed cross section thereby keeping the solid particles in constant motion, and preventing the formation of defuidization zones within the bed. The distributor is normally constructed from metal plate with a number of perforations, in a definite geometric pattern. The perforations may be located in simple nozzles or nozzles with bubble caps, which serve to prevent solid particles from flowing back into the space below the distributor. The distributor plate forms the furnace floor and this is protected from high temperature of the furnace by: Refractory Lining A Static Layer of the Bed Material or Water Cooled Tubes.
L2.	Explain at least six advantages of fluidized bed boilers? **i) High Efficiency** FBC boilers can burn fuel with a combustion efficiency of over 95% irrespective of ash content. FBC boilers can operate with overall efficiency of 84% + 2%. **ii) Reduction in Boiler Size** High heat transfer rate over a small heat transfer area immersed in the bed result in overall size reduction of the boiler. **iii) Fuel Flexibility** FBC boilers can be operated efficiently with a variety of fuels and these can be fed either independently or in combination with coal into the same furnace. Even fuels like flotation slimes, washer rejects, agro waste can be burnt efficiently.

	iv) Ability to Burn Low Grade Fuel FBC boilers would give the rated output even with inferior quality fuel. The boilers can fire coals with ash content as high as 62% and having calorific value as low as 2,500 kcal/kg. Even carbon content of only 1% by weight can sustain the fluidized bed combustion. **v) Ability to Burn Fines** Coal containing fines below 6 mm can be burnt efficiently in FBC boiler, which is a very difficult proposition in conventional firing system. **vi) Pollution Control** SO_2 formation can be greatly minimized by addition of limestone or dolomite for high sulphur coals. The amount of like stone addition is about 3% for every 1% sulphur in the coal feed. Low combustion temperature eliminates NO_x formation. **vii) Less Excess Air – Higher CO_2 in Flue Gas** The FBC boiler operates with 20 – 25% excess air only, CO_2 in the flue gases will be of the order of 14 – 15% at full load. **viii) Fast Response to Load Fluctuations** Inherent high thermal storage characteristics can easily absorb fluctuation in fuel feed rates. Response to changing load is comparable to that of oil fired boilers. **ix) No Slagging in the Furnace-No Soot Blowing** In FBC boilers, volatilization of alkali components in ash does not take place and the ash is non stocky. This means there is no slagging in the furnace and no soot blowing is required. **x) Provision of Automatic Coal and Ash Handling System** Automatic systems for coal and ash handling can be incorporated, making the plant easy to operate comparable to oil or gas fired installation. **xi) Quick Responses to Changing Demand** A fluidized bed combustor can respond to changing heat demands more easily than stoker fired systems. This makes it very suitable for applications such as thermal fluid heaters, requiring rapid rates of response. **xii) High Efficiency for Power Generation** By operating the fluidized bed at elevated pressure, it can be used to generate hot pressurized gases to power a gas turbine**.** This can be combined with a conventional steam turbine to improve the efficiency of electricity generation to give a potential fuel savings of at least 4%.
L3.	Retrofitting stoker fired boilers with FBC – Explain. Retrofitting fluidized bed coal fired combustion systems to conventional boilers have been carried out successfully both in India and abroad. The important aspects to be considered in retrofit projects are: a) Water/steam circulation design b) Furnace bottom-grate clearance c) Type of particulate control device

	d) Fan capacity e) Availability of space. Retrofitting of a fluidized bed combustor to a conventional stoker fired water tube boiler may involve: a) The replacement of grate by a distributor plate with short stand pipes for admitting air from the wind box located underneath. b) Installation of stand pipes to remove ash from the bed. c) Provision of horizontal hair pin tubes in the bed with a pump for forced circulation from the boiler drum. d) Modification of crusher to size the coal/limestone mixture for pneumatic under bed injection of the mixture. It may be emphasized that conversion of a conventional coal fired system to a fluidized bed combustion system can be accomplished without effecting major changes, after making a cost-benefit analysis. Oil fired boilers can also be converted to coal fired fluidized bed combustion systems. However it has to be examined on a case to case basis.
L4.	Explain in details "CFBC boilers". Circulating Fluidized Bed Combustion (CFBC) technology has evolved from conventional bubbling bed combustion as a means to overcome some of the drawbacks associated with bubbling bed combustion. This CFB technology utilizes the fluidized bed principle in which crushed (6 –12 mm size) fuel and limestone are injected into the furnace or combustor. The particles are suspended in a stream of upwardly flowing air (60-70% of the total air), which enters the bottom of the furnace through air distribution nozzles. The balance of combustion air is admitted above the bottom of the furnace as secondary air. While combustion takes place at 840-900^{o}C, the fine particles (<450 microns) are elutriated out of the furnace with flue gas velocity of 4-6 m/s. The particles are then collected by the solids separators and circulated back into the furnace. This combustion process is called circulating fluidized bed (CFB). The particles circulation provides efficient heat transfer to the furnace walls and longer residence time for carbon and limestone utilization. Similar to Pulverized Coal (PC) firing, the controlling parameters in the CFB combustion process are temperature, residence time and turbulence. In a circulating system the bed parameters are so maintained as to promote solids elutriation from the bed. They are lifted in a relatively dilute phase in a solids raiser, and a down-comer with a cyclone provides a return path for the solids. There is no steam generation tube immersed in the bed. Generation and super heating of steam takes place in the convection section, water walls, at the exit of the riser. A CFB could be good choice if the following conditions are met. ❑ Capacity of boiler is large to medium (75-100 T/hr of steam) ❑ Sulphur emission and NOx control is important ❑ The boiler is required to fire low grade fuel or fuel with highly fluctuating fuel quality. Major performance features of the circulating bed system are as follows: a) It has a high processing capacity because of the high gas velocity through the system.

	b) The temperature of about 870°C is reasonably constant throughout the process because of the high turbulence and circulation of solids. The low combustion temperature also results in minimal NOx formation. c) Sulphur present in the fuel is retained in the circulating solids in the form of calcium sulphate is removed in solid form. The use of limestone or dolomite sorbents allows a higher sulphur retention rate, and limestone requirements have been demonstrated to be substantially less than with bubbling bed combustor. d) The combustion air is supplied at 1.5 to 2 psig rather than 3-5 psig as required by bubbling bed combustors. e) It has high combustion efficiency. f) It has a better turndown ratio than bubbling bed systems. g) Erosion of the heat transfer surface in the combustion chamber is reduced, since the surface is parallel to the flow. In a bubbling bed system, the surface generally is perpendicular to the flow.
L5.	Explain the mechanism of fluidized bed combustion. When an evenly distributed air or gas is passed upward through a finely divided bed of solid particles such as sand supported on a fine mesh, the particles are undisturbed at low velocity. As air velocity is gradually increased, a stage is reached when the individual particles are suspended in the air stream. Further, increase in velocity gives rise to bubble formation, vigorous turbulence and rapid mixing. The bed of solid particles exhibits the properties of a boiling liquid and assumes the appearance of a fluid. In this state the bed is said to be fluidized. The furnace combustion takes place at about 840°C to 950°C. Control of sulfur dioxide and nitrogen oxide emissions in the combustion chamber without the need for additional control equipment is one of the major advantages over conventional boilers. The fluidized bed is a system in which the air distributed by a grid or distribution plate, is blown through the bed solids developing a "fluidized condition." Fluidization depends largely on the particle size and the air velocity. At low air velocities, a dense defined bed surface forms and is usually called a bubbling fluidized bed. With higher air velocities, the bed particles leave the combustion with the flue gases so that solids recirculation is necessary to maintain circulating fluidized bed. The mean solids velocity increases at a slower rate than does the gas velocity. Therefore, a maximum slip velocity between the solids and the gas can be achieved resulting in good heat transfer and contact time with the limestone, for sulphur dioxide removal.

Chapter 2.7 Cogeneration

Part-I: Objective type questions and answers

<table>
<tr><td>1.</td><td>Cogeneration is the simultaneous generation of heat and power.</td></tr>
<tr><td>2.</td><td>In the context of cogeneration turbine, thermodynamic process takes place
a) contraction b) expansion c) condensation d) all the above</td></tr>
<tr><td>3.</td><td>Rankine cycle is related to
a) boiler b) steam turbine c) condenser d) all the above</td></tr>
<tr><td>4.</td><td>Find the thermodynamic cycle not related to cogeneration.
a) Brayton cycle b) Rankine cycle
c) Joule cycle d) Bell-Coleman cycle</td></tr>
<tr><td>5.</td><td>In a combined cycle power plant consisting of gas turbine and waste heat boiler, the exhaust gas temperature is ____ .
a) around 100 °C b) around 200 °C
c) around 300 °C d) around 400 °C</td></tr>
<tr><td>6.</td><td>Match the following:
<table>
<tr><td>Cogeneration system</td><td>Overall efficiency (%)</td></tr>
<tr><td>1. Reciprocating engine</td><td>i) 70 – 85</td></tr>
<tr><td>2. Gas turbine</td><td>ii) 60 – 80</td></tr>
<tr><td>3. Extraction-condensing steam turbine</td><td>iii) 75-85</td></tr>
<tr><td>4. Back pressure steam turbine</td><td>iv) 84-92</td></tr>
</table>
1-iii; 2-i; 3-ii, 4-iv</td></tr>
<tr><td>7.</td><td>For cogeneration system, extraction condensing turbine type of steam turbines would have higher power to heat ratio?</td></tr>
<tr><td>8.</td><td>Most likely condition of which gas turbines operate ____ .
a) low speed & low temperature b) low speed & high temperature
c) high speed & low temperature d) high speed & high temperature</td></tr>
<tr><td>9.</td><td>Cogeneration is also known as combined heat and power (CHP)</td></tr>
<tr><td>10.</td><td>In case of conventional power plant, which equipment has highest efficiency?
a) boiler b) turbine c) generator d) cooling tower</td></tr>
<tr><td>11.</td><td>How far the statement to read as “the overall thermal efficiency of an extraction</td></tr>
</table>

	condensing turbine in cogeneration system is lower than that of back pressure turbine system" is <u>True</u> / False?
12.	Heat to power ratio in a paper industry will be in the range of a) 1.1 – 4.5 b) 1.5 – 2.5 c) 0.8 – 3.0 d) <u>1.5 – 2.5</u>
13.	In a glass industry, exhaust gas from the glass melting furnace has potential to go for power generation by installing steam boiler and turbine. Which type of co-generation can be applied there: a) gas turbine b) diesel generator c) topping cycle d) <u>bottom cycl</u>
14.	Heat to power ratio of combined cycle cogeneration is: a) 4.0 – 5.0 b) <u>1.0 – 1.7</u> c) 2.0 – 10 d) 1.0 – 5.0
15.	The type of cogeneration which has the maximum overall efficiency is: a) extraction and condensing steam turbine b) diesel engine c) gas turbine <u>d) back pressure steam turbine</u>
16.	The overall efficiency of combined cycle cogeneration is of the order of: <u>a) 69 – 83</u> b) 90 – 95 c) 70 – 90 d) 55 – 60
17.	Which one of the following cogeneration system has maximum power to heat ratio: a) <u>extraction condensing turbine</u> b) back pressure turbine c) combined cycle d) none of the above
18.	Which one of the following cannot be used as fuel for the gas turbine: a) naphtha b) LPG c) natural gas d) <u>LSHS</u>
19.	Thermodynamic cycle applicable to gas turbine is ____. <u>Brayten cycle</u> b) Rankine cycle
20.	Which of the following industry will not use cogeneration concept? a) sugar b) paper & pulp c) refinery d) <u>refractory</u>

Part-II: Short type questions and answers

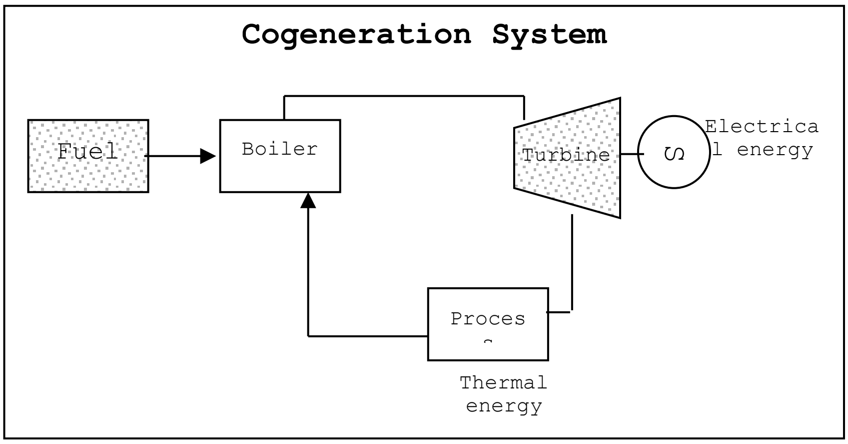
S1.	What will be the values of efficiency figures for a conventional power plant? The efficiency of conventional power plant is around 35%.

S2. What is cogeneration? Explain Briefly.

Cogeneration is the sequential generation of two different forms of useful energy from a single primary energy source.

The two different forms of energy are:

- Electrical and thermal energy
- Mechanical energy and thermal energy



In conventional power plant efficiency is only 35% and remaining 65% of energy is lost. In cogeneration system efficiency can go up to 90%. Cogeneration is also known as combined heat and power (CHP) and total energy system. Cogeneration offers energy savings ranging between 15-40%.

S3. What percentage of input energy escapes through exhaust of turbine steam and gas?

When steam or gas expands through a turbine, nearly 60 to 70% of the input energy escapes with the exhaust steam or gas.

S4. Why cogeneration system efficiency will be higher?

Cogeneration is the simultaneous generation of heat and power, both of which are used. Electricity generated by cogeneration plant is normally used locally and hence the transmission and distribution losses are negligible.

S5. Write the other known name of cogeneration?

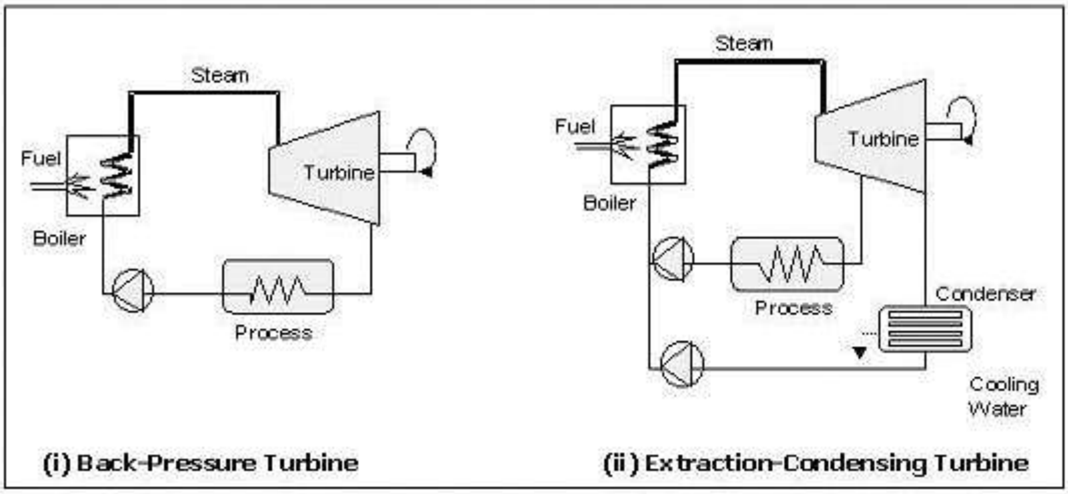
Cogeneration is also known as 'combined heat and power (CHP)' and 'total energy system'.

S6. Explain gas turbine cogeneration system?

In the gas turbine energy input comes from the fuel that is injected into the combustion chamber. The gas/air mixture drives the turbine with high temperature waste gases existing to the atmosphere. If steam is generated using this waste heat for the process it is called a 'gas turbine cogeneration system'.

S7. Explain the term 'back pressure steam' in steam turbines.

In the back pressure steam turbine, steam enters the turbine chamber at high pressure and expands to low or medium pressure. Enthalpy difference is used for generating power/work.

S8.	Differentiate "Back Pressure Turbine" and "Extraction Condensing Turbine" through sketches?  **Schematic diagrams of steam turbine cogeneration systems**
S9.	What is the main difference between "Topping Cycle" and "Bottoming Cycle"? A topping cycle plant generates electricity or mechanical power first whereas a bottoming cycle plant generates heat first.
S10.	What is heat to power ratio for a cogeneration application? Heat to power ratio is defined as the ratio of thermal energy to electricity required by the energy consuming facility. It can be expressed in different units such as Btu/kWh, kcal/kWh, lb./hr/kW, etc
S11.	State the principle of Rankine Cycle cogeneration? The Rankine Cycle provides an ideal outlet for waste heat recovered from any process or generation situation. Instead of condensing the entire steam if the back pressure steam is utilised in the process, it is called a Rankine cycle cogeneration.
S12.	Compare the "Overall cogeneration efficiencies of various configurations?

Cogeneration System	***Overall efficiency (percent***
Back-pressure steam turbine	84-92
Extraction-condensing steam turbine	60-80
Gas turbine	70-85
Combined cycle	69-83
Reciprocating engine	75-85

S13. List important technical parameters to be considered in a cogeneration system.

a) Heat to power ratio

b) Quality of thermal energy needed

c) Load pattern

d) Fuel available

e) System reliability

f) Dependent systems Vs independent system

g) Retrofit Vs new installation

h) Electricity buy back

i) Local environment consideration

S14. What is heat-to-power ratio and give these ratios for different cogeneration system.

Heat to power ratio is defined as the ratio of thermal energy to electrical energy on the basis of same energy unit (kW)

Heat to power ratio is one of the most important technical parameters influencing the selection and type of cogeneration system and should match with the cogeneration system which is planned to be installed.

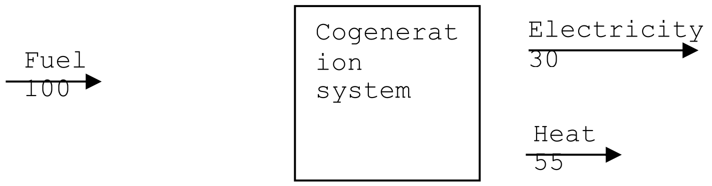
The following table gives the heat to power ratios of different types of cogeneration system.

Cogeneration system	Heat to power ratio kW_{th} / kW_e	Power output % fuel input	Overall efficiency %
Back pressure steam turbine	4.0 – 14.3	14 – 28	84 – 92
Extraction-condensing turbine	2.0 – 10.0	22 – 40	60 – 80
Gas turbine	1.3 – 2.0	24 – 35	70 – 85
Combined cycle	1.0 – 1.7	34 – 40	69 – 83
IC engine	1.1 – 2.5	33 – 53	75 – 85

The steam turbine cogeneration system can offer a large range of heat to power ratio.

S15. Evaluate efficiency of the following.

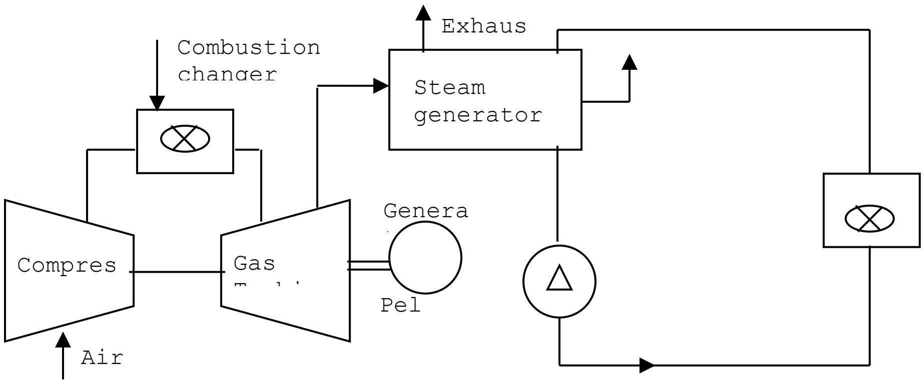
Cogeneration	Total efficiency



?

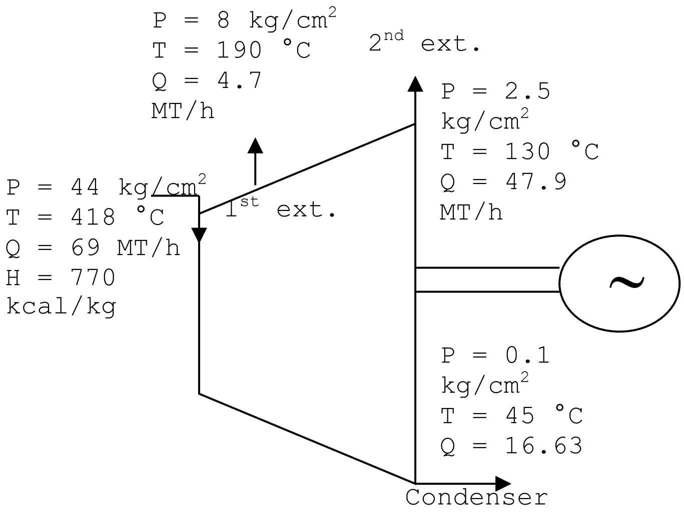
Efficiency of cogeneration system

	$\left(\frac{30+55}{100}\right)x100 = 85\%$
S16.	Match the following. Cogeneration system — Heat to power ratio kW_{th}/KW_e a) Back pressure steam turbine — 1) 4.0 – 14.3 b) Extraction-condensing steam turbine — 2) 1.1 – 20 c) Gas turbine — 3) 1.0 – 1.7 d) Combined cycle — 4) 1.3 – 2.0 e) Reciprocating engine — 5) 2.0 – 10 (a) – (1) (b) – (5) (c) – (4) (d) – (3) (e) – (2)
S17.	Advantages and disadvantages of diesel engine and waste heat recovery boiler and cooling water heat exchangers cogeneration. **Advantages** • Low civil construction cost due to block foundation and least number of auxiliaries • High power efficiency • Best suitability as stand by power source **Disadvantageous** • Low overall efficiency • Limited suitability for low quality fuels • Availability of low temperature steam • High maintenance prone
S18.	In a power plant terminology, what do you mean by combined cycle operation? Combined cycle form a hybrid which includes Brayten cycle in the first portion and standard Rambine cycle following it is the combination. Typical cycle is shown below.

	
S19.	Space heating and cooling application falls under cogeneration heat recovery – explain? One of the topping cycle cogeneration, where hot water from an engine jacket cooling system flowing to a heat recovery boiler, it is converted to process steam and hot water for space heating and cooling applications.
S20.	How the combustion air is supplied to gas turbines? Combustion air is supplied to gas turbines from air compressors, where in let air taken in to compressor from the atmosphere.

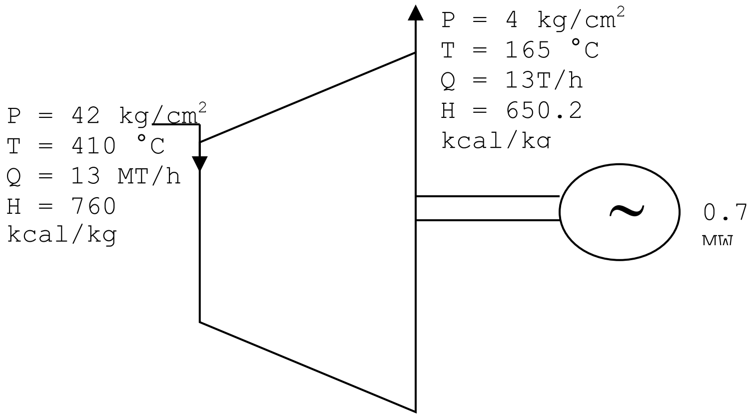
Part-III: Long type questions and answers

L1.	Where the cogeneration is applied? Where there is simultaneous need for heat and power (electrical and thermal (mechanical)), there is a potential for cogeneration. However, significant savings is energy costs can be achieved and cogeneration system can be more meaningful if the energy consuming facility has the following characteristics. 1) Reliable power requirement 2) Utilisation of higher thermal energy than electricity 3) Quite stable load patterns of thermal energy and electricity 4) Long operating hours 5) High price of grid electricity or inaccessibility to grid Thermal energy need of a facility may be for the following purposes. o Drying, preheating, process steam, o producing chilled water, o hot water generation, heating fluids etc. Some of the application areas where cogeneration has been successfully practised are listed below: ✓ Industrial cogeneration: Food processing, Pharmaceutical, Pulp and paper, Refinery, Fertilizers, Textile, Brewery and distillery, Steel, cement, Glass, Ceramic industry, etc. ✓ Residential / commercial / institutional cogeneration: Hospitals, Hotels and Commercial buildings

	There are typical clients of cogeneration, however the feasibility of cogeneration system is very much site specific and depends on many factors.
L2.	Explain any four types of topping cycle cogeneration plant? The four types of topping cycle cogeneration systems are: (1) A gas turbine or diesel engine producing electrical or mechanical power followed by a heat recovery boiler to create steam to drive a secondary steam turbine. This is called a combined-cycle topping system. (2) The second type of system burns fuel (any type) to produce high-pressure steam that then passes through a steam turbine to produce power with the exhaust provides low-pressure process steam. This is a steam-turbine topping system. (3) A third type employs hot water from an engine jacket cooling system flowing to a heat recovery boiler, where it is converted to process steam and hot water for space heating. (4) The fourth type is a gas-turbine topping system. A natural gas turbine drives a generator. The exhaust gas goes to a heat recovery boiler that makes process steam and process heat.
L3.	From the given diagram, evaluate (i) heat load on cooling tower (ii) power generation in MW.  Input heat to turbine (a) : 69,000 x 770 = 5,31,30,000 kWh Output heat at different streams 1^{st} extraction (b) : 4700 x 672.6 = 31,61,220 Kcal/h 2^{nd} extraction (c) : 47,900 x 650.2 = 3,11,44,580 Kcal/h Condenser heat load (d) : 16,630 x 571.6 = 95,05,708 Kcal = 4,38,11,508 Kcal/h (i) Heat load on cooling tower : 95,05,708 Kcal (ii) Heat equivalent to power generation: Input-Output : 5,31,30,000 – 4,38,11,508 : 93,18,492 Kcal/h Power generation : 93,18,492/860

<table>
<tr><td></td><td>: 10,835 kW
: 10.835 MW</td></tr>
<tr><td>L4.</td><td>

From the given diagram, evaluate the cogeneration efficiency.



<table>
<tr><td>Input heat to turbine (a)</td><td>: 13,000 x 760 = 98,80,000 Kcal/h</td></tr>
<tr><td>Output heat as extraction</td><td>: 13,000 x 650.2 = 84,52,600 Kcal/h</td></tr>
<tr><td>Thermal efficiency</td><td>: total useful heat/input heat</td></tr>
<tr><td></td><td>: 8452600/9880000 = 0.855 = 85.5%</td></tr>
<tr><td>Electrical efficiency (Ep)</td><td>: Electrical energy produced/input heat</td></tr>
<tr><td></td><td>: 602000/9880000 = 0.06 = 6%</td></tr>
<tr><td>Overall cogeneration efficiency</td><td>: Eth + Ep = 85.5 + 6</td></tr>
<tr><td></td><td>: 91.5%</td></tr>
</table>

</td></tr>
</table>

Chapter 2.8 Waste Heat Recovery

Part-I: Objective type questions and answers

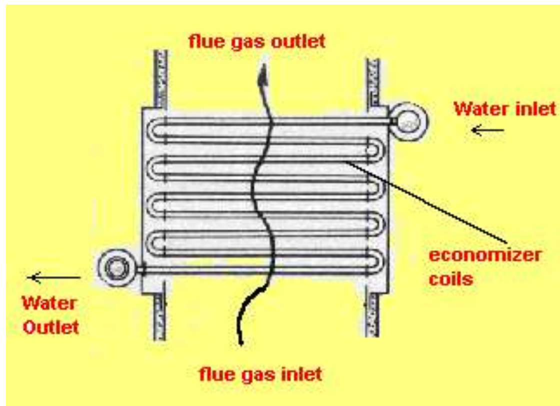
1.	Major limitations of metallic recuperator? a. limitations of handling CO_x, NO_x etc b. limitations of reduced life for handling temperature more than 1000 °C c. manufacturing difficulty of the required design d. none of the above
2.	Recuperator is used mainly as a waste heat recovery system in a ____ . a) boiler b) billet Reheating Furnace c) compressor d) none of the above
3.	Air preheater is not used as a waste heat recovery system in a____ . a) boiler b) billet Reheating Furnace c) beat treatment furnace d) compressor
4.	Economizer is provided to utilize the flue gas heat for ___ a) preheating the boiler feed water b) preheating the stock c) preheating the combustion air d) preheating fuel
5.	Low to medium temperature waste heat recovery which of the device is suitable: a) economiser b) heat wheels c) air preheater d) recuperator
6.	Recovery of waste heat from hot fluid to fluid is called: a) thermo compressor b) waste heat recovery boiler c) heat Pump d) economizer
7.	From a reciprocating engine exhausts (turbo charged), the temperature of waste gases lie in the range of: a) 230-450 °C b) 600 °C c) 800-900 °C d) none of the above
8.	A major advantage of waste heat recovery is: a) reduction in pollution b) increase in efficiency c) both a & b d) none of the above
9.	Economizer functions to: a) preheat the feed water to boiler b) to preheat the air c) both a & b d) none
10.	Recovery of heat from dryer exhaust air is a typical application of: a) waste heat recovery boiler b) heat pump c) heat wheels d) economizer
11.	Thermo-compressor is commonly used for: a) compressing hot air b) flash steam recovery c) distillation d) reverse compression of CO_2

12.	Capillary wick is a part of : a) heat pump b) heat wheel c) heat pipe d) regenerator
13.	Pick up the odd one out: a) regenerator b) recuperator c) metallic recuperator d) economiser
14.	Regenerator is widely used in: a) reheating Furnaces b) heat treatment furnaces c) baking Ovens d) glass melting furnaces
15.	For every 6°C rise in feed water temperature through an economiser the fuel savings in the boiler is of the order of: a) 1% b) 1.5% c) 3% d) 2%
16.	Pick up the "odd" one out: a) heat pipe b) heat pump c) heat wheel d) run around coil
17.	Recuperator will be more efficient if the flow path of hot and cold fluids is in: a) co-current mode b) counter current mode c) cross current mode d) none of the above
18.	Typical waste gases temperature from glass melting furnace: a) 1000-1550 b) 800-950 c) 650–750 d) 760-815
19.	Heat recovery equipment will be most effective when the temperature of flue gas is: a) 250°C b) 200 °C c) 400 °C d) 280°C
20.	Ceramic recuperators can withstand temperatures up to: a) 600 °C b) 1300 °C c) 1700°C d) 950°C

Part-II: Short questions and answers

S1.	Briefly mention direct and indirect benefits of waste heat recovery systems. Ans. Direct Benefits 1. Efficiency of process is increased 2. Reduction in process cost. Indirect Benefits: a. Reduction in pollution b. Reduction in equipment sizes c. Reduction in auxiliary energy consumption
S2.	What are the major points to be considered for developments of WHRS? Ans. Understanding the process is essential for development of Waste Heat Recovery system. This can be accomplished by reviewing the process flow sheets, layout diagrams, piping isometrics, electrical and instrumentation cable ducting etc. Detail

	review of the following documents will help in identifying: a) Sources and uses of waste heat b) Upset conditions occurring in the plant due to heat recovery c) Availability of space d) Any other constraint, such as dew point occurring in an equipment etc. After identifying source of waste heat and the possible use of it, the next step is to select suitable heat recovery system and equipment to recover and utilize the same.
S3.	What is a 'heat wheel'? Ans. A heat wheel is a sizable porous disk, fabricated with material having a fairly high heat capacity, which rotates between two side-by-side ducts: one a cold gas duct, the other a hot gas duct. The axis of the disk is located parallel to, and on the partition between, the two ducts. As the disk slowly rotates, sensible heat (moisture that contains latent heat) is transferred to the disk by the hot air and, as the disk rotates, from the disk to the cold air. The overall efficiency of sensible heat transfer for this kind of regenerator can be as high as 85 percent.
S4.	What are the major applications of a 'heat wheel'? Ans. The main area of application of heat wheel is where heat exchange between large masses of air having small temperature differences is required. Heating and ventilation systems and recovery of heat from dryer exhaust air are typical applications.
S5.	What is a 'heat pipe'? Ans. A heat pipe can transfer up to 100 times more thermal energy than copper, the best known conductor. In other words, heat pipe is a thermal energy absorbing and transferring system and have no moving parts and require minimum maintenance.
S6.	List at least five applications of 'heat pipe'? Ans. • Process to Space Heating • Process to Process • HVAC Applications make up air. • Preheating of boiler combustion air • Recovery of Waste heat from furnaces • Reheating of fresh air for hot air driers • Recovery of waste heat from catalytic deodorizing equipment • Reuse of Furnace waste heat as heat source for other oven • Cooling of closed rooms with outside air • Preheating of boiler feed water with waste heat recovery from flue gases in the heat pipe economizers. • Drying, curing and baking ovens • Waste steam reclamation • Brick kilns (secondary recovery) • Reverberator furnaces (secondary recovery)

	• Heating, ventilating and air-conditioning systems
S7.	Explain with a neat sketch the function of an economizer along with uses? Ans. Economizer is provided to utilize the flue gas heat for pre-heating the boiler feed water. A schematic diagram of the economizer is shown in Figure. For every 22^0 C reduction in flue gas temperature by passing through an economizer or a pre-heater, there is 1% saving of fuel in the boiler. 
S8.	What is the principle of run around coil? Ans. The heat from hot fluid is transferred to the colder fluid via an intermediate fluid known as the Heat Transfer Fluid. One coil of this closed loop is installed in the hot stream while the other is in the cold stream. Circulation of this fluid is maintained by means of land circulating pump.
S9.	What is the principle of heat pump? Ans. By nature heat must flow spontaneously from a system at high temperature to one at a lower temperature. Heat pump reverses the direction of spontaneous energy flow by the use of a thermodynamic system.
S10.	What is the advantage of 'plate heat exchanger' over 'shell and tube heat exchanger'? Ans. The heat recovery efficiency is higher for plate heat exchanger when compared with shell and tube heat exchanger.
S11.	Why 'thermo compressors' are required? Ans. Thermo compressors are required to reuse very low pressure steam, by compressing it with very high pressure steam and reuse as a medium pressure steam.
S12.	What is the advantage of 'ceramic recuperators' over 'metallic recuperators'? Ans. The ceramic recuperators can allow operation on gas side up to 1300 ^oC , whereas metallic recuperators can with stand up to 1000 ^oC only.
S13.	Give three examples of low temperature air to air heat recovery devices?

	Ans. a) Heat wheel b) Heat pipe c) Heat pump
S14.	What is the principle of 'regenerators'? Ans. The regenerator is a waste heat recovery device used to recover heat from waste gases to preheat the combustion air. Regenerator consists of multiples of slightly separated metal plates supported in a frame attached to a slowly moving rotor shaft, which is arranged edge on to the gas and air flow. As these plates pass progressively through the gas stream, they give up heat to the air before re-entering the hot stream, thus maintaining the regenerative cycle.
S15.	What is the principle of 'recuperators'? Ans. The recuperator is a waste heat recovery device or a heat exchanger between waste gases and the air to be pre-heated. Heat exchange takes place between the flue gases and the air through metallic or ceramic walls.
S16.	Give two examples of usage of 'heat pipe'? Ans. i) Process to Space Heating: The heat pipe heat exchanger transfers the thermal energy from process exhaust for building heating. The preheated air can be blended if required. The requirement of additional heating equipment to deliver heated make up air is drastically reduced or eliminated. ii) Process to Process: The heat pipe heat exchangers recover waste thermal energy from the process exhaust and transfer this energy to the incoming process air. The incoming air thus become warm and can be used for the same process/other processes and reduces process energy consumption.
S17.	Briefly explain the principle of 'thermo compression'. Ans. In many cases, very low pressure steam is reused as water after condensation for lack of any better option of reuse. In many cases it becomes feasible to compress this low pressure steam by very high pressure steam and reuse it as a medium pressure steam. The major energy in steam is in its latent heat value and thus thermo compressing would give a large improvement in waste heat recovery. The thermo compressor is simple equipment with a nozzle where HP steam is accelerated into a high velocity fluid. This entrains the LP steam by momentum transfer and then recompresses in a divergent venturi. It is typically used in evaporators where the boiling steam is recompressed and used as heating steam.
S18.	Briefly mention important points to be considered for evolving waste heat recovery system. Ans. (a) Sources and uses of waste heat (b) Upset conditions occurring in the plant due to heat recovery (c) Availability of space (d) Any other constraint, such as dew point occurring in an equipment etc. (e) Economic Evaluation of Waste Heat Recovery System
S19.	Mention three commercial waste heat recovery devices Ans.

	1. Recuperator 2. Economizers 3. WHRSG 4. Heat pump
S20.	When run around coils are preferred? Ans. Run around coils is preferred when the hot and cold fluids are located far away from each other and are not easily accessible.

Part-III: Long type questions and answers

L1.	Explain any three types of 'recuperators'? Ans. a) Metallic radiation recuperator: The simplest configuration for a recuperator is the metallic radiation recuperator, which consists of two concentric lengths of metal tubing. The inner tube carries the hot exhaust gases while the external annulus carries the combustion air from the atmosphere to the air inlets of the furnace burners. The hot gases are cooled by the incoming combustion air which now carries additional energy into the combustion chamber. The radiation recuperator gets its name from the fact that a substantial portion of the heat transfer from the hot gases to the surface of the inner tube takes place by radiative heat transfer. b) Convective recuperator: These are all shell and tube type recuperator and are generally more compact and have a higher effectiveness than radiation recuperator, because of the larger heat transfer area made possible through the use of multiple tubes and multiple passes of the gases. The hot gases are carried through a number of parallel small diameter tubes, while the incoming air to be heated enters a shell surrounding the tubes and passes over the hot tubes one or more times in a direction normal to their axes. c) Ceramic Recuperator: The principal limitation on the heat recovery of metal recuperator is the reduced life of the liner at inlet temperatures exceeding 1100^{o}C. In order to overcome the temperature limitations of metal recuperator, ceramic tube recuperator have been developed whose materials allow operation on the gas side to 1550^{o}C and on the preheated air side to 815^{o}C on a more or less practical basis. These recuperator have short silicon carbide tubes which can be joined by flexible seals located in the air headers.
L2.	Explain the principle of operation of heat pipe. Discuss three examples of its industrial application. Ans. The heat pipe is a thermal energy absorbing and transferring system and has no moving parts and hence requires minimum maintenance. The Heat Pipe comprises of three elements – a sealed container, a capillary wick structure and a working fluid. The capillary wick structure is integrally fabricated into the interior surface of the container tube and sealed under vacuum. Thermal energy applied to the external

	surface of the heat pipe is in equilibrium with its own vapour as the container tube is sealed under vacuum. Thermal energy applied to the external surface of the heat pipe causes the working fluid near the surface to evaporate instantaneously. Vapour thus formed absorbs the latent heat of vapourization and this part of the heat pipe becomes an evaporator region. The vapour then travels to the other end the pipe where the thermal energy is removed causing the vapour to condense into liquid again, thereby giving up the latent heat of the condensation. This part of the heat pipe works as the condenser region. The condensed liquid then flows back to the evaporated region. The heat pipe heat recovery systems are capable of operating at 315^{o}C. with 60% to 80% heat recovery capability. <u>Industrial applications of heat pipe:</u> The heat pipes are used in following industrial applications: a. Process to Space Heating: The heat pipe heat exchanger transfers the thermal energy from process exhaust for building heating. The preheated air can be blended if required. The requirement of additional heating equipment to deliver heated make up air is drastically reduced or eliminated. b. Process to Process: The heat pipe heat exchangers recover waste thermal energy from the process exhaust and transfer this energy to the incoming process air. The incoming air thus become warm and can be used for the same process/other processes and reduces process energy consumption. c. HVAC Applications: Cooling: Heat pipe heat exchanger precools the building make up air in summer and thus reduces the total tons of refrigeration, apart from the operational saving of the cooling system. Thermal energy is supply recovered from the cool exhaust and transferred to the hot supply make up air.
L3.	What are waste heat recovery boilers? Explain the need and benefits? Ans. Waste heat boilers are ordinarily water tube boilers in which the hot exhaust gases from gas turbines, incinerators, etc., pass over a number of parallel tubes containing water. The water is vaporized in the tubes and collected in a steam drum from which it is drawn off for use as heating or processing steam. Because the exhaust gases are usually in the medium temperature range and in order to conserve space, a more compact boiler can be produced if the water tubes are finned in order to increase the effective heat transfer area on the gas side. The pressure at which the steam is generated and the rate of steam production depends on the temperature of waste heat. The pressure of a pure vapor in the presence of its liquid is a function of the temperature of the liquid from which it is evaporated. If the waste heat in the exhaust gases is insufficient for generating the required amount of process steam, auxiliary burners which burn fuel in the waste heat boiler or an after-burner in the exhaust gases flue are added. Waste heat boilers are built in capacities from 25 m^3 almost 30,000 m^3 / min. of exhaust gas. Typical applications of waste heat boilers are to recover energy from the exhausts of gas turbines, reciprocating engines, incinerators, and furnaces.
L4.	Explain the principles of 'Heat pump'.

	Ans. Heat must flow spontaneously "downhill", that is from a system at high temperature to one at a lower temperature. It is possible to reverse the direction of spontaneous energy flow by the use of a thermodynamic system known as a heat pump. This device consists of two heat exchangers, a compressor and an expansion device. A liquid or a mixture of liquid and vapor of a pure chemical species flows through an evaporator, where it absorbs heat at low temperature and, in doing so, is completely vaporized. The low temperature vapor is compressed by a compressor, which requires external work. The work done on the vapor raises its pressure and temperature to a level where its energy becomes available for use. The vapor flows through a condenser where it gives up its energy as it condenses to a liquid. The liquid is then expanded through an expansion valve back to the evaporator where the cycle repeats. The heat pump was developed as a space heating system where low temperature energy from the ambient air, water, or earth is raised to heating system temperatures by doing compression work with an electric motor-driven compressor. The heat pumps have the ability to upgrade heat to a value more than twice that of the energy consumed by the device. The potential for application of heat pump is growing and number of industries have been benefited by recovering low grade waste heat by upgrading it and using it in the main process stream. Heat pump applications are most promising when both the heating and cooling capabilities can be used in combination. One such example of this is a plastics factory where chilled water from a heat is used to cool injection-moulding machines whilst the heat output from the heat pump is used to provide factory or office heating. Other examples of heat pump installation include product drying, maintaining dry atmosphere for storage and drying compressed air.
L5.	Explain various steps in Development of a Waste Heat Recovery System. (**EA**) Ans. Understanding the process Understanding the process is essential for development of Waste Heat Recovery system. This can be accomplished by reviewing the process flow sheets, layout diagrams, piping isometrics, electrical and instrumentation cable ducting etc. Detail review of these documents will help in identifying: a) Sources and uses of waste heat b) Upset conditions occurring in the plant due to heat recovery c) Availability of space d) Any other constraint, such as dew point occurring in an equipment etc. After identifying source of waste heat and the possible use of it, the next step is to select suitable heat recovery system and equipment to recover and utilize the same. Economic Evaluation of Waste Heat Recovery System It is necessary to evaluate the selected waste heat recovery system on the basis of financial analysis such as investment, depreciation, payback period, rate of return

	etc. In addition the advice of experienced consultants and suppliers must be obtained for rational decision.

Chapter 3.1 Electrical System

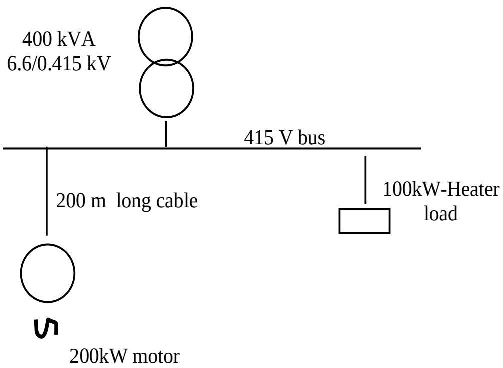
Part-I: Objective type Questions and Answers

1.	The heat input required for generating 'one' kilo watt-hour of electrical output is called as ___. a) Efficiency b) Heat Rate c) Calorific Value d) Heat value
2.	Which of the voltage is not available for Pakistan distribution system? a) 33 kV b) 11 kV c) 280 V d) 433 V
3.	The power loss in transmission/distribution line depends on ____. a) Current in the line b) Resistance of the line c) Length of the line d) All
4.	If distribution of power is raised from 11 kV to 66 kV, the voltage drop would lower by a) 6 times b) 1/6 times c) 36 times d) 1/36 times
5.	If the distribution voltage is raised from 11 kV to 33 kV, the line loss would be: a) Less by 1/9 b) More by 9 times c) No change d) None of the above
6.	The maximum demand of an industry, if trivector motor records 3600 KVA for 15 minutes and 3000 kVA for next 15 minutes over a recording cycle of 30 minutes is_____. a) 3600 kVA b) 3000 kVA c) 3300 kVA d) 600 kVA
7.	Presenting the load demand of a consumer against time of the day is known as___. a) Time Curve b) Load curve c) Demand curve d) Energy curve
8.	The vector sum of active power and reactive power required is ____. a) Apparent Power b) Power Factor c) Load Factor d) Maximum Demand
9.	Power factor is the ratio of ____ and apparent power. a) Active power b) Reactive power c) Load Factor d) Maximum Demand
10.	The kVAr rating required for improving the power factor of a load operating at 500 kW and 0.85 power factor to 0.95 is _______. a) 145 kVAr b) 500 kVAr c) 50 kVAr d) 100 kVAr
11.	The rating of the capacitor at motor terminals should not be greater than _____ . a) magnetizing kVAr of the motor at full load b) magnetizing kVAr of the motor at no load c) magnetizing kVAr of the motor at half load d) magnetizing kVAr of the motor at 75% load
12.	The percentage reduction in distribution loses when tail end power factor raised from 0.8 to 0.95 is _______. a) 29% b) 15.8% c) 71% d) 84%
13.	If voltage applied to a 415 V rated capacitors drops by 10%, its VAR output drops by ____. a) 23% b) 87% c) 19% d) 10%

14.	The ratio between the number of turns on the primary to the turns on the secondary of a transformer is know as: a) turns ratio b) efficiency c) winding factor d) power factor
15.	The ratio of overall maximum demand of the plant to the sum of individual maximum demand of various equipments is ______. a) load factor b) diversity Factor c) demand Factor d) maximum demand
16.	Core losses in transformer are caused by ______. a) Hysteresis loss b) Eddy current loss c) both a & b d) None
17.	The load losses in transformer vary according to ________. a) Loading of transformer b) Square of loading of transformer c) Cube of loading of transformer d) None
18.	The total losses in a transformer operating at 50% load with designed no load and load losses at 2 kW and 20 kW respectively are _______. a) 7 kW b) 12 kW c) 4.5 kW d) 22 kW
19.	The total amount of harmonics present in the system is expressed using ___. a) Total Harmonic Factor b) Total Harmonic Ratio c) Total Harmonic Distortion d) Crest Factor
20.	The 5^{th} and 7^{th} harmonic in a 50 Hz power environment will have: a) voltage and current distortions with 55 Hz & 57 Hz b) voltage and current distortions with 500 Hz & 700 Hz c) voltage and current distortions with 250 Hz & 350 Hz d) no voltage and current distortion at all
21.	If the voltage level of the electricity distribution system is raised from 11 kV to 33 kV for the same loading conditions, the distribution losses are reduced by a factor of a) 1/9 b) 1/3 c) 1/6 d) none of the above
22.	In electricity distribution, if the voltage is raised from 11 kV to 33 kV for the same loading conditions, the voltage drop in the distribution system would be lower by a factor of a) 1/4 b) 1/2 c) 1/3 d) none of the above
23.	If the reactive power drawn by a particular load is zero, it means the load is operating at a) lagging power factor b) leading power factor c) unity power factor d) none of the above
24.	Select the location of installing capacitor bank, which will reduce the electricity distribution losses to the maximum extent a) main sub-station bus bars b) motor terminals c) motor control centre d) distribution board bus bars

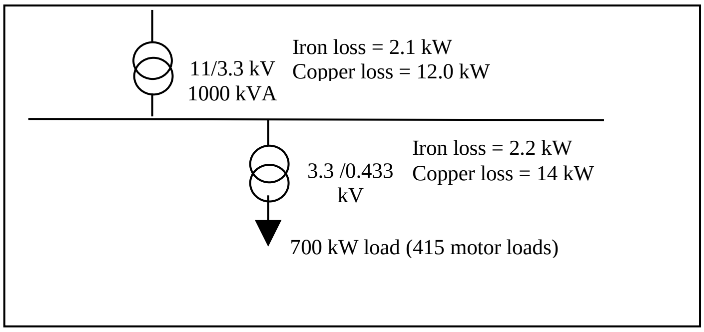
25.	A pure inductive load draws a) leading reactive power b) active power c) lagging reactive power d) none of the above
26.	The nearest kVAr compensation required for improving the power factor of a 100 kW load from 0.8 lag to unity power factor is a) 50 kVAr b) 75 kVAr c) 100 kVAr d) none of the above

Part II: Short type Questions and Answers

S1.	Define "Heat Rate" in the simplest form? "HEAT RATE" is a quantity of heat input in "kilo Calories" or "kilo Joules", for generating 'one' kilo Watt hour of electrical output.
S2.	List all the important and useful parameters that a tri-vector meters records for industry/utility electricity billing. The important parameters that are read from "Trivector meters" for a billing cycle are: a) Maximum demand during the month (kW or kVA) b) Active energy (kWh) c) Reactive energy (kVArh) d) Apparent energy (kVAh) Apart from this it can also read other instantaneous values like, voltage & current, power factor, etc.
S3.	The following single line diagram explain the location of 100 kW heater load and 200 kW motor, which is at 200 mtrs away from 415V, LT bus using suitable cable. The main incoming power factor of system is 0.85 lag. Calculate the rating of capacitors to improve pf of incomer to 0.9 lag.  Total Inductive load requiring PF compensation=200kW (since the other 100 kW is a resistive load)

	Operating PF cos φ1= 0.85 lag. Desired PF cos φ2= 0.90lag kVAr required=kW((tan(cos^{-1}φ$_1$)-tan(cos^{-1}φ$_2$)) =200(tan (cos^{-1}0.85)-tan (cos^{-1}0.90)) =200(tan(31.78)-tan(25.84)) =200(0.619-0.484) =200(0.135) =27 kVAr
S4.	During April-2020, the plant has recorded a maximum demand of 600 kVA and average PF is observed to be 0.82 lag, The minimum average PF to be maintained is 0.92 lag as per the independent utility supplier and every one % dip in PF attracts a penalty of PKR 10,000/in each month. a) Calculate the improvement in PF for May-2020 by installing 100kVAr capacitors. b) Calculate penalty to be paid if any during May-2020. Ans. Recorded Maximum Demand =600kVA @ 0.82 lag a. (i) From power triangle, operating kW = kVA x PF = 600 x 0.82 = 492 kW (ii) kVAr required at Unity PF = $\sqrt{(600^2 - 492^2)}$ = 343 kVAr (iii) Since 100 kVAr compensation is proposed, the new load kVAr would be :243 kVAr New kVA after 100kVAr compensation: $\sqrt{kW^2 + (kVAr)^2_{new}}$ = $\sqrt{(492)^2 + (243)}^2$ = 548 kVA b. New pf with 100 kVAr= $\frac{kW}{kVA} = \frac{492}{548} = 0.898$ □0.90 lag. The difference between tariff requirement and actual is less by 0.92–0.90 = 0.02 or 2%. Penalty to be paid=PKR. 10,000 x 2 = PKR. 20,000 for May-2020
S5.	Compute the MD recorded for a plant where the recorded load is as mentioned below in the recording cycle of 30 minutes. - 1000 kVA for 5 minutes - 200 kVA for 5 minutes - 500 kVA for 10 minutes - 800 kVA for 8 minutes - 1500 kVA for 2 minutes The MD recorder will be computing MD as: $\frac{(1000\times5)+(200\times5)+(500\times10)+(800\times8)+(1500\times2)}{30} = 680 kVA$

S6.	What are the different reactive power compensation options available in an electrical system? Following are the possible reactive power compensations methods: a) Use of HT capacitors b) Use of LT capacitors c) Use of synchronous motors d) Proper sizing of motors based on loads and use of energy efficient motors.
S7.	Explain tariff based on "two part" basis which is generally applicable for most of medium and large type of industrial enterprises in India? The two part tariff has one part for capacity (or demand) drawn and the second part for actual energy drawn during the billing cycle. Capacity or demand is in kVA (apparent power) or kW terms. The reactive energy (i.e.) kVArh drawn by the service is also recorded and billed for in some utilities, because this would affect the load on the utility. In addition, other fixed expenses are also levied like tax, meter rent etc.
S8.	What are the benefits of power factor improvement? The following are the benefits of PF improvement: (i) Reduced KVA (Maximum demand) charges in utility bill (ii) Avoidance of penalty on PF if relevant. (iii) Option of availing any incentives the utility offers on high power factor. (iv) Better voltage at load ends (improved voltage regulation) (v) Reduced distribution losses (kWh) within the plant network
S9.	Which is the best location for capacitor banks for power factor improvement from energy conservation point of view? Locating capacitors at tail or load end will help to reduce losses within the plants distribution network. Further the voltage at tail end will also improve, thus the performance of equipment will improve.
S10.	What are the important conditions one should consider before transformers are connected in parallel? Satisfactory parallel operations of two transformers depend on the following key factors. Both transformers should have the same: a) voltage ratio b) polarity c) phase sequence d) percentage impedance e) phase angle between primary and secondary terminals.
S11.	Calculate the transformer total losses for a transformer loading at 60% and with no load and full load losses of 3 kW and 25 kW respectively? Transformer losses = No load losses + (% loading)^2 x Full load losses = 2 + $(0.6)^2$ x 25 = 11 kW

S12.	What are the likely affects on plant's electricity bill if Power Factor is found to be low say 0.7? * It would have attracted penalty towards low PF as per utility tariff stipulations * It might have lead to recording excess demand (kVA or kW) and in turn high fixed charges.
S13.	Define load factor. Calculate annual load factor (%) in a facility having an annual consumption of 150.0 lakh kWh, maximum demand of 2421 kVA at 0.95 PF lag. Load factor is a ratio of the average demand (kVA or kW) to the peak demand for a power system. Average yearly consumption = 150.0 lakh kWh Load Factor = 150,00, 000/(8760 hr x 2421 x 0.95) LF = 74.45%
S14.	Refer the sketch below: In the above facility, determine the best option to reduce transformer losses even considering long-term options. Indicate other system benefits if any. Instead of two step transformation in power supply, one new transformer of voltage ratio 11/o.433kV can be installed and losses can be minimized. In addition cost of maintaining two transformers, cables, switchgears etc. can be minimized. 
S15.	What do you mean by better 'load management' from the point of view of electric supply utility? The popular measures for better load management by supply utilities include the issues relating to: · time of day tariff (ToD) · penalties on exceeding allowed maximum demand
S16.	Name two types of transformer losses and write a brief note on this. Transformer losses consist of two parts: No-load loss and Load loss 1. No-load loss (also called core loss) is the power consumed to sustain the magnetic field in the transformer's steel core. Core loss occurs whenever the transformer is energized; core loss does not vary with load. Core losses are caused by two factors: hysteresis and eddy current losses. Hysteresis loss is that energy lost by reversing the magnetic field in the core as the magnetizing AC rises and falls and reverses direction. Eddy current loss is a result of induced currents circulating in the core. 2. Load loss (also called copper loss) is associated with full-load current flow in the

	transformer windings. Copper loss is power lost in the primary and secondary windings of a transformer due to the ohmic resistance of the windings. Copper loss varies with the square of the load current. ($P=I^2R$).
S17.	Explain what you have understood by 'total harmonic distortion or THD' In case of harmonics, the 'magnitude' and 'order' of harmonics is governed by the nature of device being used and the impact is expressed as "total harmonic distortion" or THD
S18.	List any five problems that can arise due to harmonics in a system. The problems that arise due to harmonics in a system are: 1. Blinking of Incandescent Lights - Transformer Saturation 2. Capacitor Failure - Harmonic Resonance 3. Circuit Breakers Tripping - Inductive Heating and Overload 4. Conductor Failure - Inductive Heating 5. Electronic Equipment Shutting down - Voltage Distortion
S19.	List down any three common type of devices which cause harmonics in the system? 1. Electronic switching power converters 2. Arcing devices 3. Ferromagnetic devices
S20.	What are the likely affects of voltage deviations from rated voltages in an electrical system? The likely affects of voltage deviations from rated voltages are 1. Over voltages for motors 2. reduce efficiency, power actor and equipment life 3. increased temperature

Part III: Long Type Questions & Answers

L1.	Define components of tariff structure? Explain in detail. The tariff structure generally includes the following components: *a) Maximum demand Charges* These charges relate to maximum demand registered during month/billing period and corresponding rate of utility. *b) Energy Charges* These charges relate to energy (kilowatt hours) consumed during month / billing period and corresponding rates, often levied in slabs of use rates. Some utilities now charge on the basis of apparent energy (kVAh), which is a vector sum of kWh and kVArh. *c) Power factor* penalty or bonus rates, as levied by most utilities, are to contain reactive power drawl from grid. *d) Fuel cost* adjustment charges as levied by some utilities are to adjust the increasing fuel expenses over a base reference value.

e) Electricity duty charges levied w.r.t units consumed.

f) Meter rentals

g) Lighting and fan power consumption is often at higher rates, levied sometimes on slab basis or on actual metering basis.

h) Time Of Day (TOD) rates like peak and non-peak hours.

i) Penalty for exceeding contract demand

j) Surcharge if metering is at LT side in some of the utilities

L2. Calculate the following from the data given below:

a) kVAr required to improve PF to 0.95 lag

b) reduction in kVA demand

c) techno-economics of PF improvement option

<u>Data</u>

Rating of transformer	=	1600 kVA
Average loading on the transformer	=	1020 kVA
Present power factor (old pf)	=	0.64 (lag)
Demand charges/kVA	=	PKR 150/kVA
Unit cost of Capacitor/kVAR	=	PKR. 300
Transformer no-load loss/hour	=	2.4 kW
Transformer Full -load loss/Hour	=	18.57 kW

Required rating of the capacitor banks to improve the pf from the present PF of 0.64 (lag) to 0.95 (lag). Take the unit price of capacitor as PKR.300 per kVAr.

<u>Calculation:</u>

Present kW load = kVA x PF = 1020 x 0.64 = 653 kW

Present kW load = kVA x PF = 1020 x 0.64 = 653 kW

Present kVAr value = $\sqrt{(kVA)^2 - (kW)^2} = \sqrt{(1020)^2 - (653)^2} = 784$ kVAr

New value of kVA when pf is improved from old value of 0.64 (lag) to new pf of 0.95 (lag)

New kVA = $\left(\frac{\text{Old pf}}{\text{New pf}}\right) \times \text{Old kVA} = \left(\frac{0.64}{0.95}\right) \times 1020 \text{ kVA} = 687$ kVA

New kVAr after pf improvement = $\sqrt{(kVA)^2 - (kW)^2} = \sqrt{(687)^2 - (653)^2} = 213$ kVAr

Value of capacitor required = (New kVAr - Old kVAr) = 784 kVAr - 213 kVAr

= 570 kVAr

<u>(Alternate method with formula for kVAr computation)</u>

Capacitor value required = kW [tan (Cos^{-1} (old pf) – tan (Cos^{-1} (New pf)]

= 653 [tan (Cos^{-1} (0.64)) – tan (Cos^{-1} (0.95))]

= 653 x 0.8719 = 569.4 $\approx$ 570 kVAr

Reduction / release of kVA demand and cost savings

Release or reduction in kVA = (Old kVA - New kVA) = (1020 - 687)

= 333 kVA

Annual cost savings due to reduction in kVA=kVA(savings) x PKR/ kVA x 12Months

= 333 x 150 x 12 = PKR.5,99,400/-

Cost of implementation

Cost of 570 kVAr capacitor bank, taking PKR.300/ kVAr = PKR.300 x 570 kVAr

= PKR.1,71,000

Simple Payback period = 171000/599400 =0.29 years

L3. In an engineering industry, one MCB is connected with single run copper cable of 16 sq.mm cross section from MCC. The cable is laid in air. The load connected to the MCB is 100A.The length of cable is 40 m. The resistance of cable is 1.15 ohms/KM. The designed current carrying capacity of cable is 78 A. The load factor is 0.632. These loads operate continuously for 8760 hours in a year. The cost of electricity is PKR. 5.5 per kWh. Calculate

a) the cable existing losses

b) measure to minimize cable losses

c) annual cost savings by the suggested measure

It is recommended either to lay one more parallel cable (i.e. total 2 runs) or to replace the 16 sq.mm cable with 35 sq.mm cable. The comparison for both the options with the present is shown below:

a) Cable losses are calculated with the following formula:

$$\text{Cable losses} = \frac{3 \times I^2 \times R \times \text{Load Factor} \times l \times h}{1000} \text{ kWh}$$

Where

I = Current, A

R = Resistance of the cable, Ohm/km

l = Length of the cable, km,

h = Operating hours

Parameter	Present	Proposed	
		Option # 1 Additional cable	Option # 2 35 sq. mm cable
Total Current, A	100	100	100
Cable Size, Sq.mm	16	16	35
Cable Resistance, ohms/KM	1.15	1.15	0.524
Number of Runs of Cable	1	2	1
Cable Length, m	40	40	40
Load Factor	0.632	0.632	0.632
Annual Operating Hours	8760	8760	8760

Energy Charge, PKR./kWh	5.5	5.5	5.5
kWh losses per annum	7640	3820	3481
Annual cost of losses	42020	21010	19145
Annual cost savings	--	21010	22875

Note: Based on the investment for option 1 & 2, the pay back period can be derived at.

L4. The maximum demand approved by a utility is 5500 kVA and tariff provides for minimum billing demand of 80% of approved. Review of past 12 months records of bills reveals that the monthly maximum demand recorded is around 4200 kVA.

Will there be any benefits in surrendering part of contract demand? If so what is the kVA that you recommend for surrendering?

Give the costs savings by surrendering demand, if unit rate for kVA demand is PKR 200.

Approved maximum demand : 5500 kVA
Minimum billing demand (MBD) : 4400 kVA
Maximum demand recorded : 4200 kVA

The approved maximum demand is selected such a way that the gap between MD recorded and minimum billing demand are narrowed down.

A different scenario is to be created.

Contract demand	5500	5400	5300	5200
(Minimum Billing Demand) 80% of contract demand	4400	4320	4240	4116
Monthly demand recorded	4200	4200	4200	4200

From above, it would be advantage to surrender '300 kVA' demand and set new approved demand at 5200 kVA.

The actual savings possible is calculated below:

New contract (approved) demand :5200 kVA

New minimum billing demand :4160kVA)

Existing MD recorded :4200kVA

Present billing demand :4200 (since recorded kVA is more than MBD)

Original minimum billing demand : 4400kVA (Before surrendering demand)

Reduction demand value taken for billing:200 kVA

Savings in demand charges/month PKR 200 * 200kVA

PKR40,000

(Note: The pay back in above case will be 'immediate' as there is no investment.)

L5. Why maximum demand can be controlled? What are the options for controlling maximum demand?

MD control is very important because the utility charges user not only for the energy consumed but also for the maximum demand made irrespective of energy consumed (as per two part tariff). Hence in order to reduce the energy cost it is essential to control the

	maximum demand. MD control can be achieved by a step by step and a systematic approach as given below: i) Generate load curve & analyze all electrical loads in the plant with respect to the demand drawn by the particular equipment/process/ department. Stagger operation of loads as far as possible. ii) Identification of electrical loads/process/department that can be rescheduled towards load factor improvement. iii) Incorporation of automation such as demand controllers and maximum demand controllers. iv) Adoption of alternative sources such as captive generation / co-generation for peak demand reduction v) Reactive power demand compensation to maintain highest possible power factor so that maximum demand in KVA is optimized

Chapter 3.2: Electric Motors

Part–I: Objective type questions and answers

1.	The synchronous speed of a motor with 6 poles and operating at 50 Hz frequency is ___. a) 1500 b) 1000 c) 3000 d) 750
2.	The efficiency figures for energy efficient motors (in comparison with standard efficiency motor) can be generally higher by___%. a) 1% b) 3-7% c) 10% and above d) 8-10%
3.	The power consumption, in case of centrifugal loads (like pump, fan, blower etc.), proportional to ____. a) speed b) square of speed c) cube of speed d) not applicable
4.	Which types of following motors are most efficient? a) TEFC b) SPDP c) Both d) None
5.	What determines the thermal loading on the motor? a) Duty/Load cycle b) Temperature of the winding c) Age of the motor d) Ambient conditions
6.	Unbalance in voltages at motor terminals is caused by ____. a) Supplying single phase loads disproportionately b) Use of different sizes of cables c) Both (a) & (b) d) None of the above
7.	With decrease in speed of the motor, the required capacitive kVAr: a) Increases b) Decreases c) Does not change d) None of the above
8.	Application of DC motors is generally restricted to a few load speed applications because of _____. a) cost of the motor is high b) problems with mechanical commutation c) Maintenance problems d) None of the above
9.	The speed of an AC motor depends on ____ . a) Frequency b) No. of poles c) both (a) and (b) d) None of the above
10.	The speed of the motor can be varied by ___. a) Changing supply frequency b) Varying the input voltage c) Using multi speed windings d) All the above

11.	Which of the following are ill suited for energy efficient motors application? a) Pumps b) Fans c) Punch Presses d) All the above
12.	Reduction in supply voltage by 10% will change the torque of the motor by ___. a) 38% b) 19% c) 9.5% d) no change
13.	Five percent increase in supply frequency will change the synchronous speed by _____. a) -5% b) +5% c) -10% d) +10%
14.	The inexpensive way to improving energy efficiency of a motor which operates consistently at below 40% of rated capacity is by _____. a) Operating in Star mode b) Replacing with correct sized motor c) Operating in delta mode d) None
15.	Which of the following needs to be measured after rewinding of motor? a) No load current b) winding resistance c) air gap d) all the above
16.	Output power requirements of constant torque loads vary with _____. a) Speed b) voltage c) Current d) power factor
17.	Which of the following is an AC motor? a) Slip ring motor b) Synchronous motor c) Squirrel cage Induction d) all of the above
18.	Stray losses in an induction motor generally are ____ . a) proportional to the square of the stator current b) proportional to the square of the rotor current c) proportional to the rotor current d) inversely proportional to the square of rotor current
19.	Which of the following information available on name plate of a motor? a) HP rating b) RPM c) Frame model d) all the above
20.	Machine tools are a typical example of a) Constant power load b) Constant torque load c) Variable torque load d) A & C

Part – II: Short type questions and answers

S1.	Name the two important parameters that attribute to efficiency of electricity use by AC induction Motors? The important parameters that attribute to efficiency of electricity use by AC induction Motors are 1. Efficiency of the motor 2. Power Factor
S2.	How do you define percentage unbalance in voltage? Percentage unbalance in voltage is defined as $[(V_{max} - V_{avg})/V_{avg}]$ x 100, where V_{max} and V_{avg} is the largest and the average of the three phase voltages respectively.
S3.	Why is it beneficial to operate motors in star mode for under loaded motors? For motors which consistently operate at loads below 50 % of rated capacity, an inexpensive and effective measure might be to operate in star mode. A change from the standard delta operation to star operation involves re-configuring the wiring of the three phases of power input at the terminal box. Operating in the star mode leads to a voltage reduction by a factor of '$\sqrt{3}$'. Motor output falls to one-third of the value in the delta mode, but performance characteristics as a function of load remain unchanged. Thus, full-load operation in star mode gives higher efficiency and power factor than partial load operation in the delta mode. However, motor operation in the star mode is possible only for applications where the torque-to-speed requirement is lower at reduced load.
S4.	What is the thumb rule for installing capacitors to motor terminal? The size of capacitor required for a particular motor depends upon the no-load reactive kVA (kVAR) drawn by the motor, which can be determined only from no-load testing of the motor. In general, the capacitor is then selected to not exceed 90 % of the no-load kVAR of the motor. (Higher capacities could result in over-voltages and motor burn-outs). Alternatively, typical power factors of standard motors can provide the basis for conservative estimates of capacitor ratings to use for different size motors.
S5.	Write some applications of constant torque and variable torque loads. Constant Torque Loads: Conveyors, rotary kilns, constant displacement pumps Variable torque loads: Centrifugal pumps and fans.
S6.	What is an energy efficient motor? An "energy efficient" motor produces the same shaft output power (HP), but uses less input power (kW) than a standard-efficiency motor.

S7.	What is synchronous speed and how to determine the % slip of a motor? The speed of a motor is the number of revolutions in a given time frame, typically revolutions per minute (RPM). The speed of an AC motor depends on the frequency of the input power and the number of poles for which the motor is wound. The synchronous speed in RPM is given by the following equation, where the frequency is in hertz or cycles per second: a) $\text{Synchronous Speed (RPM)} = \frac{120 \times \text{Frequency}}{\text{No. of Poles}}$ b) Slip (%) = [(Synchronous Speed–Full Load Speed)/Synchronous Speed] x 100
S8.	List down the parameters that influence the motor selection? The following parameters influence the motor selection: (a) Torque requirement/load characteristics (b) Ambient operating conditions (c) Anticipated switching frequency (d) Reliability (e) Inventory (f) Price (g) efficiency
S9.	What are the types of losses in any motor? The losses in any motor are shown below: Fixed Loses – core loss, friction & windage loss. Variable Losses - Copper & Stray Losses
S10.	Write the relation to determine the energy savings by motor replacement with energy efficient one. kW savings = kW output x $[1/\eta_{old} - 1/\eta_{new}]$
S11.	What steps should an energy manager take to minimize voltage unbalance? 1. Balancing any single phase loads equally among all three phases 2. Segregating any single phase loads which disturb the load balance and feed them from a separate line/transformer
S12.	Comment on 'construction aspects' how an "energy efficient motor" is different from a "standard motor"? Energy efficient motors have the following positive features compared to standard motor: ☞ Higher quality low loss laminations for magnetic circuit ☞ More & better quality copper in the windings. ☞ Better quality insulation ☞ Optimised air gap between the rotor and stator. ☞ Reduced fan losses. ☞ Closer matching tolerances ☞ A greater core length

S13.	A 440 V, 20 HP 3-ph motor operates at full load, 88% efficiency and 0.65 power factor lagging: A. Find the current drawn by the motor B. Find the real and reactive power absorbed by the motor A. P_{in} (Input power) = 20 x 746 / 0.88 = 16955 W I_L (Input current) = 16955 / (√3 x 440 x 0.65) = 34.2 A B. PF = 0.65 ∴ = $\cos^{-1}(0.65) = 49.5^o$ (also sin 49.5 °C = 0.76) P (kW) = √3 x V_L x I_L x cos 49.5^o = √3 x 440 x 34.2 x 0.65 = 16.95 kW Q (kVAr) = √3 x V_L x I_L x sin 49.5^o = √3 x 440 x 34.2 x 0.76 = 19.8 kVAr S (kVA) = √3 x V_L x I_L = √3 x 440 x 34.2 = 26.1 kVA {Note also: $S^2 = \sqrt{(P^2+Q^2)}$}
S14.	A 4-pole 415 V 3-phase, 50 Hz induction motor runs at 1440 RPM at .88 pf lagging and delivers 10.817 kW. The stator loss is 1060 W, and friction & windage losses are 375 W. Calculate A. Slip B. Rotor Copper loss C. Line current D. Efficiency A. Slip = **4%** B. Rotor Copper loss= **466.33W** C. Line Current= **20.11A** D. Efficiency= **85%**
S15.	Give short note on the features of a Synchronous motor? AC power is fed to the stator of the synchronous motor. The rotor is fed by DC from a separate source. The rotor magnetic field locks onto the stator rotating magnetic field and rotates at the same speed. The speed of the rotor is a function of the supply frequency and the number of magnetic poles in the stator. While induction motors with a slip, i.e., rpm is less than the synchronous speed, the synchronous motor rotate with no slip i.e., the rpm is same as the synchronous speed governed by supply frequency and number of poles. The slip energy is provided by DC excitation power.
S16.	Write a short note on a 'multi-speed motor'? Motors can be wound such that two speeds, in the ratio of 2:1, can be obtained. Motors can also be wound with two separate windings, each giving 2 operating speeds, for a total of four speeds. Multi-speed motors can be designed for applications involving constant torque, variable torque, or for constant output power. Multi-speed motors are suitable for applications which require limited speed control (two or three fixed speeds instead of continuously variable speed), in which cases they tend to be very economical.

S17.	Why 'induction motors' are so popular over all types of motors? Low cost (compared with DC) and Wide availability Low maintenance - no brushes or commutator Rugged design - can be used in harsh environments Low inertia rotor designs High electrical efficiency Wide speed ranges • No separately-powered field windings
S18.	How do you size the capacitor rating required for an induction motor? The size of capacitor required for a particular motor depends upon the no-load reactive kVA (kVAR) drawn by the motor, which can be determined only from no-load testing of the motor. In general, for full loading operating motor, the capacitor selected to not exceed 90 % of the no-load kVAR of the motor. (Higher capacities could result in over-voltages and motor burn-outs).
S19.	Write some strategies for correcting poor power factor in motors? The following are strategies for correcting power factor in motors: 1. Minimise operation of idling or lightly loaded motors 2. Ensuring correct supply of rated voltage and phase balance 3. Installing capacitors to decrease reactive power loads
S20.	List down some ill suited application for 'energy efficient motors'? Because the favourable economics of energy-efficient motors are based on savings in operating costs, there may be certain cases which are generally economically ill-suited to energy-efficient motors. These include highly intermittent duty or special torque applications such as hoists and cranes, traction drives, punch presses, machine tools, and centrifuges. In addition, energy, efficient designs of multi-speed motors are generally not available. Furthermore, energy-efficient motors are not yet available for many special applications, e.g. for flame-proof operation in oil-field or fire pumps or for very low speed applications (below 750 rpm). Also, most energy-efficient motors produced today are designed only for continuous duty cycle operation.

Part – III: Long type questions and answers

L1.	What are the losses in the 'induction motor' and briefly explain them? Losses are the source of inefficiency in motors, i. e. energy that goes into a motor but does not produce useful work. Losses in induction motors are classified into two types: 1. No-load Losses: These losses are independent of load and incurred even when the motor is idling. 2. Load dependent Losses: Vary as function of motor loading The losses in a motor are of two types such as fixed i.e. independent of load on the motor and the other variable i.e. dependent on the load.

<table>
<tr><td></td><td>
Fixed losses consist of Iron loss and mechanical loss (friction and windage loss). The iron loss vary with the material and geometry and with input voltage whereas friction and windage losses are caused by friction in the bearings of the motor and aerodynamic losses associated with the ventilation fan and other rotating parts.
Variable losses consist of resistance losses in the stator and in the rotor and other stray losses. Resistance to current flow in the stator and rotor result in heat generation that is proportional to the resistance of the material and square of the current. Stray losses arise from a variety of sources and are difficult to measure directly or to calculate and are generally considered proportional to the square of the rotor current.
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<tr><td>L2.</td><td>
What are the factors to be considered while selecting a motor?
A. Torque Requirement
The primary consideration defining the motor choice for any particular application is the torque required by the load. The relationship between the maximum torque generated by the motor (break-down torque) and the torque requirements for start-up (locked rotor torque) and during acceleration periods is very important. The thermal loading on the motor is determined by the duty/load cycle. One important consideration with totally enclosed fan cooled (TEFC) motors is that the cooling may be insufficient when the motor is operated at speeds lower than its rated speed.
B. Sizing to Variable Load
Industrial motors frequently operate under varying load conditions due to process requirements. A common practice in cases where such variable loads are found is to select a motor based on the highest anticipated load. In many instances, an alternative approach is typically less costly, more efficient and provides equally satisfactory operation. With this approach, the optimum rating for the motor is selected on the basis of the load duration curve for the particular application. Thus, rather than selecting a motor of high rating that would operate at full capacity for only a short period, a motor would be selected with a rating slightly lower than the peak anticipated load and would operate at overload for a short period of time. Since operating within the thermal capacity of the motor insulation is of greatest concern in a motor operating at higher than its rated load, the motor rating is selected as that which would result in the same temperature rise under continuous full-load operation as the weighted average temperature rise over the actual operating cycle.
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<tr><td>L3.</td><td>
Write the checklist of good maintenance practices for proper motor operation? –
A checklist of good maintenance practices to help insure proper motor operation would include.
❑ Inspecting motors regularly for wear in bearings and housings (to reduce frictional losses) and for dirt/dust in motor ventilating ducts (to ensure proper heat dissipation).
❑ Checking load conditions to ensure that the motor is not over or under loaded. A change in motor load from the last test indicates a change in the driven load, the cause of which should be understood.
❑ Lubricating appropriately. Manufacturers generally give recommendations for how and when to lubricate their motors. Inadequate lubrication can cause problems, as noted above. Over-lubrication can also create problems, e.g. excess oil or grease from the motor bearings can enter the motor and saturate the motor insulation, causing premature failure or creating a fire risk.
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- Checking periodically for proper alignment of the motor and the driven equipment. Improper alignment can cause shafts and bearings to wear quickly, resulting in damage to both the motor and the driven equipment.
- Ensuring that supply wiring and terminal box are properly sized and installed. Inspect regularly the connections at the motor and starter to be sure that they are clean and tight.

L4. What are the effects of harmonics on motor operation and performance?

Harmonics increase motor losses, and can adversely affect the operation of sensitive auxiliary equipment. The non-sinusoidal supply results in harmonic currents in the stator which increases the total current drawn. In addition, the rotor resistance (or more precisely, impedance) increases significantly at harmonic frequencies, leading to less efficient operation. Also, stray load losses can increase significantly at harmonic frequencies. Overall motor losses increase by about 20% with a six-step voltage waveform compared to operation with a sinusoidal supply. In some cases the motor may have to be de-rated as a result of the losses. Alternatively, additional circuitry and switching devices can be employed to minimize losses.

Instability can also occur due to the interaction between the motor and the converter. This is especially true of motors of low rating, which have low inertia. Harmonics can also contribute to low power factor.

L5. Calculate the annual energy savings and simple payback from replacing an existing standard motor with a premium efficiency Motor versus repairing a standard efficiency motor with a sample example.

Energy Cost Savings (PKR./year) = HP x LF x 0.746 kW/HP x hrs x [100/η_{std} - 100/$\eta_{premium}$] x PKR./kWh

Simple Payback (years) = Price premium / Annual cost savings (in (PKR)

Energy cost savings $= \text{HP x LF x 0.746 x} \left[\frac{100}{\eta_{standard}} - \frac{100}{\eta_{premium}} \right]$

Example: Simple Payback Analysis for an average 20 HP, 1800 RPM, TEFC Motor Repair or Replacement:

	Average Efficiency	Average Cost, PKR.
Rewind of Standard Efficiency Motor	88.3%	5000
Pr Premium Efficiency Motor	93.5%	40,000
Operating Hours	8,000	
Load Factor (LF)	75%	
Utility Rate	PKR. 4.0/kWh	

Energy Cost Savings = 20 HP x 0.75 x 0.746 x 8,000 hrs x [100/88.3 - 100/93.5] x PKR. 4/kWh

	= PKR. 21,485/year Simple Payback = (PKR. 40000 – Rs.5000) / PKR. 21485 = 1.6 years

Chapter 3.3: Compressed Air System

Part–I: Objective type questions and answers

1.	Which of the following type does Screw compressor belongs to? a) Positive displacement compressor b) Dynamic compressors c) Both a & b d) None of the above
2.	The compressor capacity of a reciprocating compressor is directly proportional to _ a) Speed b) Pressure c) Volume d) All
3.	Vertical type reciprocating compressors are used in the capacity range of ____ a) 50 – 150 cfm b) 200 – 500 cfm c) Above 10ooo cfm d) 10 – 50 cfm
4.	The specific power consumption of non lubricated compressor compared to lubricated type is ___ a) Lesser b) Same c) Higher d) None
5.	The discharge temperature of two stage compressor compared to single stage one is ___ a) Lesser b) Same c) Higher d) None
6.	The compression ratios for axial flow compressors are ___. a) Lesser b) Higher c) moderate d) None
7.	The volumetric efficiency of the compressor _____ with the increase in altitude of place a) increases b) decreases c) does not change d) None
8.	The ratio of isothermal power to actual measured input power of a compressor is known as: a) Isothermal efficiency b) Volumetric Efficiency c) Barometric efficiency d) None
9.	The basic function of air dryer in a compressor is: a. prevent dust from entering compressor b. storage and smoothening pulsating air output c. reduce the temperature of the air before it enters the next state to increase efficiency d. to remove remaining traces of moisture after after-cooler
10.	For every 4°C raise in air inlet temperature of an air compressor, the power consumption will increases by____ a) 2% b) 1% c) 3% d) 4%

11. The percentage increase in power consumption of a compressor with suction side air filter and with the pressure drop across the filter of 200 mmWc is ____

a) 1.0% b) 3% c) 2.4% d) <u>1.6%</u>

12. Which of the statement is "True" for centrifugal compressors?

a) The compressor should not be operated at full load
b) The compressor should be operated at shut off pressure
c) The compressor should not be operated with inlet-guide vane control
d) <u>The compressor should not be operated close to the surge point</u>

13. Identify the correct statement for air compressors.

a. For every 5.5°C drop in the inlet air temperature, the increase in energy consumption is by2%.
b. For every 4 °C rise in the inlet air temperature, the decrease in energy consumption is by 1%
c. <u>For every 4 °C rise in the inter air temperature, the increase in energy consumption is by 1%</u>
d. The energy consumption remains same irrespective of inlet air temperature

14. Reduction in the delivery pressure of a compressor by 1 bar would reduce the power consumption by

a) <u>6 to 10 %</u> b) 2 to 3 % c) 12 to 14 % d) None of the above

15. The acceptable pressure drop at the farthest point in mains header of an industrial compressed air network is:

a)<u>0.3 bar</u> b) 0.5 bar c) 1.0 bar d) 2 bar

16. The likely estimate on equivalent power wastage for a leakage from 7 bar compressed air system through 1.6 mm orifice size is ____

a) 0.2 kW b) 3.0 kW c) <u>0.8 kW</u> d) 12 kW

17. From the point of lower specific energy consumption, which of the following compressors are suitable for part load operation?

a) <u>Single stage reciprocating compressors</u> b) Centrifugal compressors
c) Two stage screw compressor d) Single stage screw compressor

18. From base load operation and from achieving best specific energy consumption point of view, which of the following compressors are suitable?

a) Single stage reciprocating compressors b) <u>Centrifugal compressors</u>
c) Two stage reciprocating compressor d) Multi stage reciprocating compressor

19. Which of the following parameters are not required for evaluating volumetric efficiency of the compressor?

a) <u>Power</u> b) Cylinder bore diameter c) Stroke length d) FAD

20. If the compressor of 200 cfm loads in 10 seconds and unloads in 20 seconds, the air leakage would be_____

a) <u>67 cfm</u> b) 100 cfm c) 10 cfm d) 133 cfm

Part – II: Short type questions and answers

S1.	Give major classifications of compressors and the basic principle of its working. The major classifications of compressors are positive displacement and dynamic type. Positive displacement can be further divided in to (a) Reciprocating (b) Rotary and Dynamic compressors divided into (a) Centrifugal (b) Axil. In case of positive displacement compressors increase the pressure of air/gas by reducing the volume. Dynamic compressors increase the air or gas velocity, which is then converted to increase the pressure.
S2.	If the compressor of 200 m^3/min loads in 10 seconds and unloads in 20 seconds, calculate the amount of air leakages in the system. The system leakage is calculated by: System leakage in ‘m^3/min’ = $\frac{QxT}{(T+t)}$ Where Q = Actual free air being supplied during trial in m^3/min T = Load time in minutes t = Unload time in minutes = 200 x 10 / (10 + 20) = 67 m^3/min
S3.	Briefly describe about ‘rotary compressor’? Rotary compressors have rotors in place of pistons and give a continuous, pulsation free discharge. They operate at high speed and generally provide higher throughput than reciprocating compressors. They are directly coupled to the prime mover and require lower starting torque as compared to reciprocating machines. Also they require smaller foundations, vibrate less, and have a lower number of parts which are subject to wear.
S4.	What are the limitations of a centrifugal compressor operation? The major limitation of a centrifugal compressor is that is operates at peak efficiency at design point only and any deviation from the operating point is detrimental to its performance. When selecting centrifugal compressors, close attention should be paid during system design to ensure that at high pressure, with the consequent reduction in flow, the surge point is not reached.
S5.	What is a surge point and how do you prevent surging, if required for a compressed air system? Surge point is the point on the performance curve where a further decrease inflow (typically in the region of 50-70 % of rated capacity) causes instability, resulting in a pulsating flow, which may lead to overheating, failure of bearings due to thrust reversals, or excessive vibration. Bypass valves advents are commonly used to prevent surging.
S6.	What is the function of an air receiver? The main purpose of a receiver is to act as a pulsation damper, allowing intermittent high demands for compressed air to be met from a small compressor set, resulting in lesser energy consumption.

S7.	Calculate the free air delivery (FAD) of a compressor for the following observed data: Receiver capacity: 0.25 m³ Initial pressure: 1 kg/cm² (g) Final pressure: 13 kg/cm² (g) Initial temperature: 22 °C Final temperature: 42 °C Additional holdup volume: 0.05 m³ Compressor pump up time: 3.9 minutes Q $= \frac{P_2 - P_1}{P_0} \times \frac{V}{t} \times \left(\frac{273+t_1}{273+t_2}\right)$ $= \frac{13-1}{1.026} \times \frac{(0.25+0.05)}{3.9} \times \left(\frac{273+22}{273+42}\right)$ = 0.843 m³/min
S8.	Explain about the importance of optimal Pressure settings of a compressed air network The power consumed by a compressor depends on its operating pressure and rated capacity. They should be operated above their optimum operating pressure as this not only wastes energy, but also leads to excessive wear, leading to further energy wastage. The volumetric efficiency is also less at higher delivery pressure. The possibility of down setting the delivery pressure should be explored by careful study of pressure requirements of various equipment and pressure drop between generation point and utilization point. The pressure switches must be adjusted such that the compressor cut-in and cuts-off at optimum levels.
S9.	List the components of a compressed air system. The various components of a compressed air system are: • Intake air filters • Inter-stage coolers • After coolers • Air-dryers • Moisture traps • Receivers
S10.	Why inter-coolers are required for multi-stage reciprocating compressors? The intercoolers reduce the temperature of air/gas discharged between stages. Ideally, the intake temperature at each stage should be the same as that at the first stage (referred to a perfect cooling), so that the volume of air to be compressed does not increase and hence reduced power consumption.
S11.	What are the likely effects of using very cold water in intercoolers for reciprocating compressors? Use of very cold water can result in condensation which may result in water entering the cylinder, thereby reducing valve life, accelerating wear and scoring of piston, piston rings and

	cylinder. The condensed water may also wash away the oil film on the cylinder and cause rust which will result in abrasion during compressor operation and significantly reduce efficiency.
S12.	Give the empirical relation to evaluate the volumetric efficiency. Volumetric efficiency = $\frac{\text{Free air delivered m}^3\text{/min}}{\text{Compressor displacement}}$ Compressor Displacement = $\frac{(\Pi) \times (D^2) \times (L) \times (S) \times (\chi) \times (n)}{4}$ D = Cylinder bore, metre L = Cylinder stroke, metre S = Compressor speed rpm χ = 1 for single acting and 2 for double acting cylinders n = No. of cylinders
S13.	List the means of capacity control for reciprocating compressors. ▪ On/off control ▪ Load and unload control ▪ Multi-step control
S14.	List the advantages of keeping the discharge pressure for reciprocating compressors at minimum. ▪ Lower power consumption ▪ Less load on the piston rods and hence reduced maintenance costs ▪ Lower leakage losses
S15.	What are the different types of pressure regulators available for air compressor system? ▪ Pilot operated type ▪ Direct acting type ▪ Self – relieving type
S16.	What are the most common types of compressed air dryers used? a. Heat – less dryer (absorption) b. Adsorption dryer c. Chiller dryer (refrigerated dryers)
S17.	Can you explain how temperature of inlet air affects the energy consumption of an air compressor? As a thumb rule "for every 4 °C rise in inlet air temperature results in a higher energy consumption by 1% to achieve equivalent output". Hence cool air intake leads to a more efficient compression.

S18.	Which type of energy efficient dryer can be opted if a user in a plant requires compressed air at atmosphere dew point of -40°C? Desiccant regenerative type dryer can be opted if a user in a plant requires compressed air at atmosphere dew point of -40°C.
S19.	What is the effect of increase in altitude on the performance of single stage reciprocating compressors? With the increase in altitude, there will be reduction in air pressure, which results in increase in compression ratio, leading to higher discharge temperature and reduced efficiency.
S20.	What are the methods of capacity control in centrifugal air compressors? Centrifugal compressors operate best at the design point. They are prone to surging at flow rates less than 50% of the rated capacity. The following types of controls are employed in centrifugal compressors. a) Modulating controls: Modulating (throttling) inlet controls allows he output of a compressor to be varied to meet flow requirements. Throttling is usually accomplished by closing down inlet vane, thereby restricting inlet air to the compressors. The amount of capacity reduction is limited by the potential for surge and minimum throttling capacity. b) Variable speed drives: Efficient way of compressor capacity control is application of variable speed drives to match compressor output to meet varying load requirements is by speed control

Part – III: Long type questions and answers

L1.	Explain the simple steps that can be followed in shop – floor for quantification of compressed air leakages. The following steps can be followed for quantification of compressed air leakages. • Shut off compressed air operated equipments (or conduct test when no equipment is using compressed air). • Run the compressor to charge the system to set pressure of operation • Note the sub-sequent time taken for 'on load' and 'off load' cycles of the compressors. For accuracy, take ON & OFF times for 8 – 10 cycles continuously. Then calculate total 'ON' Time (T) and Total 'OFF' time (t). • The system leakage is calculated as • % leakage = T × 100 / (T + t) (or) System leakage (cmm) = Q × T / (T + t) Q = Actual free air being supplied during trial, in cubic meters per minute (cmm) T = Time on load in minutes t = Time unload in minutes

L2. In an automobile industry one compressor of rated capacity of 1000 cfm is operated to evaluate leakage quantity in the plant during a holiday when no equipment was using compressed air. FAD test was also carried out before conducting leakage test and found that the compressor is delivering out put of 90% of rated capacity.

The observations on leakage test are:

a) Compressor was on load for 08 minutes

b) Compressor was unloaded for 48 minutes

c) Compressor was consuming 150 kW

Evaluate

a) Free air delivery

b) Specific power consumption

c) % leakage in compressed air system

d) Leakage quantity

e) Power lost due to leakage

Compressor capacity : 1000 cfm

a. Operating capacity (FAD) : 90% of rated capacity

: 0.90 x 1000 cfm

: 900 cfm

b. Specific power consumption

Actual power consumption : 144 kW

Actual output : 900 cfm

Specific power consumption : 900/144

: 6.25 cfm / kW

c. % Leakage in the system

Load time (T) : 08 minutes

Un load time (t) : 48 minutes

% leakage in the system : $\frac{Tx-}{(T+t)}x100$

: $\frac{08}{(08+48)}x100$

: 14.2%

d. Leakage quantity : 0.142 x 900

: 127.8 cfm

e. Power lost due to leakage : $\frac{Leakage\,quality}{Specific\ energy}$

: $\frac{127.8}{6.25}$

: 20.45 kW

L3.	In a chemical industry reciprocating compressor of two stages was tested for free air delivery. The test details are as follow: a) Receive capacity : 5 m^3 b) Initial pressure : 1 kg/cm^2 g c) Final pressure : 7.0 kg/cm^2 g d) Connecting pipe volume and moisture separator volume : 0.5 m^3 e) Compressor pump up time : 5 minutes f) Motor power consumption : 37 kW g) Temp. of air in the receiver : 36 °C h) Ambient air temperature : 30 °C Evaluate the FAD (free air delivery), and specific power consumption. <u>Actual free air delivery</u> $Q = \frac{p_2 - p_1}{p_0} x \frac{V}{T} x \left(\frac{273+t_1}{273+t_2} \right)$ Q = m^3/min, P2 = Final pressure in kg/cm^2 w = 8 kg /cm^2 a P1 = Initial pressure in kg/cm^2 w = 2 kg / cm^2 a P0 = Absolute pressure kg/cm^2 w = 1.026 kg/cm^2 a V = Receiver+connecting pipe volume in m^3 = 5 + 0.5 = 5.5 m^3 T = Time taken to fill the receiver in minutes t1 = Ambient temp. in °C = 30 °C t2 = Final temp. is received °C = 36 °C FAD (Q) = $\frac{(8-2)}{1.026} x \frac{5.5}{5} x \frac{(273+30)}{(273+36)}$ = 6.3 m^3/min = 378 m^3/h = 236 cfm Specific power consumption kW/cfm = 0.156 cfm/kW = 6.37

L4.	Explain about the air compressor modulation by optimal pressure settings. Very often in an industry, different types, capacities and makes of compressors are connected to a common distribution network. In such situations, proper selection of a right combination of compressors and optimal modulation of different compressors can conserve energy. Where more than one compressor feeds a common header, compressors have to be operated in such a way that the cost of compressed air generation is minimal. ▪ If all compressors are similar, the pressure setting can be adjusted such that only one compressor handles the load variation, whereas the others operate more or less at full load. ▪ If compressors are of different sizes, the pressure switch should be set such that only the smallest compressor is allowed to modulate (vary in flow rate). ▪ If different types of compressors are operated together, unload power consumptions are significant. The compressor with lowest no load power must be modulated. ▪ In general, the compressor with lower part load power consumption should be modulated. ▪ Compressors can be graded according to their specific energy consumption, at different pressures and energy efficient ones must be made to meet most of the demand.
L5.	Explain the simple method of capacity assessment of air compressors. • Isolate the compressor along with its individual receiver being taken for test from main compressed air system by tightly closing the isolation valve or blanking it, thus closing the receiver outlet. • Open water drain valve and drain out water fully and empty the receiver and the pipe line. Make sure that water trap line is tightly closed once again to start the test. • Start the compressor and activate the stop watch. • Note the time taken to attain the normal operational pressure P_2 (in the receiver) from initial pressure P_1. • Calculate the capacity as per the formulae given below : **Actual Free air discharge** $Q = \frac{P_2 - P_1}{P_0} \times \frac{V}{T} \; NM^3/Min.$ Where P_2 = Final pressure after filling (kg/cm^2 a) P_1 = Initial pressure (kg/cm^2a) after bleeding P_0 = Atmospheric Pressure (kg/cm^2 a) V = Storage volume in m^3 which includes receiver, after cooler, and delivery piping T = Time take to build up pressure to P_2 in minutes The above equation is relevant where the compressed air temperature is same as the ambient air temperature, i.e., perfect isothermal compression. In case the actual compressed air temperature at discharge, say t_2 ^{0}C is higher than ambient air temperature say t_1 ^{0}C (as is usual case), the FAD is to be corrected by a factor $(273 + t_1) / (273 + t_2)$.

Chapter 3.4: HVAC & Refrigeration System

Part–I: Objective type questions and answers

1.	One ton of refrigeration (TR) is equal to ____. a) 3024 Kcal/h b) 3.51 kW c) 120oo BTU/h d) all
2.	The driving force for refrigeration in vapour absorption refrigeration plants is____ a) Mechanical energy b) Thermal energy c) Electrical energy d) All
3.	The main disadvantage of use of HFCs and HCFCs compared to use of CFCs is_____ a) Low Efficiency b) High heat output c) High emissions d) All
4.	COP of absorption refrigeration systems a) Between 4-5 b) less than 1.1 c) above 1.1 d) always 2.5
5.	Match the following in respect of typical specific energy consumption (kW per TR) of refrigeration compressors. **Refrigeration Compressor** — **kW/TR** a) Reciprocating — i) 0.63 kW/TR b) Centrifugal — ii) 0.65 kW/TR c) Screw — iii) 0.7 – 0.9 kW/TR Ans. a-iii; b-i; c-ii
6.	The essential parameters to estimate cooling load from air side across air handling unit (AHU) / Fan Coil Unit (FCU) are_______. a) Flow rate b) dry bulb temperature c) RH% or wet bulb temperature d) all
7.	In water cooled refrigeration systems, condenser cooling water temperature should be close to: a) dry bulb temperature b) wet bulb temperature c) dew-point temperature d) any of the above
8.	Centrifugal compressors are most efficient when they are operating at_____. a) 50% load b) Full load c) 75% Load d) All load conditions
9.	In general, designed chilled water temperature drop across the chillers is____ °C. a) 5 °C b) 1 °C c) 10 °C d) 15 °C
10.	Higher COP can be achieved with_____. a) Lower evaporator temperature and higher condenser temperature b) Higher evaporator temperature and Lower condenser temperature

	c) Higher evaporator temperature and higher condenser temperature d) Lower evaporator temperature and Lower condenser temperature
11.	The required A/C size for comfort conditions for general living room (12 ft x 12 ft) at residence is_____. a) < 0.5 TR b) 1 to 1.5 TR c) > 2.5 TR d) any of the above
12.	Typical range of COP value for a compression refrigeration cycle is: a) 1 to 10 b) 1 to 20 c) 2 to 5 d) 2 to 20
13.	The specific energy for a centrifugal chiller producing chilled water at 5.5 °C and condenser water temperature around 30 °C is the order of: a) 0.65 – 0.8 kW / TR b) 1.0 kW / TR c) 1.15 – 1.25 kW/ TR d) 0.45 – 0.55 kW/ TR
14.	Approximate percentage reduction in power consumption with 1 °C rise in evaporator temperature in refrigerating systems is ______. a) 2% b) 3% c) 1% d) 4%
15.	The refrigerant side heat transfer area in evaporators is of the order of ____. a) 0.1 sqm/TR b) 0.3 sqm/TR c) 0.4 sqm/TR d) 0.5 sqm/TR and above
16.	The percentage refrigeration compressor power reduction with 0.55 deg. C temperature reduction in water returning from cooling tower is _______. a) 2% b) 3% c) 1% d) 4%
17.	Cascade systems for refrigeration are preferable in the temperature range of ______. a) 5^{o}C to 10^{0}C b) -5^{o}C to -10^{0}C c) -46^{o}C to -101^{0}C d) 0^{o}C to 10^{0}C
18.	The efficiency of screw compressor at part load compared to centrifugal compressor is __. a) higher b) lower c) Same d) None
19.	Which of the following compressor has recently become practical in the market? a) reciprocating b) screw c) scroll d) all the above
20.	The device used to cool the refrigerant in vapour absorption chiller is: a) vacuum pump b) condenser c) vacuum condenser d) none of the above
21.	The refrigerant temperature after the expansion device compared to after condenser in the vapour compression refrigeration cycle is____ a) higher b) lower c) Same d) None

Part – II: Short type questions and answers

S1.	Define one 'Ton of Refrigeration (TR)'. A ton of refrigeration is defined as the quantity of heat to be removed in order to form one ton of ice in 24 hours when the initial temperature of water is 0 °C. This is equivalent to 50.4 Kcal/min or 3024 Kcal/h in metric system.
S2.	What are the commonly used refrigerants for vapour compression chillers? Commonly used refrigerants for vapour compression chillers are R410A, R407C, R134a, R404a, R717 (Ammonia)
S3.	In which range of temperature the application of 'brine plants' are made use of? 'Brine plants' are used for typically sub zero temperature applications.
S4.	List the main parameters on which the choice of HVAC components depends on. The choice of refrigerant and the required cooling temperature and load determine the choice of compressor, as well as the design of the condenser, evaporator, and other auxiliaries. Additional factors such as ease of maintenance, physical space requirements and availability of utilities for auxiliaries (water, power, etc.) also influence component selection.
S5.	Write down basic formula for estimating the tonnage of a chiller? (Or refrigeration TR). The refrigeration TR is assessed as TR = $Q \cdot C_p \cdot (T_i - T_o) / 3024$ Where Q is mass flow rate of coolant in kg/hr C_p is coolant specific heat in kCal /kg °C T_i is inlet, temperature of coolant to evaporator (chiller) in ^{0}C T_o is outlet temperature of coolant from evaporator (chiller) in ^{0}C.
S6.	What do you mean by kW / TR pertaining to refrigeration? "KW/TR" is the specific power consumption which is a useful indicator of the performance of refrigeration system. By measuring refrigeration duty performed in TR and the Kilo Watt inputs measured, kW/TR is used as a reference energy performance indicator.
S7.	Define COP? COP is nothing but Coefficient of performance which is a standard measure of refrigeration efficiency of an ideal refrigeration system depends on two key system temperatures, namely, evaporator temperature T_e and condenser temperature T_c with COP being given as ; $COP = T_e / T_c - T_e$
S8.	Ice is formed at 0°C from water at 30 °C. In the refrigeration system, same temperature water is used for condenser cooling and the temperature of the brine is- 15°C at evaporator. Consider the system as ideal refrigeration; find the CoP of the refrigeration system. Evaporator temperature (T1) = -15 °C Condenser temperature (T2) = 30 °C CoP of ideal cycle = T1/(T2-T1) $= \frac{(-15+273)}{(30+273)-(-15+273)} = 5.7$

S9.	What are the parameters required to be measured while estimating the chiller performance in KW/TR? Q : mass flow rate of coolant in kg/hr T_i : inlet, temperature of coolant to evaporator (chiller) in ^{0}C T_o : outlet temperature of coolant from evaporator (chiller) in ^{0}C. Actual power drawn by compressor, chilled water pump, condenser water pump and cooling tower fan
S10.	Name the parameters that a psychometric chart provide for an air conditioning engineer? Air parameters in psychometric chart

♦ Dry bulb temperature (°C)	♦ Relative humidity (%)
♦ Wet bulb temperature (°C)	♦ Specific volume (m^3/kg of dry air)
♦ Enthalpy (Kcal/kg of dry air)	♦ Specific humidity (gm/kg of dry air)

S11.	List the types of refrigeration compressors used in industries. Select the lowest specific power consumption (kW/TR) refrigeration system and compare with other options (w.r.t power consumption) for 350 TR cooling load. Major refrigeration compressor types for industrial application are: a) Reciprocating b) Centrifugal c) Screw Lowest specific power consumption (kW/TR) can be achieved from centrifugal compressors for 350 TR air conditioning load comparison among the compressors for specific power (kW/TR)

	Reciprocating	Centrifugal	Screw
Sp. Power (kW/TR)	0.7-0.9	0.63	0.65

S12.	List out any two types of vapour absorption chillers based on the refrigerant- absorbent combination. ▪ Lithium bromide- water (LiBr- H2O) cycle ▪ Ammonia- Water (NH3-H2O) cycle
S13.	Which refrigerants based on their absorption system are used for sub-zero temperature applications? Ammonia refrigerant based absorption systems operate at above atmospheric pressures and are capable of low temperature operation (below 0 °C)
S14.	How do you calculate TR across the Air Handling Units? Refrigeration load in TR is assessed as ;

$$TR = \frac{Q \times \rho \times (h_{in} - h_{out})}{3024}$$

	Where Q is the air flow in CMH ρ is density of air kg/m³ h_{in} is enthalpy of inlet air kCal/kg h_{out} is enthalpy of outlet air kCal/kg
S15.	A reciprocating refrigeration compressor of 100 TR is working at full load with 4.5 °C temperature difference across the evaporator. i) Estimate the water flow rate if water is secondary coolant, ii) Assess the connected motor size (kW) to this refrigeration compressor Capacity of reciprocating compressor = 100 TR Working fluid = Water (sp. Heat of water 1.0 Kcal/kg °C) Chilled temperature across evaporator = 4.5 °C i) Chilled water flow rate Q (kg/h) = $\frac{100x3024}{4.5x1}$ = 67200 kg/hr ii) Specific power consumption of reciprocating compressor = 0.7-0.9 kW TR For connected motor assessment consider higher specific power consumption Required motor power = 100 x 0.9 = 90 kW So, connected motor may be 90 kW (or) next higher size – 110 kW
S16.	What is the function of a condenser in a refrigeration cycle? The function of a condenser is to receive superheated refrigerant vapour from the compressor, remove the superheat and then liquefy the refrigerant with the rejection of latent heat.
S17.	Why CFC's are phased out? Which are the alternatives to CFC's? CFC's are phased out due to their damaging impact on the protective troposphere ozone layer around the earth. Two alternative refrigerants developed which are: a) Hydro chloro Fluro carbon (HCFC) b) Hydro fluro carbon (HFC)
S18.	Under what conditions 'screw chillers' perform better when compared to other type of 'chillers'? The efficiency of screw compressors operating at part load is generally higher than either centrifugal compressors or reciprocating compressors, which may make them attractive in situation, where part-load operation is common.
S19.	List three important characteristics of 'evaporative cooling systems'. Three important points of 'evaporative cooling system' are: a) Less expensive and less energy intensive b) Most suitable for tropical weather conditions c) The temperature can be controlled by controlling the air flow and the water circulation rate

S20.	Write short note on 'chilled water storage'. Cold storage: By providing a chilled water storage facility with very good cold insulation, chilled water requirements can be met without operating the chillers continuously. These systems are economical if small variations in temperature are acceptable. It allows chillers to operate at periods of low electricity demand to reduce peak demand charges.

Part–III: Long type questions and answers

L1. Estimate tonne of refrigeration from the data given below for two AHUs?

Parameter	AHU-A	AHU-B
Evaporator area (m^2)	8.75	0.39
Inlet velocity (m/s)	1.81	11.50
Inlet air DBT (°C)	21.5	24.5
RH (%)	75.0	73.5
Enthalpy (kJ/kg)	53.0	59.3
Out let air DBT (°C)	17.4	19.5
RH (%)	90.0	83.0
Enthalpy (kJ/kg)	46.4	53.0
Density of air (kg/m^3)	1.14	1.05

AHU refrigeration load =

$$\frac{Air\ \ flow\ rate\ (m^3h)\ x\ Density\ of\ \ air\ (kg/m^3)\ x\ Difference\ in\ enthalpy}{3024\ \ x\ 4.18}$$

AHU-A $= \frac{(8.75\,x\,1.81\,x\,3600)\,x\,(1.1.4)\,(53-46.4)}{3024\,x\,4.18} =$ 33.9 TR

AHU-B $= \frac{(0.39\,x\,11.5\,x\,3600)\,x\,(1.05)\,x\,(59.3-53)}{3024} =$ 8.4 TR

L2. Compare the performance of centrifugal chiller with vapour absorption chiller using the data given below

Parameter	Centrifugal chiller	VAM
Chilled water flow (m^3/h)	189	180
Condenser water flow (m^3/h)	238	340
Chiller inlet temp (°C)	13.0	14.6
Condenser water inlet temp (°C)	27.1	33.5
Chiller outlet temp (°C)	7.7	9.0
Condense water outlet temp (°C)	35.7	39.1
Comp. power consumption (kW)	190	-
Steam consumption (kg/h)	-	1570
Chilled water pump (kW)	28	28
Condenser water pump (kW)	22	33
Cooling tower fan (kW)	6.0	15

i) Evaluate the tonnes of refrigeration (TR) of both the system?

ii) Compare both the chillers auxiliary power consumption, give the reason?

Refrigeration load (TR) =

$$\frac{Chilled\ water\ flow\ (m^3 h)\ x\ Sp.heat\ x\ Differ.temp\ (°C)}{3024}$$

Density of water = 1000 kg/m^3

i) Centrifugal chiller TR = $\frac{189\,x\,1000\,x\,1\,x\,(13-7.7)}{3024}$ = 331 TR

VAM TR = $\frac{180\,x\,1000\,x\,1(14.6-9.0)}{3024}$ = 333 TR

ii) Auxiliary power consumption : Chilled water pump + condenser water pump + cooling tower fan

Auxiliary power (kW) : 28 + 22 + 6.0 = 56 kW

VAM auxiliary power (kW) : 28 + 33 + 15 = 76 kW

Reason: For the same refrigeration load around 330 TR centrifugal chiller auxiliary power consumption is lower compared to VAM. It is mainly due to higher condenser heat load, where condenser pump and cooling tower fan power consumption is high.

L3. Briefly explain the methodology of refrigeration plant energy audit?

The cooling effect produced is quantified as tons of refrigeration.

1 ton of refrigeration = 3024 kCal/hr heat rejected.

The specific power consumption kW/TR is a useful indicator of the performance of refrigeration system. By measuring refrigeration duty performed in TR and the Kilo Watt inputs measured, kW/TR is used as a reference energy performance indicator.

The refrigeration TR is assessed as TR = $Q \cdot C_p \cdot (T_i - T_o) / 3024$

Where Q is mass flow rate of coolant in kg/hr

C_p is coolant specific heat in kCal /kg deg C

T_i is inlet, temperature of coolant to evaporator (chiller) in ^{0}C

T_o is outlet temperature of coolant from evaporator (chiller) in ^{0}C.

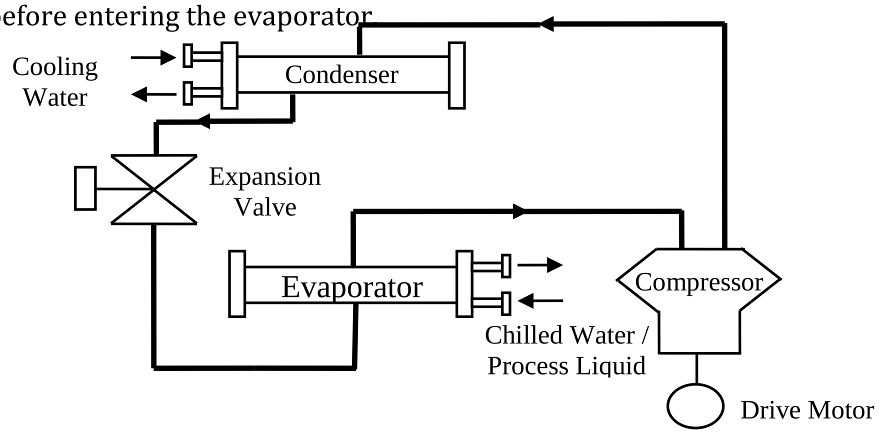
The above TR is also called as chiller tonnage. In a centralized chilled water system, apart from the compressor unit, power is also consumed by the chilled water (secondary) coolant pump as well condenser water (for heat rejection to cooling tower) pump and cooling tower fan in the cooling tower fan. Effectively, the overall energy consumption would be towards ;

- Compressor kW
- Chilled water pump kW
- Condenser water pump kW
- Cooling tower fan kW, for induced / forced draft towers

The specific power consumption for certain TR output would therefore have to include :

- Compressor kW/TR

	▪ Chilled water pump kW/TR ▪ Condenser water pump kW/TR ▪ Cooling tower fan kW/TR and overall kW/TR as a sum of the above. In case of air conditioning units, the air flow at the Fan Coil Units (FCU) or the Air Handling Units (AHU) can be measured with an anemometer. Dry bulb and wet bulb temperatures are measured at the inlet and outlet of AHU or the FCU and the refrigeration load in TR is assessed as: $$TR = \frac{Q \times \rho \times (h_{in} - h_{out})}{3024}$$ Where Q is the air flow in CMH ρ is density of air kg/m^3 h_{in} is enthalpy of inlet air kCal/kg h_{out} is enthalpy of outlet air kCal/kg Use of handy psychometric charts can help to calculate h_{in} and h_{out} from dry bulb, wet bulb temperature values which are, in-turn measured, during trials, by a whirling psychrometer.
L4.	Explain how capacity is controlled in refrigeration machines. The capacity of compressors is controlled in a number of ways. Capacity control of reciprocating compressors through cylinder unloaders results in incremental capacity modulation as opposed to continuous capacity modulation of centrifugal and screw compressors through vane control or sliding valves, respectively. Therefore, temperature control requires careful system design. Usually, when using reciprocating compressors in applications with widely varying loads, it is desirable to control the compressor by monitoring the return water (or other secondary coolant) temperature rather than the temperature of the water leaving the chiller. This prevents excessive on-off cycling or unnecessary loading / unloading of the compressor. However, if load fluctuations are not high, the temperature of the water leaving the chiller should be monitored. This has the advantage of preventing operation at very low water temperatures, especially when flow reduces at low loads. The leaving water temperature should be monitored for centrifugal and screw chillers. Capacity regulation through speed control is the most efficient option. However, when employing speed control for reciprocating compressors, it should be ensured that the lubrication system is not affected. In the case of centrifugal compressors, it is usually desirable to restrict speed control to about 50 % of the capacity to prevent surging. Below 50 %, vane control or hot gas bypass can be used for capacity modulation. The efficiency of screw compressors operating at part load is generally higher than either centrifugal compressors or reciprocating compressors, which may make them attractive in situations where part-load operation is common. Screw compressor performance can be optimized by changing the volume ratio. In some cases, this may result in higher full-load efficiencies as compared to reciprocating and centrifugal compressors. Also, the ability of screw compressors to tolerate oil and liquid refrigerant slugs makes them preferred in some situations.

L5.	Explain the principle of 'vapour compression' system with a neat sketch? A 'vapour compression' refrigeration system has four basic components : (1)an evaporator where cooled low pressure liquid refrigerant evaporates as it absorbs heat (2) a compressor, where the refrigerant in vapour form is compressed (3) a condenser, where heat in the high temperature, high pressure vapour is extracted by heat exchange with a cooler medium and (4) an expansion device, where the liquid refrigerant pressure is reduced to the evaporator pressure, further cooling the refrigerant in the process. The refrigerant leaves the expansion valve as a low temperature, low pressure liquid and is returned to the evaporator process is the heat load for evaporator and cooling tower is the sink for condenser in industrial refrigeration systems. The refrigerant absorbs heat from the coolant in the evaporator and evaporates. The low pressure refrigerant is then compressed to high pressure in the compressor. The hot discharge is cooled in the condenser before entering the expansion valve where it expands and cools before entering the evaporator.  *Fig : Schematic of a Basic Vapour Compression Refrigeration System*

Chapter 3.5: Fans and Blowers

Part – I: Objective type questions and answers

1. The parameter used by ASME to define fans, blowers and compressors is____

a) Fan ration b) Specific ratio c) Blade ratio d) Twist factor

2. Which of the following axial fan types is most efficient?

a) Propeller b) Tube axial c) Vane axial d) Radial

3. Which of the following is not a centrifugal fan type?

a) Vane axial b) Radial c) Airfoil, backward d) Forward curved

4. Match the following for centrifugal fan types.

Type	Suitable for
a) Backward curved	i) High pressure, medium flow
b) Forward curved	ii) Medium pressure, high flow
c) Radial	iii) High pressure, high flow

(a)-iii); (b)-ii); (c)-i)

5. For fans, the relation between discharge and speed is indicated by____

a) $\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$ b) $\frac{Q_1}{Q_2} = \frac{N_1^{2}}{N_2^{2}}$ c) $\frac{Q_1}{Q_2} = \frac{N_1^{3}}{N_2^{3}}$ d) None

6. The choice of fan type for a given application depends on _______

a) Flow b) Static Pressure c) Both a & b d) neither (a) nor (b)

7. The efficiency of backward curved fans compared to forward curved fans is_

a) Higher b) Lower c) Same d) None

8. Name the fan which is more suitable for high pressure application?

a) Propeller type fans b) Tube-axial fans

c) Backward curved centrifugal fan d) None of the above

9. Axial fans are best suitable for____ application.

a) Large flow, low head b) Low flow, high head

c) High head, large flow d) Low flow, low head

10.	The efficiency of forward curved fans compared to backward curved fans is ____ a) Lower b) higher c) Same d) none
11.	The efficiency values of Vane axial fans are in the order of: a) 78 – 85% b) 60 – 70% c) 90 – 95% d) 50 – 60%
12.	Backward curved fans have efficiency in the range of: a) 65 – 70% b) 75– 85% c) 90 – 95% d) 50 – 60%
13.	The pressure to be considered for calculating the power required for centrifugal fans is: a) Discharge static pressure b) Static + dynamic pressure c) Total static pressure d) Static + ambient air pressure
14.	Typical design efficiency of aerofoil fan handling clean air is: a) 40 to 50% b) 80 to 90% c) 60 to 70% d) 70 to 80%
15.	The clearance required for efficient operation of impeller of 1 meter plus diameter in Radial type fans is ____ a) 5 to 10 mm b) 1 to 2 mm c) 20 to 30 mm d) 0.5 to 1.5 mm
16.	Which type of control gives maximum benefits for fan application from energy saving point of view? a) Discharge damper control b) Inlet guide vane control c) Variable pitch control d) Speed control
17.	The pressure along the line of the flow that results from the air flowing through the duct is _____ a) Static pressure b) velocity pressure c) Total pressure d) Dynamic pressure
18.	The outer tube of the pitot tube is used to measure _____ a) Static pressure b) velocity pressure c) Total pressure d) Dynamic pressure
19.	Axial-flow fans are equipped with ______ a) fixed blades b) Curved blades c) Flat blades d) variable pitch blades
20.	The ratio of maximum to minimum flow rate is called ________- a) turn – up ratio b) turn-down ratio c) up-down ratio d) None
21.	The density of a gas at a temperature of 50 deg. C at site condition is __ a) 0.94 kg/m^3 b) 1.2 kg/m^3 c) 1.5 kg/m^3 d) 1.4 kg/m^3

Part – II: Short type Questions and Answers

S1.	Differentiate between 'centrifugal' and 'axial flow' fans? In centrifugal fans, pressure is developed due to the centrifugal force imparted to air, unlike axial flow fans where velocity energy is imparted to air, which in turn is converted to pressure energy at the fan outlet.
S2.	Which type of fan is suitable for higher pressure application? Centrifugal fans are suitable for high pressure applications as compared to axial flow fans.
S3.	Under which conditions of pressure ratios and volumes, low speed fans are preferred? Low speed fans are preferred for low pressure ratios and large volumes.
S4.	Why generally fans operate at very poor efficiency? A very conservative approach is adopted allocating large safety margins, resulting in oversized fans, which operate at flow rates much below their design values and consequently which leads to operate at very poor efficiency.
S5.	What are the types of centrifugal fans available? Radial, forward curved and backward inclined fans
S6.	Write the advantages of forward curved fans? Forward curved fans have the advantage of lower shut off power, which is desirable for low flow rate operation.
S7.	Which type of housing is more efficient for better fan performance? Performance of fans also depends on the fan enclosure and duct design. 'Spiral housing' designs with inducers, diffusers are more efficient as compared to 'square housings'.
S8.	Name different options available to control the speed of a fan? a) changing pulley ratio for drive and driven equipments. b) variable frequency drive c) variable speed fluid coupling
S9.	How do you calculate the velocity of air in the duct using the average differential pressure and density of the air/gas?

	Velocity v, m/s = $\frac{C_p \times \sqrt{2 \times 9.81 \times \Delta p \times \gamma}}{\gamma}$ C_p = Pitot tube constant, 0.85 (or) as given by the manufacturer Δp = Average differential pressure measured by Pitot tube by taking measurement at number of points over the entire cross section of the duct. γ = Density at air/gas at test condition
S10.	List at least five energy saving opportunities for a fan application. 1. Change of impeller by a high efficiency impeller along with cone. 2. Change of fan assembly as a whole, by a high efficiency fan 3. Impeller derating (by a smaller dia impeller) 4. Fan speed reduction by pulley dia modifications for derating 5. Option of two speed motors or variable speed drives for variable duty conditions 6. Option of energy efficient flat belts, or, cogged raw edged V belts, in place of conventional V belt systems, for reducing transmission losses. 7. Adopting inlet guide vanes in place of discharge damper control 8. Minimizing system resistance and pressure drops by improvements in duct system
S11.	What are affinity laws governing fan performance in terms of speed, power and pressure? The affinity laws governing fan performance is given below: Flow x speed Pressure x $(\text{speed})^2$ Power x $(\text{speed})^3$
S12.	Distinguish "speed control" vs "guide vane control"? **Speed control**: The flow is varied in accordance with the process requirement by changing the speed of the fan. **Guide vane control**: The flow is varied by guiding the inlet air into the fan in the direction of impeller rotation in accordance with the process requirement.
S13.	List out main factors to be considered for proper sizing of fans The following are the factors considered for fan sizing: a) Flow requirement in m^3/hr

	b) Pressure drop c) Power requirement d) Density of flowing gas at the site condition
S14.	What are the factors that affect the fan performance? The main factors affecting the performance of fans are flow, pressure, temperature, speed and damper positions on the fan side and the power input in KW on the motor side.
S15.	What are axial fans? Give some examples for its application? When the flow of air (or) fluid is parallel to the axis of the fan it is called an axial fan. Application areas of axial fans are: HVAC, drying ovens, exhaust system
S16.	What conditions suit for the application of radial type of centrifugal fans? Radial type of centrifugal fans is used at high pressure, medium flow conditions. E.g. Dust laden, moist air/gas in textile industry.
S17.	What are the merits of 'backward curved blade centrifugal fans'? The merits of backward curved blade centrifugal fans are: a) High pressure generation b) High efficiency c) Power reduction with increased flow
S18.	Describe 'inlet guide vane control' for fan? Inlet guide vane control is one type of capacity control of fans. The inlet guide vanes are designed to guide the inlet air into the fan in the direction of impeller rotation and, therefore, improve performance, resulting in somewhat better energy efficiency than damper controlled operation.
S19.	Explain how the variations in flue gas temperature will change the operating efficiency of the fan Variation in flue gas temperature will change the density of the gas given by a formula, Gas density = (273 x 1.29) / (273 + t°C). Density of gas is important consideration, since it affects both volume flow-rate and capacity of the fan to develop pressure.

S20.	Specify the importance of temperature during the fan selection? 1. Ambient temperatures, both the minimum and maximum are to be specified to the supplier. This affects the choice of the material of construction of the impeller. 2. Density of gas at different temperatures at fan outlet has to be considered while designing the fan. The volume of the gas to be handled by the fan depends on temperature.

Part-III: Long type questions and answers

L1. Highlight the specific differences between fan, blower and air compressors?

Fans, blowers and compressors are differentiated by the method used to move the air, and by the system pressure they must operate against. As per ASME, the specific pressure, i.e. the ratio of the discharge pressure over the suction pressure is used for defining the fans, blowers and compressors.

The details of pressure ratios are given below.

	Fan	Blower	Compressor
Specific ratio	up to 1.11	1.11 ~1.20	>1.20
Pressure rise (mm Wg)	1136	1136~2066	-

L2. List out different capacity control methods for the fans?

Basic capacity (volume) control methods adopted in fans and blowers are as follows:

1. Changing the rotational speed is the most efficient. If the volume requirement is constant, it can be achieved by selecting appropriate pulley sizes. If the volume varies with the process, adjustable-speed drives can be used.
2. Changing the blade angle is a method used with some vane-axial fans.
3. Restricting the air flow is accomplished with dampers or valves which close off the air flow at the inlet or outlet. Inlet vanes, which swirl the air entering the centrifugal fan or blower, are more efficient than dampers or butterfly valves.
4. Venting the high-pressure air, or recirculating it to the inlet, is often used with positive-displacement blowers. It is sometimes used with fan systems, but is the least efficient method as there is no reduction in the air being moved.

L3. List the types of fans, their characteristics and typical applications?

Axial-flow Fans			Centrifugal Fans		
Type	**Characteristics**	**Typical Applications**	**Type**	**Characteristics**	**Typical Applications**
Propeller	Low pressure, high flow, low efficiency, peak efficiency close to point of free air delivery (zero static pressure)	Air-circulation, ventilation, exhaust	Radial	High pressure, medium flow, efficiency close to tube-axial fans, power increases continuously	Various industrial applications, suitable for dust laden, moist air/gases

Tube-axial	Medium pressure, high flow, higher efficiency than propeller type, dip in pressure-flow curve before peak pressure point.	HVAC, drying ovens, exhaust systems	Forward-curved blades	Medium pressure, high flow, dip in pressure curve, efficiency higher than radial fans, power rises continuously	Low pressure HVAC, packaged units, suitable for clean and dust laden air / gases
Vane-axial	High pressure, medium flow, dip in pressure-flow curve, use of guide vanes improves efficiency	High pressure applications including HVAC systems, exhausts	Backward curved blades	High pressure, high flow, high efficiency, power reduces as flow increases beyond point of highest efficiency	HVAC, various industrial applications, forced draft fans, etc.
			Air foil type	Same as backward curved type, highest efficiency	Same as backward curved, but for clean air applications

L4. List the parameters to be considered for efficient operation of fan?

The parameters to be considered while fan selection are:

1. Design operating point of fan – volume and pressure
2. Normal operating point – volume and pressure
3. Maximum continuous rating
4. Low load operation
5. Ambient temperature
6. Density of gas at different temperatures
7. Composition of the gas
8. Dust concentration and nature of dust
9. Maximum temperature of the gas
10. Control mechanisms (proposed)
11. Altitude of the plant

L5. How do you assess the performance of fans? Explain.

The fans are tested for field performance by measurement of flow, head, temperature

	and damper position on the fan side and electrical motor kW input on the motor side. The fan flow is measured using Pitot tube manometer combination or a flow sensor (differential pressure instrument) or an accurate anemometer. Care needs to be taken regarding number of traverse points, straight length section (to avoid turbulent flow regimes of measurement) up stream and downstream of measurement location. The measurements can be on the suction or discharge side of the fan and preferably both where feasible. Pressure (draft) developed by the fan can be measured by Pitot tube manometer combination, or an accurate digital draft gauge. The temperatures of the gases / fluids are measurable by a digital temperature indicator and the damper position documented as percentage opening or notch position. In case of fluid couplings, the % scoop position can be the reference. Pulley diameter and fan rpm measurements help in assessing scope for derating. Fan design performance curves are needed to compare the actual efficiency with respect to design values. Drive motor input volts, amps, pf frequency and kW can be measured by a load analyzer, to assess input kW, pf, motor loading voltage imbalance if any. The fan air kW is assessed as: $$\text{Air kW} = \frac{\text{Flow in kgs/sec} \times \text{Total Head developed in meters of air column} \times 9.81}{1000}$$ Where head developed in meters of air column $$= \frac{\text{Head developed meters water column} \times \text{Density of water in kg/m}^3}{\text{Density of air in kg/m}^3}$$ Once the air kW and motor input motor kW are measured, motor, fan, damper combined efficiency is given by the relation, combined efficiency in percent $$= \frac{\text{Air kW}}{\text{In put kW}} \times 100$$ By an estimate of motor efficiency, (where the band of variation is nominal), the fan, damper efficiency is arrived at; It is also a good practice, to report percentage loading on capacity, i.e., flow, head and motor load, with respect to the rated values, while mentioning fan efficiency.

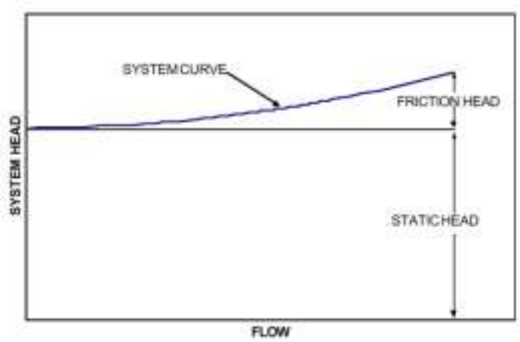
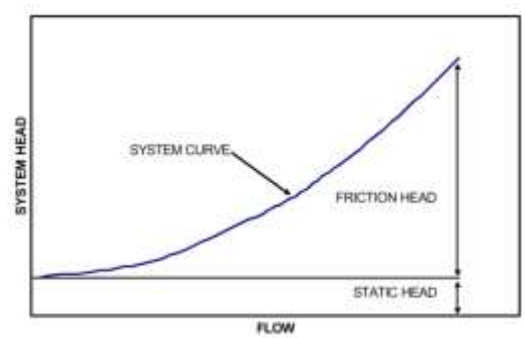
Chapter 3.6: Pumps & Pumping System

Part I: Objective type questions and answers

1.	Positive displacement pumps are generally less efficient than centrifugal pumps. State whether the statement is true or false
2.	Installing larger diameter pipe in pumping system results in reduction in-------- a) static head b) frictional head c) both a and b d) neither a nor b
3.	Generally water pipe lines are designed with water velocity of a) < 1 m/s b) up to 2.0 m/s c) > 2 m/s d) None of the above
4.	What is the impact on flow and pressure when the impeller of a pump is trimmed? a) Flow decreases with increased pressure b) Both flow and pressure increases c) Both pressure and flow decreases d) None of the above
5.	For high flow requirement, pumps are generally operated in a) parallel b) series c) any of the above d) none of the above
6.	"In case of throttling operation, the pump has to overcome additional pressure in order to deliver the reduced flow". Please indicate whether this statement is (a) True or (b) False?
7.	Friction losses in a pumping system is------ a) proportional to $1/Q$ b) proportional to $1/Q^2$ c) proportional to $1/Q^3$ d) proportional to $1/Q^4$
8.	For large capacity centrifugal pumps, design efficiencies are in the range of a) around 70% b) around 85% c) around 95% d) any of above
9.	The moving part in centrifugal pump is ----- a) impeller b) diffuser c) both a & b d) neither a nor b
10.	The most efficient method of flow control in a pumping system is------- a) Throttling the flow b) Speed control c) Impeller trimming d) None
11.	In case of increased suction lift from open wells, the delivery flow rate-------- a) increases b) decreases c) remains same d) none of the above

12.	Pump efficiency generally increases with specific speed. State whether the statement is <u>True</u> or False.
13.	Throttling the delivery valve of a pump results in increased ____. a) head b) power c) <u>both (a) and (b)</u> d) either (a) or (b)
14.	The operating point in a pumping system is identified by a) Point of intersection of system curve and efficiency curve b) Point of intersection of pump curve and theoretical power curve c) <u>Point of intersection of pump curve and system curve</u> d) Cannot be decided by pump characteristic curves
15.	The intersection point of the pump curve and the system curve is called-------- a) Pump efficiency b) <u>Best efficiency point</u> c) System efficiency d) None of the above
16.	If the speed of a centrifugal pump is doubled, its power consumption increases by------- times. a) two b) four c) <u>eight</u> d) no change
17.	Installation of Variable frequency drives (VFD) allows the motor to be operated with ____. a) <u>lower start-up current</u> b) higher start-up current c) constant current d) none of the above
18.	In case of centrifugal pumps, impeller diameter changes are generally limited to reducing the diameter to about ____ of maximum size. a) <u>75%</u> b)50% c) 25% d) None of the above
19.	If the delivery valve of the pump is throttled such that it delivers 30% of the rated flow, one of the best options for improved energy efficiency would be a) Trimming of the impeller b) Replacing the motor c) <u>Replacing the impeller with a smaller size impeller</u> d) None of the above
20.	Small by-pass lines are installed some times to _____. a) control flow rate b) control pump delivery head c) <u>prevent pump running at zero flow</u> d) reduce pump power consumption

Part II: Short type questions and answers

S1.	What are the different types of pumps? Pumps can be classified according to their basic operating principle as dynamic or displacement pumps. Dynamic pumps can be sub-classified as centrifugal and special effect pumps. Displacement pumps can be sub-classified as rotary or reciprocating pumps.
S2.	List out the parameters affecting pump system curves. The system curve is basically a plot of system resistance i.e. head to be overcome by the pump versus various flow rates. The system curves change with the physical configuration of the system; for example, the system curves depends upon height or elevation, diameter and length of piping, number and type of fittings and pressure drops across various equipment - say a heat exchanger.
S3.	What is the formula for evaluating theoretical power drawn by a pump if the flow rate and head developed are known? Theoretical power, kW = [Flow in lps] × [Head in meters W.C.] × 9.81 / 1000
S4.	Draw a centrifugal pump system curve with representation of static and friction head.  **System with High Static Head**  **System with Low Static Head**
S5.	Which are the three methods normally followed if the flow from a centrifugal pump is to be reduced? a) Throttling of the delivery valve b) Changing impellers (or) trimming impellers c) Changing of speed
S6.	How pumps operating point will be identified? The pump operating point is identified as the point, where the system curve crosses

	the pump curve when they are superimposed on each other.
S7.	What do mean by the term 'cavitation'? If the incoming liquid is at a pressure with insufficient margin above its vapour pressure, then vapour cavities or bubbles appear along the impeller vanes just behind the inlet edges. This phenomenon is known as cavitation.
S8.	What are the undesirable effects of cavitation in a pumping system? • Formation of cavitational bubbles leading to erosion of the vane surface • Noise and vibration • Partially choking of impeller passage and thereby reduction of pump performance
S9.	For a system, where static head is high proportion of the total head, which is most energy efficient method of flow control? Installation of two or more pump is the best system. Here a variation of flow rate is achieved by switching 'on' and 'off' additional pumps to meet the demand. The combined pump curve is obtained by adding the flow rates at a specific head and the system curve in this case is usually not affected by the number of running pumps.
S10.	Highlight the issues relating to impeller diameter trimming for a pump in terms of basic parameters of Q, H and P. Trimming of impeller refers to the process of matching the diameter of an impeller to reduce the energy added to the system fluid and offers useful correction to pump that is over sized for the application. The three major relations Q, H and P after impeller trimming would be as follows: $Q_{new} = \frac{D_{new}}{D_{old}}(Q_{old})$ $H_{new} = \left(\frac{D_{new}}{D_{old}}\right)^2 (H_{old})$ $BHP_{new} = \left(\frac{D_{new}}{D_{old}}\right)$
S11.	Explain briefly about static head and friction head? There are two types of losses the pump has to encounter. One is to meet the pressure requirement to make the liquid flow at the rate required and must overcome these two types head 'losses' in the system. The static head is simply the difference in height of supply & destination reservoirs and frictional head is the friction loss while moving thro' pipes, valves etc. in the system.

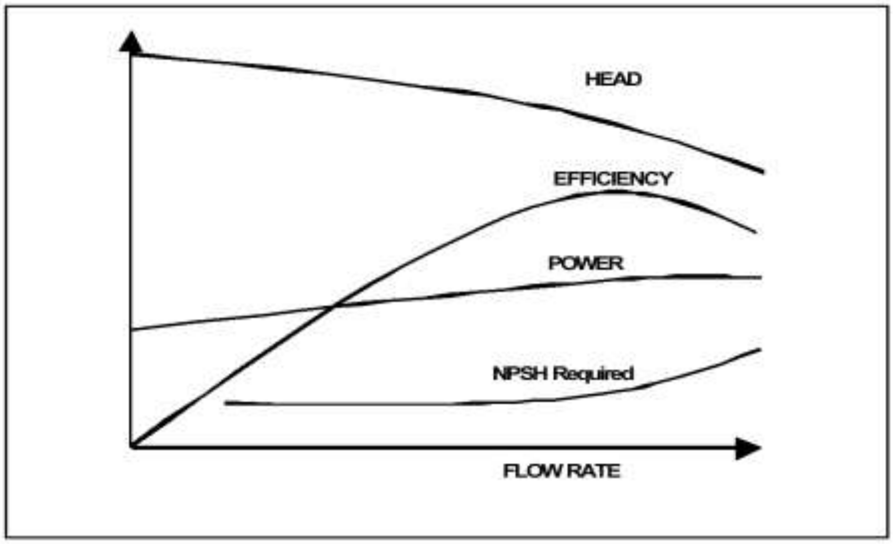
S12.	Change in impeller diameter of a pump affects the performance of the pump. Explain? The basic affinity laws which govern the performance are Q x D, pump H x D^2 and P x D^3. Efficiency varies when the diameter is changed within a particular casing. Diameter changes are generally limited to reducing the diameter to about 75% of the maximum, i.e. head reduction to about 50%. Beyond this, efficiency and NPSH are badly affected.
S13.	What do you mean by NPSH? Explain briefly. The value, by which the pressure in the pump suction exceeds the liquid vapour pressure, is expressed as a head of liquid and referred to as Net Positive Suction Head Available (NPSHA). This is a characteristic of the system design. The value of NPSH needed at the pump suction to prevent the pump from cavitation is known as NPSH required (NPSHR). This is a characteristic of the pump design.
S14	Plant has two travel grade boilers of rated capacity 38 TPH each and pressure 45 kg/cm². The design steam temperature from the boilers is 420 ± 5 °C. Installed turbo feed water pump to boiler is Q = 135 m³/h, H = 650 m, input power = 292 kW, feed water temperature at pump inlet is 105 °C. What will be the design efficiency of pump? (Assume suitable density correction) Design efficiency of pump $\eta_P = \dfrac{Q(m^3/h)xH(m)x9.81xW}{\eta x3600}$ Q = 135 m³/h; H = 650 m; P = 315 kW W = Specific weight of water at 105 °C = 0.95 η_m = Motor efficiency 0.9 $\eta_P = \dfrac{135x650\ x9.81x0.95}{0.9x3600x315}$ $= \dfrac{252}{315} = 0.8\,(80\%)$
S15.	A cooling water pump connected to pillar furnace, the specifications of the pump are as follows: Q = 12.5 lps H = 60 M p = 13.4 kW As per the pillar furnace manufacture, required quality is 12.5 lps at 3.0 kg/cm². What type of energy conservation measure can be proposed and estimate the reduction in power consumption. It can be recommended to replace the pump with new pump of same quantity (12.5 lps) and low head (30 m).

	New pump power consumption Q (lps) = 12.5 H (m) = 30 Considering operating efficiency of pump as 65%, power consumption of new pump (motor efficiency as 90%) $p = \frac{12.5x30x9.81}{1000x0.65x0.9}$ = 6.3 kW Reduction in power consumption = Present pump power – new proposed pump = 13.4 – 6.3 = 7.1 kW
S16.	What is the significance of parallel operation in case of centrifugal pumps? In pumping systems where static head is a high proportion of the total, the appropriate solution is to install two or more pumps to operate in parallel. Variation of flow rate is achieved by switching on and off additional pumps to meet demand. The combined pump curve is obtained by adding the flow rates at a specific head.
S17.	Discuss the advantages of stop/start controller in case of pumps. In stop/start control method, the flow is controlled by switching pumps on or off. It is necessary to have a storage capacity in the system e.g. a wet well, an elevated tank or an accumulator type pressure vessel. The storage can provide a steady flow to the system with an intermittent operating pump. When the pump runs, it does so at the chosen (presumably optimum) duty point and when it is off, there is no energy consumption. If intermittent flow, stop/start operation and the storage facility are acceptable, this is an effective approach to minimize energy consumption. The stop/start operation causes additional loads on the power transmission components and increased heating in the motor. The frequency of the stop/start cycle should be within the motor design criteria and checked with the pump manufacturer. It may also be used to benefit from “off peak” energy tariffs by arranging the run times during the low tariff periods.
S18.	What is the significance of by-pass control in pumping systems? By-pass control is used when; the pump runs continuously at the maximum process demand duty, with a permanent by-pass line attached to the outlet. When a lower flow is required the surplus liquid is bypassed and returned to the supply source.
S19.	What are the merits of VSD application in case of pumps? The flow control by speed regulation is always more efficient than by control valve. In addition to energy savings there could be other benefits of lower speed. The

	hydraulic forces on the impeller, created by the pressure profile inside the pump casing, reduce approximately with the square of speed. These forces are carried by the pump bearings and so reducing speed increases bearing life. It can be shown that for a centrifugal pump, bearing life is inversely proportional to the 7^{th} power of speed. In addition, vibration and noise are reduced and seal life is increased providing the duty point remains within the allowable operating range.
S19.	List any four important energy conservation opportunities in a pumping system. a) Throttled valve system b) Mismatch of head and flow c) Leakage in the piping system d) Over designed sizing of pumps to actual requirement

Part III: Long type questions and answers

L1.	Write a note on pump performance curve with sketch. The pressure (head) that a pump will develop is in direct relationship to the impeller diameter, the number of impellers, the size of impeller eye, and shaft speed. Capacity is determined by the exit width of the impeller. The head and capacity are the main factors, which affect the horsepower size of the motor to be used. The more the quantity of water to be pumped, the more energy is required. A centrifugal pump is not positive acting; it will not pump the same volume always. The greater the depth of the water, the lesser is the flow from the pump. Also, when it pumps against increasing pressure, the less it will pump. For these reasons it is important to select a centrifugal pump that is designed to do a particular job. Since the pump is a dynamic device, it is convenient to consider the pressure in terms of head i.e. meters of liquid column. The pump generates the same head of liquid whatever the density of the liquid being pumped. The actual contours of the hydraulic passages of the impeller and the casing are extremely important, in order to attain the highest efficiency possible. The standard convention for centrifugal pump is to draw the pump performance curves showing Flow on the horizontal axis and Head generated on the vertical axis. Efficiency, Power & NPSH Required (described later), are also all conventionally shown on the vertical axis, plotted against Flow, as illustrated in Figure.



Pump Performance Curve

L2. Explain parallel operation of pumps with necessary pump curves.

Pumps operating in parallel discharging into a common header exhibit a phenomenon that is completely independent of any static head that might be present. The first pump discharging to the header pressurizes the header. The second and subsequent pumps that come on line must then pump into a pressurized header. The net effect is the same as pumping against a static head. More the pumps running, the higher will be the pressure in the header, affecting system resistance as shown in Figure below:

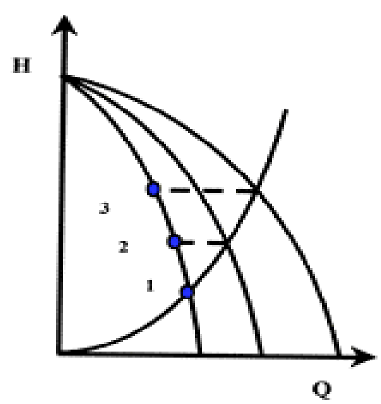


Fig: Parallel Pumps

Three curves indicate effect of pumps, in parallel. Innermost curve is for one pump; middle curve for 2 pumps, outer curve for 3 pumps in parallel. Addition of system resistance (1 to 2 or 1 to 3) by parallel operation can be seen.

With three pumps running, each pump operates at point 3 in Figure. Thus, a fourth pump must deliver at least this pressure before it produces any tangible flow. This situation is, therefore, identical to pumping against a static head.

L3. From the parameters given below, calculate the size of the impeller trimmed. The existing impeller diameter is of 380 mm

Parameter	Unit	Rated	Required
Flow	M^3/h	310	280
Head	M	45	43.5
Power	kW	55	46

Existing impeller size = 380 mm

Rated pump parameters

Q1 = 310 m^3/h

H1 = 45 m

P1 = 55 kW

Required pump parameters after impeller trimming

Q2 = 285 m^3/h

H2 = 43.5

P2 = 46 kW

i) Q2 = $Q1\,x\left(\frac{D2}{D1}\right)^3$

= $\frac{D2}{D1}=\left(\frac{Q2}{Q1}\right)^{1/3}$

= $\left(\frac{280}{310}\right)$ = 0.96

D2 = 0.96 x 380 = 367 mm

ii) D2 = $D1\,x\left(\frac{H2}{H1}\right)$

= $380 \text{ x } \left(\frac{43.5}{45}\right)$

= 367 mm

iii) P2 = $P \text{ x } \left(\frac{D2}{D1}\right)^5$

	$\frac{D2}{D1} = \left(\frac{P2}{P1}\right)^{1/5}$ $D2 = 380 \text{ x } \left(\frac{46}{55}\right)^{1/5}$ $= 380 \text{ x } 0.96 = 367 \text{ mm}$
L4.	Estimate the reduction in power consumption of condensate transfer pump by reducing speed of the pump by 20% to the rated speed. Q= 38 m3/h H = 65m P = 12.5 kW Running pumps operating parameters at full speed (N) Q1 = 38 m^3/h H1 = 65 m P1 = 12.5 kW Power consumption at reduced speed (80% of full speed) $P2 = P1 \text{ x } \left(\frac{N2}{N1}\right)^3$ $P2 = 12.5 \text{ x } \left(\frac{0.8N1}{N1}\right)^3 \left[\because N2 = 0.8N1\right]$ $= 12.5 \text{ x } 0.512$ $= 6.4 \text{ kW}$
L5.	In an energy audit study of a cement plants following measurement were noted. (table below)

Pump ID	Measured flow, m^3/h	Measured , kW	Operating head, m	Rated flow, m^3/h	Rated head, m
P1	12.31	42	357.15	15	380
P2	13.14	35	357.15	15	380
P3	21.60	55	362.25	25	380

Note: Motor efficiency is considered as 85%

Evaluate the operating efficiency of the pumps and suitably replace the pumps with new pumps of efficiency 75%. What would be the annual reduction in energy consumption after implementation of the above measure?

Pump efficiency: $\frac{QWHx0.746}{75 \, x \, motor \, kW \, x \, motor \, efficiency}$

Q: m^3/s

W: 1000

H: in meters of fluid column

Typically for pump no. 1

Efficiency η_p : $$\frac{12.31 x 1000 x 357 x 0.746}{3600 x 75 x 42 0.85}$$

34%

P2 and P3 are calculated and tabulated below:

Pump ID	Measured flow, m^3/h	Measured kW	Operating head, m	Pump η, %	Remarks
1	12.31	42	357	34	Poor efficiency
2	13.14	35	377	46	Low efficiency
3	21.60	55	362	46	Low efficiency

Considering the operating efficiency, it is recommended to opt for new pumps of same capacity which has an efficiency of 75%.The resulting energy savings of new pumps are:

New pump efficiency: 75%

Considering the existing flow and head, the power requirement is tabulated below:

Pump ID	Present power consumption, kW	Expected power consumption, kW	Energy savings, kW	Annual energy savings, kWh
P1	42	19	23	184000
P2	35	20.3	14.7	117600
P3	55	33.8	21.2	169600

Chapter 3.7: Cooling Towers

Part-I: Objective type questions and answers

1.	The type of cooling towers with maximum heat transfer between air to water is ___. a) Natural draft b) Mechanical draft c) Both a & b d) Neither a nor b
2.	Natural draft cooling towers are mainly used in ____. a) Steel industry b) alumina industry c) fertilizer industry d) power stations
3.	In counter flow induced draft cooling towers water and air both enter the top and exist at the top of the cooling tower. State whether True or False?
4.	The range of the cooling tower is determined by the connected heat load – True or False?
5.	Match the following cooling tower parameters a) Range — i) Close to wet bulb temperature b) Approach — ii) Related to ambient conditions c) Out let water temperature — iii) Higher temperature difference Ans. a-iii) b-i) c-ii)
6.	Better indicator for cooling tower performance is ____. a) Wet bulb temperature b) Dry bulb temperature c)Range d) Approach
7.	Cooling tower effectiveness is the ratio of --------- a) Range/(range + approach) b) Approach/(range + approach) c) Range/Approach d) Approach/Range
8.	Cooling tower reduces circulation water temperature close to ---------- a) Dry bulb temperature b) ambient wet bulb temperature (WBT) c) Dew point temperature d) None of the above
9.	The ratio of dissolved solids in circulating water to the dissolved solids in make up water is termed as ____. a) Liquid gas ratio b) cycles of concentration c) cooling tower effectiveness d) None of the above
10.	Which one of the following has maximum effect on cooling tower performance: a) Fill media b) Drift c) Louvers d) Casing

11.	Which one of the following is true to estimate the range of cooling tower? a) Range = Cooling water inlet temperature – Wet bulb temperature b) Range = Cooling water outlet temperature – Wet bulb temperature c) <u>Range =</u> $\frac{Heat\ load\ in\ kcal / h}{Water\ circulation\ in\ lph}$ d) None of the above
12.	A cooling tower is said to be performing well when: a) <u>approach is closer to zero</u> b) range is closer to zero c) approach is larger than design d) range is larger than design
13.	Heat release rate to the cooling tower in vapour compression refrigeration system is equal to: a) <u>63 kcal/min/ton</u> b) 500 kcal/min/ton c) 127 kcal/min/ton d) 220 kcal/min/ton
14.	The operating temperature level in the plant or process connected with a cooling tower is determined by: a) Dry bulb temperature b) Wet bulb temperature c) <u>Hot water temperature from the process</u> d) Cold water temperature into the process
15.	Which one of the following fill material is more energy efficient for cooling tower: a) Splash fill b) <u>Film-fill</u> c) Low clog film fill d) None of the above
16.	Which one from the following types of cooling towers consumes less power? a) Cross-flow splash fill cooling tower b) Counter flow splash fill cooling tower c) <u>Counter flow film fill cooling tower</u> d) None of the above
17.	L / G ratio in cooling tower is the ratio of ___. a) Length and girth b) Length and Temperature gradient c) <u>Water flow rate and air mass flow rate</u> d) Air mass flow rate and water flow rate
18.	Normally the guaranteed best approach a cooling tower can achieve is ___. a) 5 ^oC b) 12 ^oC c) 8 ^oC d) <u>2.8 ^oC</u>
19.	The temperature selection normally chosen for designing of cooling tower is ___. a) <u>Average maximum wet bulb for summer months</u> b) Average maximum wet bulb for rainy months c) Average maximum wet bulb for winter months d) Average minimum wet bulb for summer months

20.	Select the statement which is true for a FRP fan. a) It needs low starting torque b) Increases life of gear box c) Easy handling and maintenance d) All the above

Part-II: Short type questions and answers

S1.	List out different air flow arrangements of mechanical draft cooling towers? Different air flow arrangements of mechanical draft cooling tower are: a) Counter flow induced draft b) Counter flow forced draft c) Cross flow forced draft
S2.	List out different material used for cooling tower fans. Different material used for cooling tower fans: 1. Aluminium blades (metallic) 2. Glass reinforced plastic (GRP) 3. Fibre reinforced plastic (FRP)
S3.	What are the components of the cooling tower? The basic components of an evaporative cooling tower are: Frame and casing, fill, cold water basin, drift eliminators, air inlet, louvers, nozzles and fans.
S4.	Estimate the cooling tower capacity (TR) with the following parameters Water flow rate through CT = 120 m^3/h SP. Heat of water = 1 k.Cal/kg °C Inlet water temperature = 37 °C Outlet water temperature = 32 °C Ambient WBT = 29 °C Cooling tower capacity (TR) = (flow rate x density x sp.heat x diff. temp)/3024 = 120 x 1000 x 1 x (37-32)/3024 = 198.4 TR
S5.	Specify the CT manufacturer design approach value. Generally a 2.8 °C approach to the design wet bulb is the coldest water temperature that cooling tower manufactures will guarantee.

S6.	How a continuously monitored ambient DBT and RH data can be utilised for the cooling tower design? From the monitored DBT (°C) and RH%, wet bulb temperature (WBT) can be arrived using psychometric chart and same is used for designing cooling tower. In the design of CT wet bulb temperature selected is not exceeded over 5 percent of the time in that area.
S7.	How size of cooling tower and wet bulb temperature are related? Wet bulb temperature is a factor in cooling tower selection. The higher the wet bulb temperature, the smaller the cooling tower required to give a specified approach to the wet bulb at a constant range and flow rate.
S8.	List the features of FRP fans in cooling tower. FRP blades are normally hand moulded. These blades are aerodynamic in profile to meet specific duty conditions more efficiently. Due to light weight FRP fans need low starting torque resulting in use of lower HP motors.
S9.	Under what circumstances, do the cooling tower motors excessively loaded? Reasons for excessive electrical load on CT fan motors are: 1. Voltage reduction 2. Incorrect angle of axial fan blades 3. Loose belts on centrifugal fans 4. Over loading owing to excessive air flow-fill has minimum water loading per m^3 of tower 5. Low ambient air temperature
S10.	Plant has installed 100 TR refrigeration system of compression type. It has planned to utilize waste heat in absorption chiller to meet 100 TR cooling load. What is the size of cooling tower required? For the given refrigeration capacity (100 TR), absorption type chillers require double the capacity cooling tower in comparison to compression type chiller.
S11.	What will be the effect of cooling water temperature on A/C compressor operation? Effect of cooling tower outlet water temperature on A/C compressors, 1 °C cooling water temperature rise may increase A/C compressor power consumption (kW) by 2.7%.
S12.	What is meant by "Range and Approach" of a cooling tower? i) "Range" is the difference between the cooling tower water inlet and outlet temperature. ii) "Approach" is the difference between the cooling tower outlet cold water temperature and ambient wet bulb temperature. Though both parameters should be monitored, the 'Approach' is a better indicator of cooling tower performance.

S13.	List the factors affecting cooling tower performance? i) Capacity and range ii) Heat load iii) wet bulb temperature iv) Approach and water flow v) Filling media
S14.	What do you meant by effectiveness of a cooling tower? Cooling tower effectiveness in percentage is the ratio of range, to the ideal range, i.e., difference between cooling water inlet temperature and ambient wet bulb temperature or in other words it is = Range / (Range + Approach).
S15.	How do you calculate evaporation loss in cooling tower? Evaporation loss is the water quantity evaporated for cooling duty. An empirical relation used often is: CMH evaporation loss $= \dfrac{Circulation\ Rate\ (CMH)\ x\ Temp.\ difference\ in\ °C}{675}$
S16.	What are the advantages of FRP blades over the conventional blades for cooling tower fans? • Due to optimum aerodynamic profile, energy savings of the order to 20 – 30 % can be achieved • Due to light weight, low starting torque is required, hence requiring smaller capacity motor • Also due to light weight the life of gearbox, motor and bearing is increased and allows handling and maintenance
S17.	How to calculate blowdown quantity required in cooling towers? Blow Down = Evaporation Loss / (C.O.C. – 1) C.O.C = Cycle of concentration
S18.	What will be the effect of cooling water temperature in heat rate in thermal power plants? Effect of cooling tower outlet water temperature on thermal power plant: 1 °C temperature drop in cooling water will lead to heat rate saving of 5 kcal/kWh in thermal power plant.
S19.	List the types of fill media generally used in cooling towers? Fill media is of two types: 1. Splash fill media 2. Film fill media
S20.	In case of cooling towers, which type of fill media are more 'energy efficient'? Fills made of PVC, polypropylene, and other polymers are more energy efficient.

Part-III: Long type questions and answers

L1.	Explain the terms with respect to cooling tower performance: a) Wet bulb temperature Wet Bulb Temperature is an important factor in performance of evaporative water cooling equipment. It is a controlling factor from the aspect of minimum cold water temperature to which water can be cooled by the evaporative method. Thus, the wet bulb temperature of the air entering the cooling tower determines operating temperature levels throughout the plant, process, or system. Theoretically, a cooling tower will cool water to the entering wet bulb when operating without a heat load. However, a thermal potential is required to reject heat, so it is not possible to cool water to the entering air wet bulb temperature when a heat load is applied. The approach obtained is a function of thermal conditions and tower capability. b) Capacity and Range Any cooling tower, regardless of its size, will dissipate all the kCals sent to it. Unlike a pump which will only move a certain quantity of water against a definite head, a cooling tower will continue to dissipate kCals to the atmosphere as long as they are added to the circulating water, the cooling tower will dissipate the heat coming to the tower. Specifying cooling towers in terms of water flow rate, CMH circulated is also erroneous. Other factors must be stated along with CMH. For example, a cooling tower sized to cool 4540 CMH through a 13.9°C range might be larger than a cooling tower to cool 4540 CMH through 19.5°C range. Range is determined not by the cooling tower but by the heat exchanger it is serving. The range at the exchanger is determined entirely by he heat load and the water circulation rate through the exchanger and on to the cooling water. **Here, Range °C = Heat Load in kCals/hour / Water Circulation Rate in LPH** It is obvious that the range is not a function of the flow cooling tower but is a function of the cooling tower but is a function of the heat load and the flow circulated through the system.
L2.	From the given cooling tower parameters, evaluate the following: i) Make up water requirement per day ii) Evaporation loss iii) Blow down loss Cooling water temperature : 1260 m^3/h Outlet water temperature : 32 °C Drift losses : 0.1 % No. of concentrating cycles : 3

	Estimation of cooling tower losses: a) Drift loss : 0.1% b) Evaporation loss : Range (temp. difference, °C) x 100/675 : $\frac{(37-32)}{675} x100 = 0.74\%$ c) Blow down loss : Evaporation loss/(No. of concentrating cycle-1) : $\left(\frac{0.74}{3-1}\right) = 0.37\%$ Total make up water requirement : 0.1 + 0.74 + 0.37 = 1.21% Cooling water circulation rate : 1260 m^3/h Make up water requirement : 1260 x 0.0121 = 15.2 m^3/h :364.8 m^3/day
L3.	What is the effect of change in heat load on cooling tower performance? Explain. The heat load imposed on a cooling tower is determined by the process being served. The degree of cooling required is controlled by the desired operating temperature level of the process. In most cases, a low operating temperature is desirable to increase process efficiency or to improve the quality or quantity of the product. In some applications (e.g. internal combustion engines), however, high operating temperatures are desirable. The size and cost of the cooling tower is proportional to the heat load. If heat load calculations are low undersized equipment will be purchased. If the calculated load is high, oversize and more costly, equipment will result. Process heat loads may vary considerably and are dependent upon and peculiar to the process involved. Determination of accurate process heat loads can become very complex but proper consideration can produce satisfactory results. On the other hand, air conditioning and refrigeration head loads can be determined with greater accuracy. Dependable information has been developed for the heat rejection requirements of various types of power equipment. A sample list is as follows: * Air Compressor with two-stage intercooler and after cooler - 862 kcal/kW/hr * Refrigeration, Compression - 63 kcal/min/ton * Refrigeration, Absorption - 127 kcal/min/ton * Steam Turbine Condenser - 555 kcal/kg of steam * Diesel Engine, Four-Cycle, Supercharged - 880 kcal/kW/hr
L4.	Write about the importance of wet bulb temperature in cooling towers? Wet bulb temperature is an important factor in performance of evaporative water cooling equipment. It is a controlling factor from the aspect of minimum cold water temperature to which water can be cooled by the evaporative method. The wet bulb temperature of the air entering the cooling water determines operating temperature

	levels throughout the plant, process or system. Initial selection of towers w.r.t design wet bulb temperature must be made on the basis of conditions existing at the lower side. The temperature selected is generally close to the average maximum wet bulb for the summer months.
I.5.	Why air conditioning and refrigeration heat loads have to determine with greater accuracy in case of cooling towers? Air conditioning and refrigeration equipment are sensitive comparative to other cooling loads. It is vitally important to have the cold water temperature low enough to exchange heat or to condense vapours at the optimum temperature level. A 1 °C cooling water temperature increase may increase A/C compressor power consumption (kW) by 2.75. To achieve the lower power consumption of A/C compressors ensure that inlet cooling water temperature to be the lowest as possible. It is better to isolate cooling towers of high heat loads like furnaces, air compressors, DG sets from refrigeration cooling towers to maintain lowest possible cooling water temperature.

Chapter 3.8: Lighting System

Part-I: Objective type questions and answers

1.	GLS stands for____. a) General Lamp source b) General Lamp Service c) General Lighting Service d) General Lighting Source
2.	A device that distributes and filters the light emitted from one or more lamps is ___. a) Control gear b) Lamp c) Luminaire d) Starter
3.	Ignitors are used for starting___. a) FTL b) CFL c) Sodium vapor lamps d) None of the above
4.	The ratio of luminous flux emitted by a lamp to the power consumed by the lamp is ___. a) Illuminace b) Lux c) Luminous Efficacy d) CRI
5.	Which of the following is the best definition of illuminance? a) Time rate of flow of light energy b) Luminous flux incident on an object per unit area c) Flux density emitted from an object without regard for direction d) Flux density emitted from an object in a given direction
6.	Color rendering index is measured in the scale of___. a) 1 – 100 b) 1 – 100% c) 100 – 1000 d) None
7.	Color rendering index of Halogen lamps compared to low pressure sodium vapor lamps is ___. a) Poor b) Excellent c) Average d) Very poor
8.	One lux is equal to ___. a) one lumen per meter b) one lumen per m^3 c) one lumen per m^2 d) None
9.	Color rendering index of incandescent lamp is: a) fair when compared to HPSV lamp b) poor when compared to LPSV lamp c) same when compared to HPMV lamp d) excellent when compared to fluorescent lamp

10.	Which of the following light source has least life? a) Sodium vapor b) Mercury Vapour c) Halogen <u>d) incandescent</u>
11.	The minimum illuminance required for non working interiors as per IS 3646 is___. a) 100 lux b) 50 lux <u>c) 20 lux</u> d) 1000 lux
12.	For the same lamp output, 250 W HPMV lamp can be replaced with____. <u>a) 150 W HPSV</u> b) 200 W GLS c) 25 W CFL d) 150 W HPMV
13.	If voltage is reduced for gas discharge lamps, it will result in a) <u>Reduced power consumption</u> b) Increased power consumption c) Increased light levels d) No change in power consumption
14.	The percentage savings when a 300 W GLS lamp replaced with 250 W ML lamp are: a) 83% b) <u>17%</u> c) 9% d) None of the above
15.	The average rated life of CFL is___ a) 5,000 hours b) <u>10,000 hours</u> c) 7,000 hours d) 1,000 hours
16.	Suitable lamp sources for the application of street lighting are____ a) halogen lamps <u>b) HPSV</u> c) HPMV d) Incandescent
17.	Low bay application areas are classified for heights____ a) Between 5 -7 m <u>b) less than 5 m</u> c) Above 10 m d) Less than 1 m
18.	Replacing a 400 W HPMV with 250 V HPSV lamp in street lighting operate for 4000 hours per annum will result in annual energy savings of: <u>a) 600 kWh</u> b) 300 kWh c) 150 kWh d) 1000 kWh
19.	What is the typical frequency of operation of electronic ballast? a) 50 Hz b) 10 kHz c) 50 kHz <u>d) 30 kHz</u>
20.	Which of the following options reduces the lighting consumption in the wide spread plant? a) Replacing 150 W HPSV lamps with 250 W HPMV lamps b) Maintaining 260 V for the lighting circuit with 220 V rated lamps c) <u>Installing separate lighting transformer and maintaining optimum voltage</u> d) None of the above

21.	Luminous efficacy of which of the following is the highest? a) CFL b) HPMV c) HPSV d) LPSV

Part-II: Short type questions and answers

S1.	What is a lamp and describe briefly the most commonly used lamps? Lamp is equipment which produces light. Lamps that are commonly used are: Incandescent, gas discharge lamps, include mercury, metal halide and high pressure sodium, low pressure sodium and fluorescent lights.
S2.	What is the difference between a 'filament lamp' and a 'gas discharge lamp'? Filament lamps like incandescent lamps produce light by virtue of a filament heated to incandescence by the flow of electric current through it. The light from a gas discharge lamp is not produced by heating a filament, but by the excitation of gas contained in either a tubular or elliptical outer bulb.
S3.	What is the function of Luminaire in a lighting system? Luminaire is a device that distributes filters or transforms the light emitted from one or more lamps.
S4.	What does a luminaire consists of? Luminaire or light fixture consists of the following components: - Lamps, - Lamp socket, - Ballasts, - Reflective material, - Lenses, refractors or louvers, - housings
S5.	Define Lux (lx)? Lux (lx) is the illuminance produced by a luminous flux of one lux, uniformly distributed over a surface area of one square meter. It is also defined as the International System unit of illumination, equal to one lumen per square meter.
S6.	Define luminous efficacy? Luminous efficacy is defined as the ratio of luminous flux emitted by a lamp to the power consumed by the lamp. Efficacy is energy efficiency of conversion from electricity to light form.
S7.	What is "Colour Rendering Index (CRI)" in lighting technology? Colour Rendering Index (CRI) is a measure of the degree to which the colours of surfaces illuminated by a given light source confirm to those of the same surfaces under a reference illuminent; suitable allowance having been made for the state of Chromatic adaptation.

S8.	What should be the criteria for selecting energy efficient lamps replacement options? The lamp efficacy i.e., the ratio of light output in lumens to power input to lamps in watts should form the basis for energy efficient replacement options. Over the years development in lamp technology has led to improvements in efficacy of lamps. However, the low efficacy lamps, such as incandescent bulbs, still constitute a major share of the lighting load. High efficacy gas discharge lamps suitable for different types of applications offer appreciable scope for energy conservation.
S9.	Highlight advantages of CFL lamp (compact fluorescent lamp) over incandescent lamps? CFL lamps are generally used as replacement for incandescent lamps. The following are the advantages of CFL lamps over incandescent lamps: a. Higher illumination level (55-65 lm/watt) b. Longer life (typically 10,000 hours), c. Higher energy savings and hence cost savings (nearly 80% saving), d. less heat generation
S10.	What are the main disadvantages of 'filament lamps' for panel indicator lamp application? • Comparatively high energy consumption (15 W/lamp) than 'LED lamps' • Failure of lamps is high • Very sensitive to voltage fluctuations
S11.	What are the merits of 'LED lamps' over 'filament lamps'? • Less power consumption (less than 1Watt/lamp) • Withstand high voltage fluctuation in the power supply • Longer operating life (more than 100000 hours)
S12.	How 'good lighting distribution' can be achieved in a plant? For achieving better efficiency, luminaires that are having light distribution characteristics appropriate for the task interior should be selected. The luminaires fitted with a lamp should ensure that discomfort glare and veiling reflections are minimised. Installation of suitable luminaires depends upon the height - Low, Medium & High Bay. System layout and fixing of the luminaires play a major role in achieving energy efficiency. This also varies from application to application. Hence, fixing the luminaires at optimum height and usage of mirror optic luminaries leads to energy efficiency.

S13.	Highlight various ways of how the light can be controlled efficiently in a facility? Various ways of light control techniques available in a facility are: • Grouping of lighting circuits which can be controlled manually or timer based control • Installation of microprocessor based controllers with occupancy sensors, infrared sensors, movement detectors • Optimum usage of day-lighting and photovoltaic controls • Installation of exclusive transformer for lighting • Installation of servo stabilizer for lighting feeder
S14.	What are the advantages of installing microprocessor based controllers for lighting circuit? A new method of lighting circuit controls through microprocessor based controllers is becoming popular. This is achieved by infrared controlled dimming, use of movement detectors, occupancy sensors, to feed signals to control ON & OFF of lighting circuits. This method of control uses pre-programmed commands using logic circuits.
S15.	Describe the advantages of providing transformer exclusively for lighting? Most of the problems faced by the lighting equipment and the gears are due to the supply voltage fluctuations. Hence, the lighting equipments have to be isolated from the power feeders. This is carried out by installing lighting voltage transformers, which regulate the voltage exclusively for lighting circuits. This reduces the voltage related problems in turn increasing the efficiency of the lighting system. This also results in energy saving during the periods when the supply voltage levels are on higher side. In addition, it increases the life and performance of the control gear units of the lamps due to better voltage regulation.
S16.	Give a short note on utilization of 'Day lighting'? Whenever the orientation of a building permits, day lighting can be used in combination with electric lighting. This should not introduce glare or a severe imbalance of brightness in visual environment. Usage of day lighting (in offices / air conditioned halls) will have to be very limited, because the air conditioning load will increase on account of the increased solar heat dissipation into the area. In many cases, a switching method, to enable reduction of electric light in the window zones during certain hours has to be designed.
S18.	What are the advantages of installing a 'servo stabilizer' for lighting circuits? Installation of a 'servo stabilizer' provides a stabilized voltage to the lighting circuits. The performance of the gears such as chokes, ballasts, will be improved due to the stabilized voltage. This set up also provides, the option to optimize the voltage level fed to the lighting feeder. In many plants, during the non peaking hours, the voltage levels are on the higher side. During this period, voltage can be optimized, without any significant drops in illumination but at

	reduced power consumption.
S19.	What do you understand by illumination ranges given in IS 3646? A range of illuminances is recommended for each type of interior or activity. Each range consists of three successive steps of the recommended scale of illuminances. For working interiors the middle value (R) of each range represents the recommended service illuminance that would be used unless one or more of the factors mentioned apply. The higher value (H) of the range should be used at exceptional cases where low reflectance's or contrast are present in the task, errors are costly to rectify, visual work is critical, accuracy or higher productivity is of great importance and the visual capacity of the worker makes it necessary. Similarly, lower value (L) of the range may be used when reflectance's or contrast is unusually high, speed & accuracy is not important and the task is executed only occasionally.
S20.	Highlight the advantages of high frequency (HF) electronic ballasts in place of conventional ballasts? • Electromagnetic chokes consume more energy compared to electronic chokes. • Less heat generation, hence reduced loading on A/c (in A/C rooms). • Lights instantly • Improved power factor • Less weight, • Increased lamp life
S21.	Describe briefly the advantage of replacing a typical 250W HPMV with suitable HPSV lamp for street lighting purpose? 150 watt high pressure sodium vapour lamp can be used to a 250 watt mercury vapour lamp for street lighting purpose. A 250 watt mercury vapour lamp produces 12700 lumens output, where as a 150 watt H.P. sodium vapour lamp produces 15000 lumens output. A HPSV lamp can produce more lumens output with 100 watt less power consumption, though colour rendering index is not as good as a mercury vapour lamp. 250W HPMW lamp has around 5000 hours of burning life while 150W HPSV has about 12000 hours of burning life.

Part-III: Long type questions and answers

L1.	List all the possible energy conservation measures possible in lighting system? Following are the possible energy conservation measures possible in lighting system: a. Use of natural day lighting, b. Use of electronic chokes instead of conventional electromagnetic ballasts, c. Use of 36 watt slim tubes instead of 40 watt standard fluorescent tube lamps, d. Use of CFL lamps instead of GLS lamps with e-chokes, e. Use of 250w, 150w, 70w sodium vapour / metal halide lamps to replace 400w, 250w, 125w mercury vapour lamps, f. Use of electronic chokes for HPSV, HPMV and metal halide lamps, g. Use of lighting voltage transformers for lighting circuits. h. Use of timer control or photo-sensors for lighting circuit control for occupancy control and street lighting purposes, i. Use of dimming controls, j. Use of high reflectivity light fittings, k. Use of task lamps instead of cluster of lamps, l. Individual lamp controls instead of group switching, etc.
L2.	Describe the step by step methodology of lighting system audit in a plant? Improvement option in lighting at any facility would involve following step by step approach: a. Step-1: Inventorise the lighting system elements with respect to device rating, population & use profile. b. Step-2: Measure and document lux levels at various plan locations at working place, at day time and night times w.r.t lamps ON or OFF during the said period. c. Step-3: Use a portable load analyzer to measure and document the voltage and power consumption profile at various lighting load distribution panels d. Step-4: Compare the measured lux values with standard values and identify locations of under-lit and over-lit areas e. Step-5: Analysis of failure rates of lamps, ballasts and actual life expectancy levels from the past data. f. Step-6: Based on above careful assessment has to be carried out along with energy saving potential, investment required and payback calculations.
L3.	Compare the techno-economics of replacing 400 W HPMV lamps with 250 W HPSV, 250 W HPMV with 150 W HPSV and 125 W HPMV with 70 W HPSV lamps for same light output for 4500 hours of annual operation and consider PKR. 4.5 as

per unit cost?

A 400 watt HPMV lamp can be replaced by a 250 watt HPSV or metal halide lamp without any change in light output (though color rendering effect may be different). Similarly 250 watt & 125 watt HPMV lamps can be replaced by 150 watt & 70 watt HPSV / metal halide lamps. Savings due to these replacements are worked out below considering 4500 hrs of operation at PKR.4.50 per unit of energy.

	Replacement of HPMV with HPSV / MH lamp		
	400 W to 250 W	250 W to 150 W	125 W to 70 W
Power savings per lamp	150W	100W	55W
Energy savings per lamp per annum (excluding ballast loss savings)	675 kWh	450 kWh	247.5 kWh
Energy cost saving per lamp per annum	PKR.3,037.50	PKR.2,025.00	PKR.1,113.75
Simple pay back period	Less than 1 to 2 years, though MH lamps are costlier compared to HPSV lamps		

L4. Compare the efficacy, colour rendering index and life of generally used lamps in the industry. Also state the typical applications of the same.

Type of Lamp	Lux / Watt		Color Rendering Index	Typical Application	Life (Hours)
	Range	**Avg.**			
Incandescent	8-18	14	Excellent	Homes, restaurants, general lighting, emergency lighting	1000
Fluorescent Lamps	46-60	50	Good w.r.t. coating	Offices, shops, hospitals, homes	5000
Compact fluorescent lamps (CFL)	40-70	60	Very good	Hotels, shops, homes, offices	8000-10000
High pressure mercury (HPMV)	44-57	50	Fair	General lighting in factories, garages, car parking, flood lighting	5000
Halogen lamps	18-24	20	Excellent	Display, flood lighting, stadium exhibition grounds, construction areas	2000-4000

High pressure sodium (HPSV) SON	67-121	90	Fair	General lighting in factories, ware houses, street lighting	6000-12000
Low pressure sodium (LPSV) SOX	101-175	150	Poor	Roadways, tunnels, canals, street lighting	6000-12000

L5. Tabulate the types of luminaries with their gear and controls used in different industrial locations?

Location	Source	Luminaire	Gear	Controls
Plant	HID/FTL	Industrial rail reflector: High bay Medium bay Low bay	Conventional/low loss electronic ballast	Manual/electronic
Office	FTL/CFL	FTL/CFL	Electronic/low loss	Manual/auto
Yard	HID	Flood light	Suitable	Manual
Road peripheral	HID/PL	Street light luminaire	Suitable	Manual

Chapter 9 Energy Conservation in Buildings

Part-I: Objective type Questions and Answers

1.	How climatic zone does the Pakistan divided? a) 4 Zones, b) 5 Zones c) 3 Zones d) 6 Zones.
2.	As per Pakistan ECBC norms, allowable conductance value in all 5 zones is lowest for: a) Wall b)Roof c) Shaded roof d)Floor unheated space
3.	The Equivalent Temperature Difference concept takes into account the location and orientation of the building. True or False?
4.	Minimum open-able window area for natural ventilation in residential space should be: a) 100% b) 75% c) 85% d) 50%
5.	As per ECBC norms, recommended internal dry bulb temperature for summers shall be: a) 24°C b) 25°C c) 26°C d)27°C

Part-II: Short type questions and answers

S1.	What is Energy Conservation Building Codes? Ans) ECBC sets minimum energy efficiency standards for design and construction of new buildings so that, it does not constrain the building function, comfort, health, or the productivity of the occupants has appropriate regard for economic considerations.
S2.	What does OTTV means? Ans) The cooling design criterion for walls, floors and roof/ceilings is known as the Overall Thermal Transfer Value (OTTV).

Part-III: Long type questions and answers

L1.	What are ECBC Impact Energy codes? Ans A) Promote market development for EE products • Building Insulation • Energy Efficient Windows (Glass and Frames) • High-Efficiency HVAC Equipment • Solar Water Heater A) Promote Improved Design Practices for

	• Lighting and Day lighting • Natural Ventilation/Free-Cooling Systems B) Promote Improved Performance of Energy use.
L2.	What are ECBC scope components of the Building? Ans ECBC - Building components included • Building Envelope (Walls, Roofs, Windows) • Lighting (Indoor and Outdoor) • Heating Ventilation and Air Conditioning (HVAC) System • Solar Water Heating and Pumping • Electrical Systems (Power Factor, Transformers)
L3.	What are the ECBC Guidelines on Building Envelope? Ans) The ECBC guidelines on building envelope provide the minimum energy conservation requirements for the building envelope. In addition to the criteria set forth in this section, the proposed design should consider energy conservation in determining the orientation of the building on its site; the geometric shape of the buildings: the building aspect ratio (ratio of length to width); the number of stories for a given floor area requirement; the thermal mass of the building; the exterior surface color; shading or reflections from adjacent structures, surrounding surfaces or vegetation; opportunities for natural ventilation: and wind direction and speed.
L4.	What is value of the Overall Thermal Transfer Value (OTTV) at different climatic zone in Pakistan? Ans) For the purpose of energy conservation, the maximum permissible OTTV shall be as per Table in below, for walls and ceilings/roofs. Maximum Overall Thermal Transfer Values

CLIMATE ZONE*	WALLS		ROOFS	
	W/m^2	$Btu/hr.ft^2$	W/m^2	$Btu/hr.ft^2$
1	91	29	26.8	8.5
2	95	30	26.8	8.5
3	95	30	26.8	8.5
4	98	31	26.8	8.5
5	101	32	26.8	8.5

L5.	What are Solar factor value for vertical surfaces for Pakistan? Ans) The solar factor value for vertical surfaces for Pakistan should be taken as

	specified in Table below. For a given orientation the solar factor may be taken from the following:

Solar factors for Walls and Roofs W/m^2 (Btu/hFt^2)

	Orientation					
Climate Zone		NE	E	SE		
	N	NW	W	SW	S	Roof
1	117	450	561	350	135	471
	(37)	(143)	(178)	(111)	(43)	(150)
2	110	432	561	378	167	471
	(35)	(137)	(178)	(120)	(53)	(150)
3	110	432	561	378	167	471
	(35)	(137)	(178)	(120)	(53)	(150)
4	104	422	558	410	217	471
	(33)	(134)	(177)	(130)	(69)	(150)
5	104	416	558	425	252	471
	(33)	(132)	(177)	(135)	(80)	(150)

L6. What does OTTV concept based ?

Ans) The OTTV concept is based on the three basic methods of heat gains through envelop of a building

(a) Heat conduction through opaque walls, roofs/ceiling and floor
(b) Heat conduction through windows and/or skylights
(c) Solar radiation through windows and/or skylights.

Chapter 4.1 Energy Performance Assessment in Thermal Power Plants

Long Type Questions & Answers

L1. A coal based power plant A is having a Gross Unit Heat Rate of 2400 kCal/kWh with Auxiliary power consumption of 8 % whereas Plant B of same size and make, has an operating Net Heat Rate of 2500 kCal/kWh. In your opinion, which plant is more efficient and why?

Ans: Gross Heat Rate of Plant A – 2400 kcal/kwh
Auxiliary Power Consumption – 8%
Net Heat Rate of Plant A = Gross Heat Rate/(100- APC)
= 2400/(1-0.08)
= 2608.70 kcal/kwh
Therefore, Plant B is more efficient with a lower Net Heat Rate of 2500 kcal/kwh than that of Plant A (2608.70 kcal/kwh).

L2. A 60 MW captive power plant (CPP) of a chemical plant has a coal fired Boiler, condensing steam Turbine and Generator. The CPP after meeting its auxiliary power consumption is exporting power to the chemical plant. The operating data of CPP is as follows:

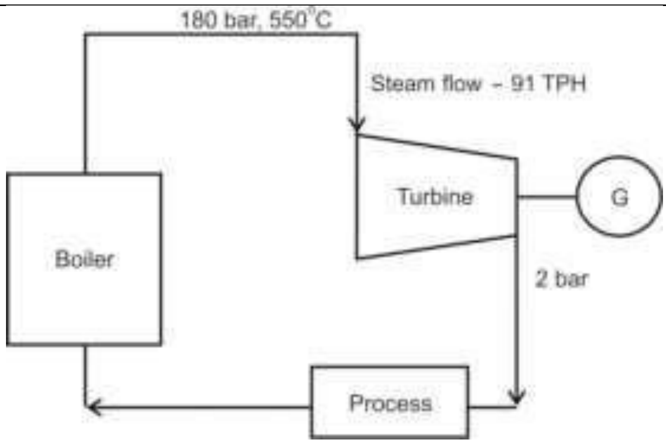
Generator output	: 60 MW
Auxiliary power consumption	: 6 MW
Steam flow to the turbine	: 231 Tons/hr
Steam inlet pressure and temperature	: 105 kg/cm2 (a) and $480^{o}C$
Enthalpy of inlet steam at operating pressure and temperature	: 793 kCal/kg
Enthalpy of feed water to boiler	: 130 kCal/kg
Condenser exhaust steam pressure and temperature	: 0.1 kg/cm2(a) and $45.5^{0}C$
Enthalpy of water at operating pressure and temperature of condenser	: 45.5 kCal/kg
Latent heat of vaporisation of steam at operating pressure and temperature of condenser	: 571.6 kCal/kg
Enthalpy of exhaust steam	: 554 kCal/kg
GCV of coal used	: 4240 kCal/kg
Efficiency of the boiler	: 86.5 %

Based on the above data, calculate the following parameters of the power plant:
a) Gross Heat Rate
b) Net Heat Rate
c) Dryness fraction of exhaust steam
d) Condenser heat load
e) Specific coal consumption
f) Overall efficiency

Ans: **(a) Gross heat rate**
Gross heat rate= Coal consumption (kg/hr) x GCV of coal (kcal/kg) ...(1)
Generator output (kw)

Given : Coal consumption=?
GCV of coal=4240 Kcal/kg
Generator output= 60 MW
Boiler efficiency= Q (H-h)/ (q x GCV) --------------(2)

	Where, Q= Quantity of steam generation (kg/hr)=231x1000 H= Enthalpy of steam (Kcal/kg) =793 h=Enthalpy of boiler feed water (kcal/kg) =130 q=Coal consumption (kg/hr) =? Boiler efficiency=0.865 Substituting the given values in equation (2) we get, 0.865=(231 x 1000 x (793—130))/q x 4240 q= 41758 kg/hr **OR** Substituting the calculated value of q in equation (1) we get, **Gross heat rate= (41758 x 4240) / (60x1000) =2950.9 kcal /kWh** **(b) Net heat rate** Net heat rate = Gross heat rate/(1-APC%) ---------(3) Auxiliary consumption =6 MW Generation= 60 MW % Auxiliary consumption=(6/60) x 100 = 10% Substituting the values in the equation (3) we get, **Net heat rate= 2950.9/(1—10/100)= 3278.8 kCal/kWh** **(C) Dryness fraction of exhaust steam** Enthalpy of exhaust steam = Enthalpy of feed water + Dryness fraction of steam x L.H. of vaporisation of steam Substituting the given values in the above, we get 554= 45.5+ dryness fraction of steam x 571.6 **Dryness fraction of steam= (554—45.5)/571.6 = 0.889** **(d) Condenser heat load** Heat load on condenser= Steam flow rate x L.H of vaporisation of steam x dryness fraction of steam = 231x 1000 x 571.6 x 0.889 **=117383.2 MCal/hr** **(e) Calculation of specific coal consumption** Specific coal consumption = Total coal consumption/Gross generation = 41758 kg/hr / (60 x 1000) kW **= 0.696 kg/kWh** **(f) Calculation of overall efficiency of plant** Overall efficiency= 860/Gross heat rate, kCal/kWh ----------------------(4) Substituting the values we get**, 860/2950.9 =29.14%** **(OR)** Overall efficiency = (Generator Output, kW x 860 kCal/kWh) /(Mass flow rate of coal kg/hr x GCV of coal,kCal/kg) = (60 x 1000 x 860)/(41758 x 4240) **=29.14%**
L3.	The schematic and operating data of a steam turbine cogeneration plant with a back pressure turbine is given below.



Enthalpy of steam at 180 bar, 550 0C – 3420 kJ/kg
Exhaust steam enthalpy at isentropic expansion from 180 bar to 2 bar – 2430 kJ/kg
Enthalpy of boiler feed water – 504.7 kJ/kg
Efficiency of boiler - 80 %
Calorific value of coal – 4500 kcal/kg
Steam flow rate into the Turbine - 91 TPH
Turbine isentropic efficiency - 90 %
Generator efficiency - 98 %
Gear box efficiency - 97 %
Calculate:
a) Electrical output from the generator in MW
b) Fuel consumption in Boiler in TPH
c) Energy Utilization factor of the cogeneration plant
d) Heat to power ratio of the cogeneration plant, kCal/kW

Ans:
a) Electrical output from the generator in MW
Actual exhaust steam enthalpy
= [3420 - (0.9 x (3420 - 2430))]
= 2529 kJ/kg
Turbine power output
= 1 x (1000/3600)) x (3420 - 2529)]/1000
= 22.52 MW
Electrical output
= (22.52 x 0.97 x 0.98)
= 21.4 MW

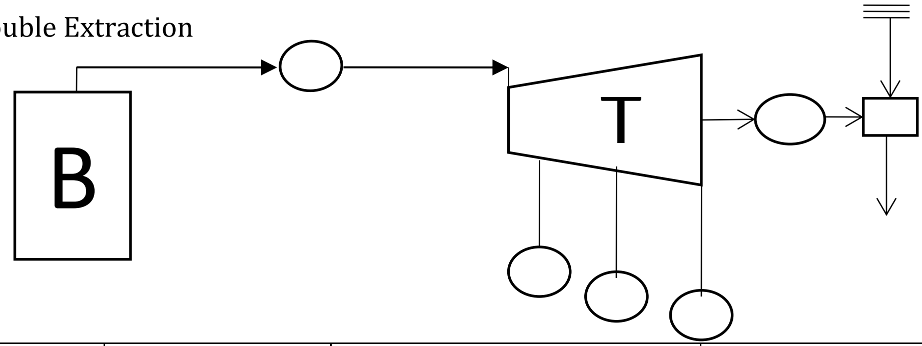
b) Fuel consumption in Boiler in TPH
Fuel consumption in Boiler
= (91,000 x (3420 – 504.7)) / (4.18 x 4500 x 0.80)
= 17.6 TPH

c) Energy Utilization factor of the cogeneration plant
= [(21,400 x 860) + (91000 x ((2529 – 504.7)/ 4.18))] / (17,600 x 4500)
= [(1,84,04,000 + 44069689) / (7,92,00,000)]
= 0.79

d) Heat to power ratio of the cogeneration plant, kCal/kW
Heat to power ratio, kcal/kW = (91000 x (2529 - 504.7)/4.18) / 21400
= 2059 kCal/kWh (or)
= 2.39 kW thermal/kW electrical

L4. In a continuous process industry Steam and Power are supplied through a cogeneration plant interconnected with grid. The design and actual operating parameters of the cogeneration plant as represented in the schematic are given in the table below.

Double Extraction – Condensing Steam Turbine Cogeneration System



		Design	actual
B -	Boiler	75tph,64kg/cm^2(a), 450^{o}C @82% efficiency	68.75tph, 64kg/cm^2(a), 450^{o}C @81% efficiency
T -	Steam Turbine	Double Extraction – Condensing type	
G -	Generator	10MW	7.2MW

Stream Ref	**Steam flow location**	**Steam Flow (tph)**	**Steam Pressure (kg/cm^2)**	**Steam Temp (^{o}C)**	**Steam enthalpy (kCal/kg)**
1	Steam input to turbine	68.75	64	450	745
2	First extraction	18.75	17	270	697
3	Second extraction	31.25	9	200	673
4	Condenser in	18.75	0.1	-	550
	Condenser out	18.75	-	-	46

The industry is installing a 1200 TR double effect absorption chiller to meet the refrigeration load due to product diversification. Additional steam will be generated by the boiler, which will go into the turbine and be extracted at 9kg/cm^2(a) to meet the VAM requirement. The additional power thus generated will reduce the imported grid power.

The following additional data has been provided:

Maximum allowable steam flow the extraction at 9 Kg/cm^{2}a	40 TPH
Minimum allowable steam to condenser	9 TPH
Critical power requirement of the plant	3800 KW

Power import from grid	500 KW
Cost of grid power	Rs.4.25 / Kwh
G.C.V. of coal	4000 Kcal/Kg.
Cost of coal	Rs. 4000/ton
Feed Water temperature	105°C
Feed Water enthalpy	105 Kcal/Kg.
Combined efficiency of gear box and generator	96%
Steam requirement for double effect absorption chiller	4.5 Kg./TR hr at 9 Kg/cm²a
Annual hours of operation.	8000 hrs/y
Steam rate at 9 Kg/cm²a at 2nd extraction for 1 KW turbine output	12 (Kg/hr)/kW

Ignore auxiliary power consumption and also return condensate from extracted steam to process.

Calculate

(i) The Energy Utilization Factor (EUF) for the existing operating case

(ii) The net additional annual operating cost, after installation of VAM.

The Energy Utilization Factor (EUF) after installation of VAM.

Ans:

(i)

Energy Utilization Factor (EUF) (before VAM installation) $= \dfrac{\text{Q thermal + P electrical}}{\text{Fuel Consumption X G.C.V.}}$

Q thermal $= m_2 h_2 + m_3 h_3 + m_4 h'_4$

Q in $= \dfrac{m (h_1 - h_f)}{\eta \text{ X G.C.V.}}$

Q thermal = 18750 X 697 + 31250 X 673 + 18750 X 46

= (18.75 X 697 + 31.25 X 673 + 18.75 X 46) X 10^3 Kcal/hr

= (13068 X 21031 + 862.5) X 10^3 Kcal/hr

= 34962.5 X 10^3 Kcal/hr

P_e = 7200 X 860

= 6192 X 10^3 Kcal/hr

Fuel Consumption $= \dfrac{(745 - 105) \text{ X } 68.750\text{x}1000}{0.81\text{X } 4000 \text{ X } 1000} = 13.58$ TPH

EUF $= \dfrac{34962.5 \text{ X } 10^3 + 6192 \text{ X } 10^3}{13.58 \text{ X } 10^3 \text{ X } 4000} \text{ -x } 100 = 75.76\%$

(iii) Refrigeration Load = 1200 TR

1TR requires 4.5 Kg./hr steam at 9 Kg./cm^2a
Steam consumption in double effect absorption chiller = 1200 X 4.5
= 5400 Kg./hr.
Increase in steam extraction at 9 Kg./ cm^2a = 5400Kg/hr

Every 12 Kg./hr extraction at 9 kg/ cm^2a gives 1 KW output at turbine ,efficiency of generator and gear box = 0.96

Additional power recovery due to increase in extraction = (5400 / 12) X 0.96
= 432 KW

Additional coal consumption due to increase in extraction

= (745 – 105)X 5400/(0.81x4000) = 1066 kg/h
Additional cost of coal = 4000x1.066 = Rs 4266.6 /hr
Monetary realisation by reducing import cost of purchased electricity = 4.25 Rs./unit
= 432 X 4.25
= 1836 Rs./hr
Net additional annual operating cost after VAM installation= (4266.6-1836)*8000
= Rs 1.94 crore/y

(iii)

Stream Ref	Steam flow location	Steam Flow (tph)	Steam Pressure (kg/cm^2)	Steam Temp (^oC)	Steam enthalpy (kCal/kg)
1	Steam input to turbine	68.75+5.4 =74.15	64	450	745
2	First extraction	18.75	17	270	697
3	Second extraction	31.25+5.4 =36.65	9	200	673
4	Condenser in	18.75	0.1	-	550
	Condenser out	18.75	-	-	46

Energy Utilization Factor (EUF)= $\dfrac{\text{Q thermal + P electrical}}{\text{Fuel Consumption X G.C.V.}}$
(after VAM installation)

Q thermal = $m_2 h_2 + m_3 h_3 + m_4 h'_4$

Q in = $\dfrac{m (h_1 - h_f)}{\eta \text{ X G.C.V.}}$

	Q thermal = 18750 X 697 + 36650 X 673 + 18750 X 46 =(18.75 X 697 + 36.65 X 673 + 18.75 X 46) X 10^3 Kcal/hr =(13068 X 21031 + 862.5) X 10^3 Kcal/hr =38596.7 X 10^3 Kcal/hr P_e =(7200+432) X 860 =6563.5 X 10^3 Kcal/hr Fuel Consumption = 13.58 TPH +1.066 TPH = 14.646TPH $$EUF = \frac{38596.7 \times 10^3 + 6563.5 \times 10^3}{14.646 \times 10^3 \times 4000} \times 100 = 77.08\%$$
L5.	A utility type captive thermal power plant of 65 MW is generating an output of 60 MW at the generator. Steam generated in the boiler at 105 kg/cm^2(a) and 510°C is expanded in the steam turbine exhausting to condenser maintained at 0.1 kg/cm^2a and 45.5°C. The cooling water flow rate through the condenser is 166m^3 per min. The other operating data and particulars are, Enthalpy of steam at 105 kg/cm^2a & 510°C = 805 Kcal/kg. Enthalpy of steam at turbine outlet = 565 Kcal/Kg. Enthalpy of water at condenser pressure 0.1 kg/cm^2a &at 45.5°C = 45.5 Kcal/Kg. Inlet/outlet temperature of cooling water at the condenser =26°C/38°C The efficiency of the generator = 97% Enthalpy of saturated steam at 10kg/cm^2a = 665 Kcal/Kg. Based on the above, find out, a. Heat load on the condenser in million kcal/hr b. Output of the steam turbine in KW c. Loss in the gear box in KW d. Condense effectiveness e. DM water at 135°C to be sprayed for desuperheating of boiler steam after pressure reduction to 10 kg/cm^2a required for auxiliary service in kgs/tonne steam Ans: a. Heat load on the condenser = 166 x 60 x 1000(38-26)/1000000 **= 119.52 million kcal/hr** b. Inlet enthalpy of steam to condenser = outlet enthalpy of steam from turbine Steam flowrate through the turbine = 119.52x 1000000/(565-45.5) = 230000 kg/hr = 230.0 tonne/hr Inlet enthalpy to turbine = 805 kcal/kg **Steam turbine out put** = 230000 x (805-565) **= 64186.00 KW** c. Generator output = 60000.0 KW Generator efficiency = 97% Generator input = 60000.00 / 0.97 = 6I,856.00 KW **Loss in gear box** = 64186 .00 – 61856.00 **= 2330.00 kW**

	d. Cooling water inlet temperature = 26°C Cooling water outlet temperature = 38°C Inlet steam temperature to condenser = 45.5°C . . . Condenser effectiveness i.e. € = = (Cooling water temp. rise) / (Inlet steam temp. to condenser – inlet cooling water temp.) = (38 – 26) / (45.5 – 26)= 0.615 e. Quantity of DM water to be sprayed for de-superheating ms = mass of high pressure superheated steam mw= mass of DM water to be sprayed ms x 805 + mw x 135 = (ms + mw) x 665 Enthalpy of 105 kg/cm²a, 510°C superheated steam 805 kcal/kg Enthalpy of saturated steam at 10 kg/cm²a 665 kcal/kg Enthalpy of DM water at 135°C = 135 kcal/kg assumed ms (805 – 665) = mw (665 – 135) mw / ms = (805 – 665) /(665 – 135) = 0.264 kg water / kg steam **= 264 kg water/ tonne steam**

Chapter 4.2 Energy Performance Assessment in Thermal Power Plants

Long Type Questions & Answers

L1. In a cement kiln producing 4500 TPD of clinker output, the grate cooler hot exhaust air is vented to atmosphere at temperature of 275°C. It is proposed to generate hot water from this waste exhaust for operating a Vapour Absorption Machine(VAM)chiller. This will replace the existing Vapour Compression Chiller (VCR) of 50 TR capacity used for air-conditioning of control rooms and office buildings.

The following are the data:

- Diameter of the cooler vent : 2 m
- Velocity of cooler exhaust air : 18.6 m/s
- Density of cooler exhaust air at 275°C : 0.64 kg / m^3
- Existing VCR Chiller Specific power consumption : 0.9 kW/TR
- Existing VCR condenser water pump power consumption : 2.8 kW
- Investment towards 50TR VAM & its associated system :PKR 6 million
- CoP of VAM system : 0.75
- Power consumption of VAM auxillaries: 2.83 kW
- Temperature of circulating hot water of VAM generator: Inlet - 90°C; outlet - 80°C
- Specific heat of exhaust cooler air : 0.24 kcal/ kg°C
- The efficiency of all pumps and their drive motors are 75% & 90% respectively.
- The cost of electricity :PKR 10/kWh
- No of hours of operation : 8000 hrs/ yr

Calculate

a) Cooler Exhaust air temperature after heat recovery

b) Payback period by replacement of VCR by VAM

Ans:

a) Cooler Exhaust air temperature after heat recovery

Area of the duct= 3.14 x (2^2)/4 = 3.14 m^2

- Volume of cooler exhaust air @ 275°C= 3.14 x 18.6 = 58.4 m^3/s = 2,10,240 m^3/h
- Mass flow rate of cooler exhaust air @ 275°C= 210240 x 0.64 = 134553 kg/ hr
- Capacity of existing chiller= 50 TR
- Cooling load = 50 x 3024 = 151200 kcal/ hr
- CoP of VAM= 0.75 = (Cooling Load / Heat Input)
- Heat Input to VAM generator = 151200 / 0.75 = 201600 kcal/hr

201600 kcal/hr= m_{hw}xC_{phw} x (90°C -80°C)

- Hot water flow rate m_{hw}= 201600 / (1 x 10) = 20160 kg/hr

Heat input to VAM generator = Heat recovered from Cooler Exhaust Air

=$m_{cxax}C_{pcxax}$(275-To)

Cooler Exhaust air temperature after heat recovery

To = 275- [201600 / (134553 x 0.24)]

= 268.76°C

b) Payback period by replacement of VCR by VAM

Hot water circulation pump capacity

motor input power Pm= m_{hw} x head developed x 9.81 / (1000 x Pump η x motor η_m)

Pm= [(20160 /3600) x 20 x 9.81/ (1000 x 0.75x 0.9)] = **1.63 kW**

	Heat load in the cooling tower= heat load from chilled water + heat load from generator hot water = 151200 + 201600 = 352800 kcal/ hr Condenser water circulation rate = 352800 / 5 = 70560 kg / hr *Condenser water circulation pump capacity* motor input power Pm = m_{condw} x head developed x 9.81 / (1000 x Pump η x motor η_m) Pm= [(70560 /3600) x 20 x 9.81/ (1000 x 0.75x 0.9)] = **5.69 kW** Savings Existing VCR Chiller Specific power consumption = 0.9 kW/TR Existing VCR Chiller total power consumption = 50 x 0.9 = 45 kW Existing VCR condenser water pump power consumption = 2.8 kW Total Energy Saving = Existing VCR Chiller total power consumption – (Proposed VAM chiller power consumption) =(45+2.8) – (1.63+2.83+5.69) Annual Energy savings = 37.65 x 8000 = 301200 kWh/yr Annual Monetary savings = 301200 x 10 = PKR. 3.01 million/y Investment towards 50TR VAM & its associated system = PKR 6.0 million Simple payback period = 60/30.12 = About 2 years
L2.	The preheater (PH) exhaust gas from a cement kiln has the following composition on dry basis: CO_2 – 23.9%, O_2 – 5.9%, CO – 0.2%, remaining is N_2. The static pressure and temperature measured in the duct are -730 mmWC and 350^{0}C respectively. The velocity pressure measured with a pitot tube is 19 mmWC in a duct of 2800 mm diameter (Pitot tube constant = 0.89). The atmospheric pressure at the site is 10350 mmWC and universal gas constant is 847.84 mmWCm^3/kg mol k. The specific heat capacity of preheater exhaust gas is 0.25 kcals/kg^{0}C. The static pressure developed by PH exhaust fan is 630mmWC and power drawn is 1582 kW. Calculate the efficiency of fan given that the motor efficiency is 92%. The management had decided to install a 1.3 MW power plant with a cycle efficiency of 15% by using this preheater exhaust gas. Calculate the exhaust gas temperature at the outlet of waste heat recovery boiler of the power plant. Ans: Molecular weight exhaust gas (dry basis) M = $\%CO_2 x M_{CO2} + \%O_2 x M_{O2} + \%CO x M_{CO} + \%N_2 \text{ x } MN_2$ = {(23.9 x 44) + (5.9 x 32) + (0.2 x 28) + (70 x 28)}/100 = 32.06 kg/kg mole Exhaust Gas density at operating temperature = γ = [PM / RT] = [(10350 – 730) x 32.06) / { 847.84 x (273+350) } = 0.584 kg/m^3 Duct Area = 3.14 x(2.8/2) ^{2}= 6.15 m^2 Volume flow rate = A Cp (2 x g x ΔP / γ)$^{1/2}$ = 6.15 x 0.89 (2 x 9.81x 19 /0.584)$^{1/2}$ = 138.3 m^3/s Volume flow rate = 497880 m^3/ h Fan efficiency = <u>volumetric flow rate x pressure developed</u>

	(102 x power drawn x motor eff) = $\underline{138.3 \times 630}$ x100 = 58.69% (102x1582x0.92) Mass flow rate of preheater exhaust gas = Volume flow rate x density = 497880*0.584 = 2,90,762 kg/hr Heat equivalent of power generated from power plant =1.3MW =1300 x 860 = 1118000 kCals/hr Heat given up to power plant by exhaust gas = 290762 x0.25 x(350-T_o)x0.15 T_o = 350 - (1118000/(290945x0.25x0.15)) = 247.5**^{0}C**
L3.	As an energy auditor, auditing a cement plant, it is essential to assess the specific coal consumption for the production of the clinker. With the following data available, calculate the specific coal consumption (kgCoal/ KgClinker).

S.No	Parameter	Value
1.	Reference temperature	20^{0}C
2.	Barometric pressure	10329 mmWC
3.	Density of the Pre-heater at NTP	1.436kg/m^3
4.	Density of Air	1.293Kg/m^3
5.	Pitot Tube Constant	0.85
6.	Clinker production rate	4127 TPD
7.	Static Pressure of the Pre-heater gas in the pre-heater duct	640mmWC
8.	Dynamic pressure of the pre-heater gas in the duct	15.8mmWC
9.	Temperature of the Pre-heater gas	320^{0}C
10.	Specific heat of the Pre-heater gas	0.247kCal/kg ^{0}C
11.	Area of the Pre-heater Duct	8.5 m^2
12.	Temperature of the exit clinker	128^{0}C
13.	Specific heat of the clinker	0.193 kCal/kg ^{0}C
14.	Static Pressure of the Cooler Exhaust gas in the duct	42mmWC
15.	Dynamic pressure of the Cooler Exhaust gas in the duct	15.5mmWC
16.	Temperature of the Cooler Exhaust gas gas	290
17.	Specific heat of the Cooler Exhaust gas	0.247kCal/kg ^{0}C
18.	Area of the Cooler exhaust duct	7.1m^2
19.	Heat of Formation of Clinker	405 Kcal/$Kg_{Clinker}$
20.	All other heat loss except heat loss through Pre-heater gas, exiting clinker and cooler exhaust gases	84.3 Kcal/$Kg_{Clinker}$
21.	All heat inputs except heat due to Combustion of fuel (Coal)	29 Kcal/$Kg_{Clinker}$
22.	GCV of the Coal	5500Kcal/Kg

Ans:

Heat Lost in the Exiting pre-heater gases:

$Q_{PH\ Gas}$ = $m_{phgas} \times Cp_{phgas} \times (t_{ephgas} - t_r)$

m_{phgas} = $V_{phgas} X\ \rho_{Phgas}$

V_{phgas} = $v_{ph\ gas}$ X A

Corrected density of the pre-heater gas:

ρ Phgas $= 1.436 \times \frac{10329 - 640}{10334} \times \frac{273}{273 + 320}$

$= 0.6198$ kg/ m^3

Velocity (v) $= P_t \times [(2g(\Delta P_{dynamic})_{avg} / \rho_{Phgas})]^{0.5}$ m/sec

$= 0.85 \times \frac{\sqrt{2 \times 9.81 \times 15.8}}{\sqrt{0.6198}}$ m/sec

= 19.0 m/sec

$V_{PH\ gas}$ = 19.0m^3/s X 8.5 m^2

= 161.5 m^3/sec

= 5,81,400m^3/hr

$M_{ph\ gas}$ = 581400 m^3/hr X 0.6198 kg/m^3

=3,60,351/72 Kg/hr

m_{phgas} = 3,60,351 kg/hr / 1,71,958 kg/hr = 2.095$Kg_{ph\ gas}$/ $Kg_{clinker}$

$Q_{PH\ Gas}$ = 2.095 X 0.247 X (320 -20)

= 155.24$Kcal/Kg_{Clinker}$

Heat Lost in the Exiting Hot Clinker:

$Q_{Hot\ clinker} = m_{clinker} \times Cp_{clinker} \times (t_{clinker} - t_r)$

= 1 x 0.193 x (128 – 20),

= 20.84 $kCal/kg_{Clinker}$

Heat Lost in the Exiting Cooler Exhaust gases:

$Q_{Cooler\ Exhaust\ Gas} = m_{Cooler\ Exhaust\ Gas} \times Cp_{Cooler\ Exhaust\ Gas} \times (t_{Cooler\ Exhaust\ Gas} - t_r)$

$m_{Cooler\ Exhaust\ Gas} = V_{Cooler\ Exhaust\ Gas}$ X $\rho_{Cooler\ Exhaust\ Gas}$

$V_{Cooler\ Exhaust\ Gas} = v_{Cooler\ Exhaust\ Gas}$ X A

Corrected density of the pre-heater gas:

ρ **Cooler Exhaust gas** $= 1.293 \times \frac{10329 - 42}{10334} \times \frac{273}{273 + 290}$

$= 0.624$ kg/ m^3

Velocity (v) $= P_t \times \sqrt{(2g(\Delta P_{dynamic})_{avg} / \rho_{Cooler\ Exhausts})}$ m/sec

$= 0.85 \times \frac{\sqrt{2 \times 9.81 \times 15.5}}{\sqrt{0.624}}$ m/sec

= 18.76 m/sec

$V_{coolerExhaustgas}$ = 18.76m/s X 7.1 m^2

= 133.196 m^3/sec

= 4,79,505m3/hr

$M_{coolerExhaustgas}$ = 479505 m^3/hr X 0.624 kg/m^3

=2,99,211 Kg/hr

$m_{coolerExhaustgas}$ = 2,99,211 kg/hr / 1,71,958 kg/hr
=1.74 $Kg_{coolerExhaustgas}$/ $Kg_{clinker}$

$Q_{coolerExhaustgas}$ = 1.74 X 0.244 X (290 -20)

= 114.63Kcal/$Kg_{Clinker}$

Heat Input = Heat output

$Heat\ Input_{coal}$ + $Heat\ input_{others}$ = $Heat_{Clinker\ formation}$ + $Heat_{PH\ gas}$ + $Heat_{Clinker}$ + $Heat_{cooler\ exhaust\ gas}$ + $Heat_{others}$

GCV_{coal} X m_{coal} + 29 = 405 + 155.24 + 20.84 +114.63 + 84.3

m_{coal} = 751 / 5500
= 0.137 Kg_{coal}/$Kg_{clinker}$

L4. During heat balance of a 5 stage preheater Kiln in a cement plant, the following data was measured at Preheater (PH) Fan Inlet and clinker cooler vent air fan inlet:

Parameter measured	Temperature	Static Pressure	Avg. Dynamic Pressure	Specific heat	Gas Density at STP	Duct Area
Unit	° C	(P_s) mm WC	(P_d) mm WC	kcal/kg°C	kg/ m^3	m^2
PH Exit Gas at PH fan Inlet	316	-650	28.6	0.248	1.4	2.27
Clinker cooler vent air at cooler Stack Fan Inlet	268	-56	9.7	0.24	1.29	2.01

Note: take Pitot tube constant as 0.85, reference temperature 20 °C and atmospheric pressure 9908 mm WC.

Other Data

Calculate the following:

- Specific volume of PH gas as well as cooler vent air (Nm^3/kg clinker)
- Heat loss in pre-heater exit gas (kcal/kg clinker)
- Heat loss in cooler vent air (kcal/kg clinker)

If the measured specific volume of PH gas (Nm^3/kg clinker) exceeds the design value, calculate the heat loss (kcal/kg clinker) and annual monetary loss due to excessive specific volume of PH gas.

Ans:

Density of Pre-heater gas at PH Fan Inlet at prevailing temp., pressure conditions:

$$Gas\ density\ at\ T, P = Gas\ density\ at\ STP \times \frac{273 \times (9908 + P_s)}{(273 + T) \times 10334}$$

$$= 1.4 \times \frac{273 \times (9908 - 650)}{(273 + 316) \times 10334} = 0.581\ kg/m3$$

Velocity of PH gas = $P_t \times \frac{\sqrt{2g(\Delta P_{rms})_{avg}}}{\rho_{t,p}}$ m/s

$= 0.85 \times \frac{\sqrt{2 \times 0.98 \times 28.6}}{0.581}$ = 26.4 m/s

Volumetric flow rate of PH gas = velocity X duct cross-sectional area
= 26.4 X 2.27
= 59.9 m^3/sec
= 59.9 X 3600
= 215640 m^3/hr

Specific volume of PH gas = 215640 X 0.58/1.4
= 89491 Nm^3/hr
= 89491/45160 = **1.98 Nm^3/kg clinker**

Similarly density of cooler vent air at cooler vent air fan Inlet at prevailing temp., pressure conditions:

X +
+ X
X –
+ X

$Gas\ density\ at\ T, P = Gas\ density\ at\ STP \times \frac{273 \times (9908 + P_s)}{(273+T) \times 10334}$ = 0.62 kg/m^3

Velocity of cooler vent air in the fan inlet duct

$= P_t \times \frac{\sqrt{2g(\Delta P_{rms})_{avg}}}{\rho_{t,p}}$ m/s

$= 0.85 \times \frac{\sqrt{2 \times 0.98 \times 9.7}}{0.62} = 14.88\ m/s =$

Volumetric flow rate of PH gas = velocity X duct cross-sectional area
= 14.88 X 2.01
= 29.9 m^3/sec
= 29.9 X 3600
= 107640 m^3/hr

Specific volume of cooler vent air = 107640 X 0.62/1.29
= 51734 Nm^3/hr
= 51734/45160 = **1.15 Nm^3/kg clinker**

i) Heat loss in PH exit gas

$Q1 = m_{ph} \times C_p \times \Delta T$

(C_p of PH gas = 0.248 kcal/kg ^{o}C)

Q1= 1.98 X 1.4 X 0.248 x (316-20)
= 203.5 kcal/kg clinker

ii) Heat loss in cooler vent air

$Q2 = m_{ca} \times C_p \times \Delta T$

(C_p of cooler vent air = 0.24 kcal/kg ^{o}C)

Q2= 1.15 x 1.29 x 0.24 x (268-20)
= 88.3 kcal/kg clinker

Chapter 4.3 Energy Performance Assessment in Textile Plants

Long Type Questions & Answers

L1. The heat balance of a stenter in a textile industry is given below:
Heat used for Drying = 48%
Heat loss in exhaust air = 42%
Heat loss through insulation = 6%
Heat loss due to air infiltration = 4%
The above stenter is drying 75 meters per min. of cloth to final moisture of 7% with inlet moisture of 50%. Temperature of cloth at inlet and outlet is 25°C and 75°C respectively. The hot air for drying in the stenter is heated by thermic fluid. The thermic fluid heater is fired by furnace oil, having an efficiency of 84%. The following data has been given:
Density of furnace oil = 0.95 Kg/litre
GCV = 10000 kcal/kg
Cost of furnace oil = Rs.24 per litre
Weight of 10 m of outgoing dried cloth= 1 Kg

a) Find out the existing furnace oil consumption for stenter drying.
b) What will be the annual furnace oil savings and annual monetary saving if the overall thermal efficiency of the stenter is improved by reducing the combined thermal insulation loss and the loss due to air infiltration, by half, for operations at 22 hours per day and 330 days per year.

Ans:
Stenter speed = 75 meters / min
Dried cloth output = 75 x 60 /10 = 450 kg/hr
Weight of bone dry cloth per hr. = 450 x 0.93
i.e. W = 418.5 kg./hr
Weight of outlet moisture per kg. of bone dry cloth
m_o = (450 – 418.5) / 450 = 0.0753 kg/kg
Inlet moisture = 50%
Inlet wet cloth flow rate = 418.5/ 0.5 = 837kg/hr
m_i inlet moisture per Kg. of bone dry cloth= (837 – 418.5) / 418.5
m_i = 1 kg/kg bone dry cloth
Heat load on the dryer = $W x (m_i – m_o) x [(T_{out} – T_{in}) + 540]$ Kcal/hr
T_{out}= Outlet cloth temperature = 75°C
T_{in}= Inlet cloth temperature = 25°C
Heat load on the dryer=418.5 kg/hr x (1 – 0.0753)kg/kg dry.clth x[(75 – 25)+540] = **2,28,322.3 kcal/hr**
Based on heat balance, dryer efficiency is 48%.
Heat input to the dryer = 228322.3 / 0.48 = 4,75,671.46 kcal/hr
Furnace oil consumption in Thermic fluid heater
= 4,75,671.46/(0.84x10000) = **56.63 kg./hr.**

After reducing insulation and air infiltration loss by half, the heat energy input will reduce by 100% – 0.5 (6 + 4)% = 95%
Dryer efficiency will increase to = (48/0.95) x 100= 50.52%

	Furnace oil consumption with = 2,28,322.3/(0.5052x0.84x10000) improved dryer efficiency = 53.80 kg/hr Saving in Furnace oil consumption due to improved stenter efficiency = 56.63 – 53.80= 2.83 kg/hr **Annual Furnace oil savings** = 2.83x22x330= **20545.8 kgs/year** **Annual monitory savings** = 20545.8x(1/0.95)x24 = **PKR 5,19,051.8**
L2.	In a textile process house the production from the stenter machine is 72000 mtrs per day. The effective operation of stenter is 20 hours per day. The percentage moisture in the dried cloth (output) is 6% and its temperature is 75^{o}C and wet cloth inlet is at 25^{o}C . The stenter is heated by steam at 8 kg/cm^{2}a and the daily steam consumption for the stenter is 16.5 tonnes. The efficiency of the stenter dryer is 47%. Calculate the (i) Linear speed of the stenter machine (ii) Inlet moisture (iii) Feed rate of the stenter. The following data have been provided Weight of 10 meter of dried cloth = 1 kg. Enthalpy of the steam to the stenter = 665 kcal/kg. Enthalpy of condensate at the exit of stenter = 130 kcal/kg. Ignore losses in start-up and stoppage. Ans: Production per day = 72000 meters Actual hours of operation = 20 hours/ day **Linear speed of the stenter = 72000 / (20x60) = 60 meters per min** Dried cloth output = 72000 / (20x10) = 360 kg/hr. Moisture in dry cloth = 6% Bone dry cloth = 360 x 0.94 = 338.4 kg/hr Moisture in outlet cloth m_o= (360 – 338.4) / 338.4 = 0.0638 Kg./Kg. bone dry cloth Steam consumption per day =16.5 tonnes = 16500 / 20 = 825 Kg./hr. Heat load on the dryer = Energy input in steam x Dryer Efficiency = Steam flow rate x (Enthalpy steam – Enthalpy condensate) x Efficiency Dryer = 825 x (665 – 130) x 0.47 = 207446.3 Kcal/hr. Further Heat load on the dryer = w x (m_i – m_o) X [(T_{out} – T_{in}) + 540] Kcal/hr. w =weight of bone dry cloth rate kg/hr m_i = weight of cloth inlet moisture Kg./Kg. bone dry cloth T_{out} = dried cloth outlet temperature = 75^{o}C T_{in} = wet cloth inlet temperature = 25^{o}C = 338.4 x (m_i – 0.0638) X [(75 – 25) + 540] = 207446.3 Kcal/hr m_i = 1.1028 Kg./Kg. bone dry cloth(1.1028) / (1.1028+1)x100 % inlet moisture in wet cloth = 52.44 % total moisture in inlet cloth = 1.1028x338.4= 373.2 kg/hr feed rate(inlet cloth rate), = total inlet moisture/hr +bone dry cloth/hr = 373.2+338.4 = 711.6 Kg./hr.

L3. Stenter operations in a textile process were significantly improved to reduce inlet moisture from 60% to 55% in wet cloth while maintaining the same outlet moisture of 7% in the dried cloth. The Stenter was operated at 80 meters/min in both the cases. The dried cloth weighs 0.1 kg /meter. Further steps were taken to improve the efficiency of the fuel oil fired thermic fluid heater from 80% to 82%, which was supplying heat energy to the dryer. The other data and particulars are

Latent heat of water evaporated = 540kcal/kg,
Inlet temperature of wet cloth = 28^oC ,
Outlet temperature of dried cloth = 80^oC,
Dryer efficiency = 50% ,
G.C.V of fuel oil = 10,300 kcal/kg,

Yearly operation of the stenter = 5000 hours

a) Find out the % reduction in Dryer heat load ,
b) Estimate the overall yearly fuel savings in tonnes by reducing moisture and efficiency improvement compared to the initial case. Assume only energy for moisture evaporation for dryer heat load

Ans:

Initial case: *Inlet moisture, 60%, outlet moisture 7%, dryer efficiency 50%, thermic fluid heater efficiency 80%*

Output of stenter = 80 mts/min x 0.1 x 60
= 480 Kg/hr

Moisture in the dried output cloth = 7%

Wt. of bone- dry cloth = 480 X (1 – 0.07)
i.e. W = 446.4 Kg/hr.

m_o= moisture in outlet cloth = (480–446.4) /446.4
= 0.0753 Kg/Kg. bone-dry cloth

Inlet moisture = 60%
Wt. of inlet cloth = 446.4 / (1 – 0.60) = 1116.00 Kg./hr.

m_i = moisture in inlet cloth
= ((60/40) x 446.4)/446.4 = 1.5 Kg./Kg. bone-dry cloth

Inlet temperature of cloth T_{in} = 28^oC
Final temperature of clothT_{out} = 80^oC

Heat load on the dryer = w x (m_i – m_o) X [(T_{out} – T_{in}) + 540] Kcal/hr.

∴ Heat load on the dryer = 446.4 (1.5 – 0.0753) X [(80 – 28) + 540]
= 3,76,503.76 Kcal/hr

Efficiency of the dryer is 50%, Efficiency of the thermic fluid heater is 80%

Fuel oil consumption in the thermic fluid heater
= 3,76503.76/(0.5x 0.8x10300) = 91.40 kg/hr

	Improved case: *Inlet moisture, 55%, outlet moisture 7%, dryer efficiency 50%, thermic fluid heater efficiency 82%* Inlet moisture = 55% Wt of inlet cloth = 446.4 / (1 – 0.55) = 992.00 Kg./hr. m_i = moisture in inlet cloth = ((55/45) x 446.4)) / 446.4 = 1.22 Kg./Kg. bone-dry cloth Heat load on the dryer = w x (m_i – m_o) X [(T_{out} – T_{in}) + 540] Kcal/hr. ∴ Heat load on the dryer = 446.4 (1.22 – 0.0753) X [(80 – 28) + 540] = 3,02508.00 Kcal/hr Efficiency of the dryer is 50%, Efficiency of the thermic fluid heater is 82% Fuel oil consumption in the thermic fluid heater in improved case = 3,02,508.00/(0.5x 0.82x10300) = 71.63 kg/hr **(a) % reduction in dryer load due to reduction inlet moisture** (3,76,504 - 3,02,508) x 100/376540 = **19.65%** (b) Saving in fuel oil consumption in improved case = 91.4 - 71.63 = 19.77 kg/hr **Yearly fuel oil savings = 19.77x 5000 x 1/1000** **= 98.85 tonnes**
L4.	In a textile unit a stenter is delivering 80 meters/min of dried cloth at 5% moisture. The moisture of wet cloth at inlet is 50%. The stenter is heated by steam at 7 kg/cm2 with inlet enthalpy of 660 kcal/kg. and condensate exits the stenter at 135 kcal/kg. Other data Latent heat of water evaporated from the wet cloth = 540 kcal/kg Weight of 10 meters of dried cloth = 1 kg Inlet temperature of wet cloth = 27oC Outlet temperature of dried cloth at stenter outlet = 80oC. i) Estimate the steam consumption in the stenter considering a dryer efficiency of 48%. ii) Determine the specific steam consumption kg/kg of dried cloth Ans: Output of stenter = 80 mts/min. = 80 x 60 /10 = 480 Kg/hr. Moisture in the dried output cloth = 5% Wt of bone dry cloth = 480 X (1 – 0.05) i.e. W = 456 Kg/hr. m_o =moisture in outlet cloth =(480 – 456)/456 =0.0526 Kg./Kg. of bone dried cloth Inlet moisture = 50% Wt of inlet cloth = 456 / (1 – 0.50) = 912 Kg./hr. mi = moisture in inlet cloth = 912 X 0.5 / 456 = 1.00 Kg./Kg. bone dried cloth

	Inlet temperature of cloth = 27°C Final temperature of cloth = 80°C Heat load on the dryer = w x (m_i – m_o) X [(T_{out} – T_{in}) + 540] Kcal/hr. Heat load on the dryer = 456 (1 – 0.0526) X [(80 – 27) + 540] = 2,56,184.5 Kcal/hr Efficiency of the dryer = 48% Heat input to the stenter = 2,56,184.5 / 0.48 = 5,33,717.71 Kcal/hr Steam consumption in the stenter = 5,33,717.71 / (660 – 135) = 1016.61 Kg/hr Steam consumption per Kg. of dried at stenter outlet cloth = 1016.61 / 480 = 2.12 Kg./Kg. dried cloth

Chapter 4.4 Energy Performance Assessment in Pulp and Paper Plants

Long Type Questions & Answers

L1. In a digester with 40MT digester shell, 100MT of chips with 50% moisture are cooked at 175°C by maintaining bath ratio of 1:4. The digester is filled with 112.5MT of white liquor at 90°C and 37.5MT of black liquor at 87°C. Find the total steam requirement per cook and steam required per tonne of chips and pulp.

- Sp. Heat of chips @ 50% moisture = 0.33 kCal/kg°C at 35°C
- Sp. Heat of white liquor = 0.91 kCal/kg°C at 90°C
- Sp. Heat of black liquor = 0.94 kCal/kg°C at 87°C
- Sp. Heat of digester shell = 0.117 kCal/kg°C at 90°C
- Sp. Heat of cooking liquor after cooking = 0.92 kCal/kg°C
- Temperature after blow = 105°C
- Radiation losses from digester = 8%
- Heat of reaction = 10% (exothermic)
- Pulp Yield = 40%
- Allowance for vent steam and heat blow = 5%

Ans:

Heat requirement of each component in digester is calculated as:

Sl. No	Component	Mass (M), MT	Sp. Heat (Cp) kCal/kg°C	ΔT (°C)	Heat Required Q = MCpΔT (x10^3kCal)
1.	Dry chips	50 (as 50% is moisture)	0.33	175-35 = 140	50x0.33x140 = 2,310
2.	Chip Moisture	50	1	175-35 = 140	50x1x140 = 7,000
3.	White liquor	112.5	0.91	175-90 = 85	112.5x0.91x85 = 8,702
4.	Black liquor	37.5	0.94	175-87 = 88	37.5x0.94x88 = 3,102
5.	Digester shell	40	0.117	175-90 = 85	40x0.117x85 = 398
Total heat required = (2,310+7,000+8,702+3,102+398) = 21,512x10^3 kCal					

Radiation loss @ 8% = 8% of 21,512x10^3 = 1,721x10^3 kCal
Heat of reaction @ 10% (exothermic) = 10% of 21,152x10^3 = 2115.2x10^3 kCal
Total heat required after considering radiation loss and heat of reaction = (21,152+1,721-2115.2)x10^3 kCal = 20,757.8x10^3 kCal

Allowance for vent steam and heat blow = 5%
Total heat required after considering vent steam and heat blow =
= 20,757.8x10^3x1.05 = 21,795.7x10^3 kCal

Steam/cook = 21,795.7x10^3/485(latent heat of steam at 175°C)
= 44.94 MT

Steam required/tonne of bone dry chips = 44.94/50 = 0.8988 MT/tonne of chips
Steam required/tonne of pulp = 44.94/(50*0.4) = 2.247 MT/tonne of pulp

L2. A multi cylinder paper machine is producing 150MT of woven paper per day with 7% moisture content without any breaks per day. Consistency of fibre suspension in head box is 0.5% and dry content leaving the couch and the last press is 22% and 36% respectively. Determine the percentage of water removed,

- By free drainage and suction at wire part
- By pressing on press
- By evaporation from dryers
- Total quantity of water evaporated from the dryer per day

Neglect fiber loss, if any, with back water

Ans:

Basis: 150 MT/day production
Quantity of dry content carried by paper per day = 0.93x150 = 139.5MT

Sl. No	Particulars	Leaving headbox	Leaving couch	Leaving press	Leaving dryer
1.	Dry content	0.5%	22%	36%	93%
2.	Fibre-water ratio	0.5:99.5	22:78	36:64	93:7
3.	Tonnes of water carried over per day	$\frac{99.5}{0.5} \times 139.5 = 27{,}760$	$\frac{78}{22} \times 139.5 = 494.6$	$\frac{64}{36} \times 139.5 = 248$	$\frac{7}{93} \times 139.5 = 10.5$

Sl. No	Particulars	Wire Part	Press Part	Dryer Section
1.	Tonnes of water removed per day	27,760-494.6 = 27,265.4	494.6 – 248 = 246.6	248 – 10.5 = 237.5
2.	% of water removed	27265.4/27760 = 98.2%	246.6/27760 = 0.88%	237.5/27760 = 0.86%

- Water removed on wire part: 98.2%
- Water removed by press: 0.88%
- Water removed by dryers: 0.86%
- Total quantity of water evaporated by dryers per day: 237.5 tonnes

L3. The average speed of the dryer of a paper machine, producing 75GSM paper of 70% moisture, is 65rpm. The deckle of the paper on the reel is 3.5m. The diameter of drier is 1.5m. The steam pressure inside drying cylinder is kept constant at 2.5kg/cm^2. If the sheet dryness after press is reduced from 40% to 30%, calculate:

- Amount of additional water evaporated per day for paper at 94% dryness
- Amount of additional steam required per day

Given that latent heat of evaporation of water at 100°C from the paper at zero pressure is 540 kcal/kg and that of the steam in the drier at 2.5kg/cm^2 at 126°C is 522 kcal/kg.

Ans:

Given, diameter of dryer = 1.5m
Machine Speed = Π x diameter x rpm
= Π x 1.5x 65 = 306.1metre/min

Production = Speed (m/min) x GSM x deckle(m) x minutes per day / (1000x1000)
= 306.1 x 75 x 3.5 x (24x60)/(1000x1000)
= 115.7 Tonnes/day

a) Evaporation when dryness after press is 40%

Moisture in wet web entering the drier
(kg of water/ kg of dry fibre) = 60/40 = 1.5
Moisture in finished paper,
(kg of water/kg of dry fibre) = 6/94 = 0.0638
Water evaporated per kg of dry fibre = 1.5 -0.0638 = 1.436
Evaporation per kg of paper produced at 94% dryness = 1.436x0.94
= 1.35

Evaporation when dryness after presses is reduced to 30%

Moisture in wet web entering the drier
(kg of water/ kg of dry fibre) = 70/30 = 2.33
Moisture in finished paper will remain same = 0.0638
Water evaporated per kg of dry fibre = 2.33 – 0.0638 = 2.27
Evaporation per kg of paper produced at 94% dryness = 2.27x0.94
= 2.13
Additional water evaporated = 2.13-1.35 = 0.78
Thus, additional water evaporated per day = 115.7 x 0.78
(kg of water evaporated/kg of paper produced) = 90.2 tonnes

b) Since steam pressure inside drying cylinder is kept constant at 2.5 kg/cm^2, additional steam requirement shall be only due to the change in the dryness after press.

At 40% dryness, evaporation = 1.35 kg/kg of paper produced

At 2.5kg/cm^2
Kg of steam condensed/kg of paper produced = 540/522 = 1.034
Therefore, steam condensed/kg of paper produced = 1.35x1.034 = 1.40

Similarly,
At 30% dryness, evaporation = 2.13 kg/kg of paper produced
Steam condensed/kg of paper produced = 2.13 x 1.034 = 2.20
Additional steam required = 2.20 – 1.4 = 0.8

Additional steam required per day = 115.7 x 0.8
(kg of steam/kg of paper produced) = 92.56 tonnes

L4. In a multiple effect evaporator, 90m^3/hr of black liquor having a specific gravity of 1.08 at an initial concentration of 18% is fed at 70°C and has to be concentrated to 55%. Live steam quantity of 13 TPH at 2.5 bar pressure and

140°C temperature is supplied to the evaporator. Find out the steam economy of the evaporator.

Ans:

Feed flow rate	:	90 m^3/hr
Specific gravity	:	1.08
Mass flow of feed	:	90 x 1.08
	:	97.2 TPH
Inlet % solids	:	18%
Final % solids	:	55%
Mass flow rate of product	:	97.2 x 18 / 55
	:	31.8 TPH
Water evaporation	:	97.2 – 31.8
	:	65.4 TPH
Live steam consumption	:	13.5 TPH
Steam Economy	:	65.4/13.5
	:	4.84

Chapter 4.5 Energy Performance Assessment in Re-rolling Mills

Long Type Questions & Answers

L1. An oil fired reheating furnace has an operating temperature of around 1000°C. Average furnace oil consumption is 440 litres/hour. The flue gas exit temperature after the air preheater is 300°C. Combustion air is preheated from ambient temperature of 35°C to 200°C through the air preheater. The other data are as given below:

Specific gravity of oil = 0.92
Calorific value of oil = 10,200 kcal/kg
Average O2 percentage in flue gas = 14%
Theoretical air required = 14 kg of air per kg of oil
Specific heat of air = 0.24 kcal/kg °C
Specific heat of flue gas = 0.23 kcal/kg °C
Find out the sensible heat carried away by the exhaust gases and heat recovered by the combustion air in kcal/hr as a percentage of the energy input.

Ans:

Energy input = 440 litres/hr
= 440 x 0.92 kg/hr
= 404.80 kg/hr
= 404.80 x 10,200
= 41,28,960 kCal/hr

Excess air = ($\%O_2$) x 100/(21-O_2%)
= 14 x 100/(21-14)
= 200%

Theoretical air required = 14 kg of air to burn 1 kg of oil
Actual mass of air required= 14 x (1 + 200/100) kg/kg of oil = 42 kg/kg of oil
Sensible heat loss in the flue gas = m x Cp x ΔT
m = mass of flue gas
= 42 + 1 = 43 kg/kg of oil
Cp = Specific heat of flue gas = 0.23
ΔT = Temperature of flue gas – Ambient Temperature
= 300°C – 35°C = 265°C
Heat loss = 43 x 0.23 x (300-35)
= 43 x 0.23 x 265 = 2620.85 kCal/kg of oil
= 2620.85 x 404.80 Kcal/hr = 10,60,920 Kcal/hr
Sensible heat loss in the flue gas as % heat loss to input energy
= 10,60,920 x 100/4128960
= 25.7 %
Heat gained by combustion air = 42 x 0.24 x (200-35)
= 1663.2 kCal/kg of oil
= 1663.2 x 404.80 Kcal/hr
= 673263.36 Kcal/hr

Heat gained by combustion air as % of input energy = 673263.36 x 100/4128960
= 16.3 %

<table>
<tr><td>L2.</td><td>The efficiency of a billet heating furnace with an output of 15 tonne/ hr was 32%. Find out the specific fuel consumption in litres/ tonne of billet heating and total fuel consumption per hour as per data given below:

<u>Billet heating furnace</u>:

Initial temp. = 50^oC
Final temp. = 1150^oC
Specific heat of billet = 0.12 kCal/ kg^oC
Density of fuel oil = 0.95 kg/ litre
GCV of fuel oil = 10,000 kCal/kg

Determine the specific fuel consumption in litres/ tonne and total fuel consumption in litres/hr.
Ans.
$\eta = M_gC_p\Delta t/M_f xGCV$

Fuel consumption per tonne S.F.C. = 1000 X 0.12 X (1150 – 50) / 0.32 X 10000
= 41.25 kg/ hr
= 41.25 / 0.95
= 43.42 litres/ tonne

Fuel consumption for 15 TPH production = 15 X 43.42 = 651.3 litres/hr</td></tr>
<tr><td>L3.</td><td>A furnace is used to heat the stock. The stock is charged through a door, which is always kept open. The door size is 800 mm x 800 mm. The furnace wall thickness is 400 mm. The furnace operating temperature is 1260°C.

Calculate the hourly direct radiation heat loss through openings? Convert the heat loss in terms of oil equivalent loss if GCV of oil is 10250 kCal/kg.

<u>Other data are as under:</u>
Blackbody radiation corresponding to 1260°C = 30 $kCal/cm^2/hr$
Emissivity = 0.82
Factor of radiation = 0.7

Ans:
Area of opening = 80 cm x 80 cm
= 6400 cm^2

The factor of radiation = 0.7
Emissivity = 0.82
Total heat loss through opening
= Black body radiation x Area of opening x factor of radiation x Emissivity
= 30 x 6400 x 0.7 x 0.82
= 1,10,208 kCal/hr

Equivalent oil loss = 110208/10250
= 10.75 kg/hr</td></tr>
<tr><td>L4.</td><td>An oil fired reheating furnace has an operating temperature of around 1200°C. The average fuel oil (FO) consumption is 420litres/hour. The flue gas exit temperature after the air preheater is 320°C. Find out the percentage sensible heat loss in exhaust gases.</td></tr>
</table>

Other data are as under:

Specific gravity of oil = 0.92

Calorific value of oil = 9300 kCal/kg

Average O_2 percentage in flue gas = 13%

Theoretical air required = 14 kg of air to burn 1 kg of oil

Ambient temperature = 40 ^{o}C

Specific heat of flue gas = 0.25 kCal/kg^{o}C

Ans:

Energy input = 420 lph
= 420 x 0.92 = 386.4 kg/hr
= 386.4 x 9300
= 3593520 kCal/hr

Sensible heat loss in flue gas

Corresponding excess air = (%O_2/ (21-O_2)) x 100
= (13/ (21-13)) x 100
= 162 %

Theoretical air required = 14 kg of air to burn 1 kg of oil

Actual air required = 14 x (1+1.62) kg/kg of oil
= 36.68 kg/kg of oil

Sensible heat loss in flue gas= m x C_p x ΔT

m = mass of flue gas
= 36.68 + 1
= 37.68 kg/kg of oil

Cp = Specific heat of flue gas
= 0.25

ΔT = Temperature of flue gas – ambient temperature
= 320°C - 40°C
= 280°C

Heat loss = 37.68 x 0.25 x (320 -40)
= 37.68 x 0.25 x 280
= 2637.6 kCal/kg of oil
= 2637.6 x 386.4
= 1019168 kCal/hr

Sensible heat loss in flue gas
as % heat loss to input energy = (1019168 x 100)/(3593520)
= 28.36%

L5. The following are the operating parameters of rerolling mill furnace

Weight of input material - 10 T/hr

Furnace oil consumption - 600 litres/hr

Specific gravity of oil - 0.92

Final material temperature - 1200oC

Initial material temperature - 40oC

Outlet flue gas temperature - 650oC

Specific heat of the material – 0.12 kCal/kg/oC

GCV of oil - 10,000 kCal/kg

Percentage yield - 92 %

a. Calculate furnace efficiency by direct method
b. Calculate Specific fuel consumption on finished product basis
The management installed a recuperator to preheat combustion air from 40 oC to 300 oC resulted in following benefits:
Increase in material input by 10 %
Reduction in fuel consumption by 13 %
Yield improvement from 92% to 96%
c. Calculate the furnace efficiency after the modifications
d. Reduction in specific fuel consumption after installing the waste heat recovery

Ans:

a) Furnace efficiency by direct method

Heat input = 600 lit/hr x 0.92 x 10000 =55,20,000 kCal/hr
Heat output= 10,000 x 0.12 x (1200 – 40)=1,39,2000 kcal/hr
Efficiency =1,39,2000 /55,20,000 =**25.21 %**

b) Specific fuel consumption on finished product basis

Weight of finished products =10 x 0.92 =9.2 T/hr
Furnace oil consumption= 600 litres/hr
Specific fuel consumption= 600/9.2 =**65.2 litres/ton**

c) Furnace efficiency with 10 % increase in input material

Fuel consumption after modification =600 x 0.87 =522 litres/hr
Production after modification= 10 + 10 x 0.1 =11 T/hr
Heat input= 522 lit/hr x 0.92 x 10000 =48,02,400 kCal/hr
Heat output= 11,000 x 0.12 x (1200 – 40) =15,31,200 kcal/hr
Efficiency =15,31,200/48,02,400 =**31.9 %**

d) Reduction in Specific fuel consumption

Yield of finished product =11 x 0.96 =10.56 T/hr
Fuel consumption= 522 litres
Specific fuel consumption =522/10.56 =49.43 litres/T
Original specific fuel consumption= 65.2 litres/T
Reduction in Specific fuel consumption=65.2 – 49.43 =**15.77 litres/T**