# Training Manual on Energy Efficiency

## for Small and Medium Enterprises

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# FOREWORD

With the rising costs of energy and concerns about global warming, it is imperative that countries adopt the most efficient energy conservation measures and technologies. Energy conservation must evolve as a way of life in developing countries in the Asia-Pacific region given the limited availability of resources. If we are to share commercial energy equitably across all sections of society, it is necessary to conserve energy and use it efficiently. Industries can become globally competitive when their production process consumes the least amount of energy.

For this purpose, energy audits and conservation studies must be conducted at regular intervals in all industries. One of the main bottlenecks in conducting these studies is the lack of technical information on various type of equipment and how energy performance should be measured.

The *Working Manual on Energy Efficiency in SMEs* is an attempt to address this issue in a practical manner. The manual is the outcome of a series of projects organized by the Asian Productivity Organization (APO) comprising e-learning courses, international workshops organized with the National Productivity Council, New Delhi, India and in Kish Island, Islamic Republic of Iran with the National Iranian Productivity Center (NIPC) and national workshops conducted by the author in 2008/09, during which the practical aspects of energy efficiency were discussed. The manual explains energy efficiency aspects for adoption by SMEs from various aspects, and is meant to provide the knowledge needed for energy efficiency adoption in the SME Sector as a complementary resource to the APO's recently published manual *Energy Auditing*.

The *Working Manual on Energy Efficiency for SMEs* was developed by the APO to promote the energy efficiency concepts so that industries in the region can perform comprehensive energy audits and become more competitive. I hope that it will find wide acceptance among industry professionals in the Asia-Pacific.

Shigeo Takenaka
Secretary-General

Tokyo, February 2010

# 1. FUELS AND COMBUSTION

Different types of fuels, such as solid, liquid and gaseous, are available for firing in industrial boilers and furnaces.

## 1.1 GENERAL CRITERIA FOR SELECTING THE FUEL TYPE

**General criteria for selecting a fuel include the following:**

**Availability:**

Availability is one of the important criteria in the selection of a fuel. It is desirable to select a fuel that is indigenous and is locally available.

**Storage and handling:**

It is desirable to select a fuel that is easy to handle; and, for storage, adequate space is required so that the fuel can be stored safely.

**Cost of fuel:**

Cost is a key deciding factor for any management.

**Fuel properties:**

The constituent properties are important from the perspectives of storage, handling, preparation, and combustion equipment performance.

**Calorific value:**

The calorific value of a fuel is the measure of energy content; it is reported as either gross calorific value (GCV) or net calorific value (NCV), units being kCals/kG. The difference between the two calorific values is the latent heat of condensation of the water vapor produced during the combustion process. Efficiency is reported both ways (GCV as well as NCV basis). It is important to note that the efficiency value reported with NCV basis would be higher than the value reported with GCV basis.

**Sulphur content in fuel:**

The presence of sulphur in fuel is related to cold end corrosion in cool parts of the chimney/stack, pre-heated air, and economic factors as the sulphur content determines the minimum stack temperature for avoiding acid dewpoint corrosion in a stack. This means higher losses from the stack when sulphur content in the fuel is higher.

**Analysis (composition) of fuel:**

Two types of analysis, proximate and ultimate analysis, are used. Ultimate analysis is at the elemental level, and includes carbon, hydrogen, nitrogen, sulphur, etc, and is often useful in design, while proximate analysis gives the broader composition of carbon, volatile matter, moisture, and ash.

## 1.2 TYPICAL CALORIFIC VALUES OF FUELS

The calorific value of coal varies considerably depending on the ash, the moisture content, and the type of coal. In fact coal is classified as of a particular grade with respect to its GCV and ash content, and the price varies accordingly. Calorific values of liquid fuels are much more consistent. Agro-based fuels have varying calorific values with respect to composition. Natural gas also has a varying calorific value due to varying constituent share.

Table 1-1 Gross calorific values of fuels

| Fuel | Typical GCV (Kcal/Kg) |
|---|---|
| Kerosene | 11,100 |
| Diesel Oil | 10,800 |
| Light Diesel Oil | 10,700 |
| Furnace Oil | 10,500 |
| LSHS | 10,600 |
| Coal | 4,000 to 6,000 |
| Natural Gas | 8,200 to 8,600 kCal/NM3 |
| Agro fuels | 3,100 to 4,500 KCal/Kg |
| LPG | 11,600 to 11,700 KCal/Kg |

## 1.3 COAL AS A FUEL

### 1.3.1 Storage and handling of coal

Storage of coal has its own disadvantages; these include build-up of inventory, space constraints, deterioration in quality over time, and potential fire hazards. Other losses associated with the storage of coal include oxidation, wind, and carpet loss. So our main effort should be to minimize the loss due to spontaneous combustion and carpet loss.

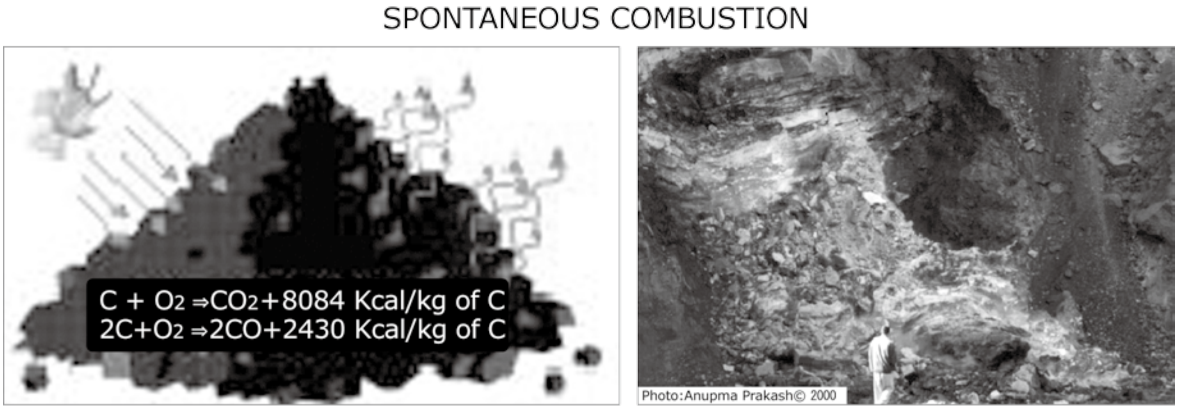


Photo:Anupma Prakash© 2000

Figure 1-1 Examples of spontaneous combustion

**Measures to minimize spontaneous combustion include:**

- Releasing stagnant trapped air in stacked coal by inserting perforated pipes in coal heaps;
- Sprinkling water occasionally as needed, especially in the hot summer months;
- Adopting "first in, first out" principles for coal use and avoiding long durations of coal stacking/storage.

**Measures to reduce carpet losses include:**

- Preparing a hard surface for coal to be stacked upon;
- Preparing standard storage bays made of concrete and brick;
- Controlling the height of coal heaps in storage.

In industry, modes of coal handling range from manual to conveyor systems. It would be advisable to minimize the handling of coal so that further generation of fine coal dust is avoided.

## 1.3.2 Preparation of coal

### Sizing of coal

Proper coal sizing, to match the specifications of the type of combustion system, helps to maintain even burning, reduce ash losses, and achieve better combustion efficiency. Proper maintenance and upkeep of equipment like crushers, screens, and mills is very important to ensure proper coal sizing in accordance with manufacturer specifications.

Using undersized coal will lead to increased loss through unburnt coal, and using oversized coal can lead to clinker formation losses apart from increases in unburnt losses.

### Conditioning of coal

Segregation of fine particles from larger coal pieces can be reduced to a great extent by conditioning coal with water. Water helps fine particles to stick to the bigger lumps due to surface tension of the moisture, thus stopping fines from falling through grate bars or being carried away by the furnace draft.

**Blending of coal**

When coal lots have excessive fines, it is advisable to blend the predominantly lumped coal with lots containing excessive fines. Coal blending may thus help to limit the proportion of fines in coal being fired to 25% or less. Blending of different qualities of coal may also help to supply a uniform coal feed to the boiler.

### 1.3.3 Parameters in coal combustion

**Fixed carbon:**

Fixed carbon gives a rough estimate of the heating value of coal. Higher carbon means higher calorific value.

**Volatile matter:**

Volatile matter includes such substances as methane, hydrocarbons, hydrogen, carbon monoxide, and incombustible gases like carbon dioxide and nitrogen found in coal. Thus volatile matter is an index of the gaseous fuels present. The typical proportion of volatile matter in coal is 20 to 35%. The presence of volatile matter:

- Proportionately increases flame length and helps in easier ignition of coal;
- Sets minimum limits on the furnace height and volume;
- Influences secondary air requirement and distribution aspects.

**Ash content:**

Ash is inorganic material that will not burn. The typical proportion of ash found in coal is 0.5 to 40%, and the ash presence has several detrimental effects:

- It reduces handling and burning capacity.
- It Increases handling costs.
- It affects flame temperature, heat transfer, combustion efficiency, and boiler efficiency.
- It causes clinkering and slagging, affecting availability.
- It increases auxiliary power consumption.

**Moisture content:**

The presence of moisture decreases the heat content per kg of coal, typically by amounts ranging from 0.5 to 10%. It also increases heat loss through stack gases, due to evaporation and superheating. A small quantity, however, at times helps in binding fines together.

**Sulphur content:**

The typical amount of sulphur found in coal is 0.5 to 5%. An excess of it affects clinkering and slagging tendencies, corrodes mild steel chimneys and other equipment such as air heaters and economizers, limits the exit flue gas temperature due to acid dewpoint, and affects efficiency.

## 1.4 OIL AS A FUEL

### 1.4.1 Tips on storage of fuel oil

- It is hazardous to store furnace oil in barrels.
- It is preferable to store oil in cylindrical tanks either above or below the ground.
- Storage capacity should be at least 10 days of normal consumption.
- Bund walls should be built around tanks.
- Periodical cleaning of tanks is necessary: annually for heavy fuels and every two years for light fuels.
- Leaks from joints, flanges, and pipelines must be attended to immediately, and should be avoided at all costs.
  - Loss of even one drop of oil every second can cost over 4000 liters a year.
  - Fuel oil should be free from contaminants such as dirt, sludge, and water before it is fed to a combustion system.

### 1.4.2 Pumping choices for fuel oil

The following are good pumping choices for fuel oils:

- Positive displacement pumps are best for heavy fuel oils.
- Gear pumps are best for light diesel oils.
- Diaphragm pumps have a shorter service life, but are easier and less expensive to repair.
- Light fuels are best pumped with centrifugal or turbine pumps. When higher pressures are required, piston or diaphragm pumps should be used.

### 1.4.3 Parameters in liquid fuel combustion

**Density:**

Density is the ratio of mass of fuel to the volume of fuel.

$$\text{Density: } \frac{\text{Mass of fuel}}{\text{Volume of fue}}$$

Reference temperature is typically 15°C, and units are (kg/m3.)

**Specific gravity:**

Specific gravity is the ratio of weight of a given volume of oil to the weight of the same volume of water at a given temperature.

$$\text{Specific gravity: } \frac{\text{Weight of a given volume of oil}}{\text{Weight of the same volume of water at a given temperature}}$$

Higher specific gravity normally means higher heating value:

- Light oil = 0.85–0.87

- Furnace oil = 0.89–0.95
- L.S.H.S. = 0.88–0.98

**Viscosity:**

Viscosity is internal resistance to flow of fluid. It influences the degree of pre-heat required for handling, storage, and satisfactory atomization.

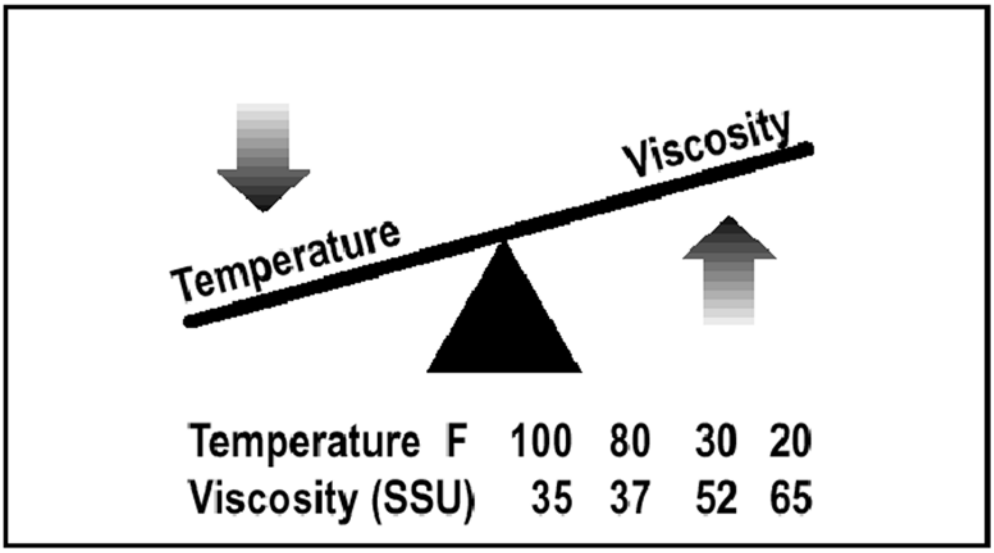


Figure 1-2 Temperature and viscosity

**Specific heat:**

The specific heat of a fuel oil is the amount of energy (kcals) needed to raise the temperature of 1 kg of oil by 1°C. The unit of specific heat is kcal/kg°C and denotes heat capacity, and is useful in designing of heating systems. It varies from 0.22 to 0.28 depending on the oil-specific gravity. It also helps to quantify how much steam or electrical energy is required for preheating.

**Flash point:**

Flash point is the lowest temperature at which the fuel vapors released flash momentarily when an open flame is passed over them. The flash point for furnace oil is 66°C. It affects safe storage conditions.

**Pour point:**

Pour point is the lowest temperature at which fuel oil can be poured/can flow under prescribed conditions. It is a very rough indication of the lowest temperature at which fuel oil can be readily pumped.

**Water content:**

Water content of fuel oil is normally very low as the product is handled hot at the refinery site and a maximum limit of 1% is specified in the standard, but water may be present in free or emulsified form. Water can cause damage to the inside furnace surfaces during combustion, especially if it contains dissolved salts. It can also cause spluttering of the flame at the burner tip, possibly extinguishing the flame and reducing the flame temperature or lengthening the flame.

### 1.4.4 Pre-heating of fuel oil for pumping

Pre-heating oil in storage may be needed to make it less viscous and easily pumpable.

Heating an entire oil tank or outflow heater may be needed to heat oil which is to be pumped away. Outflow heaters with steam or electricity are also used often to ensure smooth pumping.

### 1.4.5 Pre-heating requirements for oil combustion

For pre-heating of oil, in-line heaters are to be used to raise oil temperature from pumping to combustion temperature. In-line heaters are of either electrical or steam tracing type. The pre-heat temperatures of oil are determined by the viscosity of oil supplied at room temperature and the recommended viscosity at the burner tip.

Table 1-2 Viscosity and pumping temperature

| **Viscosity (Centistokes)** | **Pumping Temperature, °C** |
|---|---|
| 50 | 60 |
| 230 | 104 |
| 900 | 121 |

### 1.4.6 Parameters for good efficiency in fuel oil combustion

- Maintain viscosity of oil of 100 Redwood sec I at burner tip by proper setting of pre-heat temperature.
- Provide atomizing air at 1–3 kg/cm$^2$ (about 2% of total air requirement)
- About 14 kg of air/kg of fuel oil is required for complete combustion. Optimum efficiency occurs with around 10% excess air.
- To control for excess air, flue gases should be continuously analyzed for $CO_2$ or $O_2$.
- Acid formation occurs at around 160°C, and cold end corrosion should be avoided by maintaining stack temperature at above 160°C.
- Slightest damage to the burner tip may increase fuel consumption by 10–15%, and hence any wornout tips should be replaced immediately.
- Oil pressure at the burner tip for pressure jet burners should be 17–20 kg/cm$^2$.
- Correct flame is normally short. Flame impingement on walls and tubes is to be avoided since it causes carbon/soot deposits.

- Too short a flame indicates high excess air, and air supply to burners should be adjusted for a light hazy brown color at the chimney.

## 1.5 GASEOUS FUELS

**LPG**

LPG is a mixture of gases, predominantly propane and butane with a small percentage of unsaturated hydrocarbon chains (propylene and butylene). It is gaseous at normal atmospheric pressure, but may be condensed to a liquid state at normal temperature by the application of moderate pressure. Liquid LPG evaporates to produce about 250 times the volume of gas. Its vapor is denser than air.

**Natural gas**

Methane is the main constituent of natural gas, accounting for about 95% of the total volume. Other components are ethane, propane, butane, pentane, and nitrogen. The content of sulphur is negligible. Natural gas is lighter than air and disperses into air easily.

### 1.5.1 Gaseous fuel combustion

Combustion of gaseous fuels is similar to that of liquid fuels; in fact, highest efficiencies can be achieved with gaseous fuels, as very good atomization conditions can be achieved.

## 1.6 COMBUSTION

- Combustion is a high-speed, high-temperature chemical reaction in which the rapid union of an element or compound with oxygen liberate heat – controlled explosion.
- Combustion occurs when elements of fuel such as carbon and hydrogen combine with oxygen. (see Figure 1-3).

### 1.6.1 Chemical reactions involved in combustion of fuels

$\mathrm{C} + \mathrm{O_2} \rightarrow \mathrm{CO_2} + 8084$ kcals/kg of carbon

$\mathrm{2C} + \mathrm{O_2} \rightarrow \mathrm{2\,CO} + 2430$ kcals/kg of carbon

$\mathrm{2H_2} + \mathrm{O_2} \rightarrow \mathrm{2H_2O} + 28{,}922$ kcals/kg of hydrogen

$\mathrm{S} + \mathrm{O_2} \rightarrow \mathrm{SO_2} + 2{,}224$ kcals/kg of sulphur

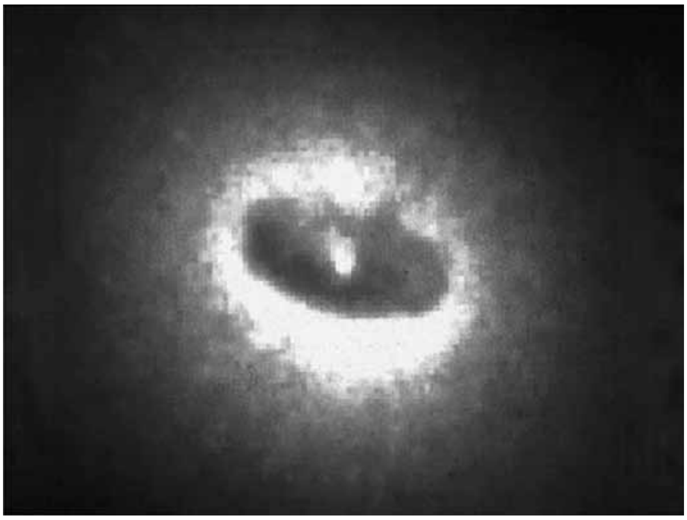


Figure 1-3 Example of chemical reaction producing combustion

### 1.6.2 The three T's (Temperature, Time, Turbulence) involved in combustion efficiency

**Time**

All combustion reactions require sufficient time (residence time) for completion, or else incomplete and inefficient combustion results.

**Temperature**

The temperature around the fuel release area at the burner tip must be must be greater than ignition temperature, or else incomplete combustion results.

**Turbulence**

Proper turbulence close to the flame area helps to bring fuel and air into intimate contact and provides ideal conditions for complete combustion.

### 1.6.3 Three types of combustion

- **Perfect combustion** is achieved when all the fuel is burnt, using only the theoretically ideal amount of air, but perfect combustion can rarely be achieved in practice.
- **Good/complete combustion** is achieved when all the fuel is burnt, using the minimal amount of excess air (over and above the theoretically ideal amount of air needed to burn the fuel). Complete combustion with minimum excess air is always our goal since heat losses due to high excess air in flue gases are unaffordable and unacceptable from the efficiency point of view.
- **Incomplete combustion** occurs when the fuel is not completely burnt and some escapes as CO in flue gases or as unburnts in refuse, both of which result in high losses and low efficiency.

Flue gas analysis of combustion is important, as it helps us to achieve efficient combustion conditions by controlling excess air and reducing CO in flue gases.

### 1.6.4 Types of draft systems used in combustion

The function of a draft in a combustion systems is to exhaust the products of combustion into the atmosphere.

**Natural draft:**

A natural draft 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 the column of outside air at the same height and cross-section.

**Mechanical draft:**

A mechanical draft is a draft artificially produced by fans. (There are three basic types.)

**Forced draft:**

A forced draft system uses a fan to deliver the combustion air into the furnace, and to force combustion products to pass through the boiler/furnace and up the stack.

**Induced draft:**

An induced draft system provides suction at the chimney side, to evacuate products of combustion all through the furnace. The furnace is kept at a slight negative pressure below the atmospheric pressure.

**Balanced draft:**

A balanced draft is a combination of a forced and an induced draft system where a forced-draft fan pushes combustion air into the furnace and an induced-draft fan draws gases into the chimney, thereby providing a draft to remove the gases from the boiler (0.05 to 0.10 in. of water gauge below atmospheric pressure).

In all the above mechanical draft systems, electric power is used for fan requirements.

## 1.7 KEY RESULT AREAS FOR COMBUSTION EFFICIENCY

For energy efficiency in combustion systems, irrespective of the fuel used, the following are the key result areas to be pursued:

- Ensuring proper fuel storage, handling, and preparation, for achieving good combustion conditions.
- Avoiding partial load operations of combustion equipment.
- Operating with minimum excess air for fuel economy.
- Operating with lowest the possible stack temperature for fuel economy.
- Operating with minimum amounts of combustibles in refuse (ash) and CO in flue gases.
- Operating with variable speed options for fan motors, if capacity control is needed (rather than inefficient damper control operations) in order to achieve power savings.

# 2. ENERGY EFFICIENCY IN BOILERS

## 2.1 INTRODUCTION

A boiler is an enclosed pressure vessel that provides means for combustion heat to be transferred into water until it becomes steam. The steam under pressure is then usable for providing heat for an industrial process.

When water is boiled into steam, its volume increases about 1,600 times, producing a force that is almost as explosive as gunpowder. This makes a boiler an extremely dangerous piece of equipment that must be treated with utmost care.

A boiler system comprises three parts:

1. A feed water system,
2. A steam system, and
3. A fuel system.

The **feed water system** provides water to the boiler and regulates it automatically to meet the steam demand. Various valves provide access for maintenance and repair. The **steam system** collects and controls the steam produced in the boiler. Steam is directed through a piping system to the point of use. Throughout the system, steam pressure is regulated using valves and checked with steam pressure gauges. The **fuel system** includes all the equipment used to provide fuel to generate the necessary heat. The equipment required in the fuel system depends on the type of fuel used by the system.

## 2.2 THE HEATING SURFACES IN A BOILER

The amount of heating surface of a boiler is expressed in square meters. Any part of the boiler metal that actually contributes to making steam is a heating surface. The larger the heating surface a boiler has, the higher will be its capacity to raise steam. Heating surfaces can be classified into several types:

1. Radiant Heating Surfaces (direct or primary) include all water-backed surfaces that are directly exposed to the radiant heat of the combustion flame.
2. Convection Heating Surfaces (indirect or secondary) include all those water-backed surfaces exposed only to hot combustion gases.
3. Extended Heating Surfaces include economizers and super heaters used in certain types of water tube boilers.

## 2.3 BOILER TYPES AND CLASSIFICATION

Broadly, boilers found in SME industries can be classified into four types: fire tube boilers, water tube boilers, packaged boilers, and fluidized bed combustion boilers.

### 2.3.1 Fire tube boilers

**Fire tube** or "fire in tube" boilers contain long steel tubes through which the hot gases from a furnace pass and around which the water to be converted to steam circulates. It is used for small steam capacities (up to 12000 kg/hr and 17.5kg/cm$^2$).

The advantages of fire tube boilers include their low capital cost and fuel efficiency (over 80%). They are easy to operate, accept wide load fluctuations, and, because they can handle large volumes of water, produce less variation in steam pressure.

### 2.3.2 Water tube boilers

In **water tube** or "water in tube" boilers, water passes through the tubes and the hot gasses pass outside the tubes. These boilers can be of single- or multiple-drum type. They can be built to handle larger steam capacities and higher pressures, and have higher efficiencies than fire tube boilers. They are found in power plants whose steam capacities range from 4.5–120 t/hr, and are characterized by high capital cost. These boilers are used when high-pressure high-capacity steam production is demanded. They require more controls and very stringent water quality standards.

### 2.3.3 Packaged boilers

The **packaged boiler** is so called because it comes as a complete package. Once delivered to a site, it requires only steam, water pipe work, fuel supply, and electrical connections in order to become operational. Package boilers are generally of shell type with fire tube design so as to achieve high heat transfer rates by both radiation and convection. These boilers are classified based on the number of passes (the number of times the hot combustion gases pass through the boiler). The combustion chamber is taken as the first pass, after which there may be one, two, or three sets of fire tubes. The most common boiler of this class is a three-pass unit with two sets of fire tubes and with the exhaust gases exiting through the rear of the boiler.

### 2.3.4 Fluidized bed combustion (FBC) boilers

In **fluidized bed boilers**, fuel burning takes place on a floating (fluidized) bed in suspension. 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. A further increase in velocity gives rise to bubble formation, vigorous turbulence, and rapid mixing, and the bed is said to be fluidized. Fluidized bed boilers offer advantages of lower emissions, good efficiency, and adaptability for use of low calorific-value fuels like biomass, municipal waste, etc.

## 2.4 PERFORMANCE EVALUATION OF BOILERS

The performance of a boiler, which include thermal efficiency and evaporation ratio (or steam to fuel ratio), deteriorates over time for reasons that include poor combustion, fouling of heat transfer area, and inadequacies in operation and maintenance. Even for a new boiler, deteriorating fuel quality and water quality can result in poor boiler performance. Boiler efficiency tests help us to calculate deviations of boiler efficiency from the design value and identify areas for improvement.

### 2.4.1 Thermal efficiency

Thermal efficiency of a boiler is defined as the percentage of heat input that is effectively utilized to generate steam. There are two methods of assessing boiler efficiency: direct and indirect.

In the **direct method**, the ratio of heat output (heat gain by water to become steam) to heat input (energy content of fuel) is calculated. In the **indirect method**, all the heat losses of a boiler are measured and its efficiency computed by subtracting the losses from the maximum of 100. The various losses are calculated as indicated in the example given below. The loss quantification formulae are given in Chapter 4 (Section 4.2.1) of this manual.

### 2.4.2 Evaporation ratio

**Evaporation ratio**, or steam to fuel ratio, is another simple, conventional parameter to track performance of boilers on-day-to-day basis. For small-capacity boilers, direct method can be attempted, but it is preferable to conduct indirect efficiency evaluation, since an indirect method permits assessment of all losses and can be a tool for loss minimization.

In the direct method, steam quality measurement poses uncertainties. Standards can be referred to for computations and methodology of evaluation. The audit worksheets given in APO's **Energy Audit Manual** can also be used for this purpose.

### EXAMPLE OF DIRECT EFFICIENCY CALCULATION:

Calculate the efficiency of the boiler from the following data:

- Type of boiler : coal-fired
- Quantity of steam (dry) generated : 8 TPH
- Steam pressure (gauge)/temp : 10 Kg/cm$^2$ (g) / 180 degC
- Quantity of coal consumed : 1.8 TPH
- Feed water temperature : 85 degC
- GCV of coal : 3200 kcal/kg

- Enthalpy of steam at 10 kg/cm$^2$ (g) pressure : 665 kcal/kg (saturated)
- Enthalpy of inlet fed water : 85 kcal/kg

$$\text{Boiler efficiency } (\eta) = \frac{8 \text{ TPH x1000Kgx } (665-85) \text{ x } 100}{1.8 \text{ TPH x } 1000\text{Kg x } 3200}$$

$$= 80.0\%$$

Evaporation Ratio = 8 TPH of steam/1.8 TPH of coal = 4.4

## 2.5 BOILER WATER TREATMENT

Boiler water treatment is an important area for attention since water quality has a major influence on the efficiency of a boiler as well as on its safe operation. The higher the pressure rating, the more stringent the water quality requirements become. Boiler water quality is continuously monitored for buildup of total dissolved solids (TDS) and hardness, and blowdown is carried out (involving heat loss) to limit the same.

Boiler water treatment methods are dependant upon quality limits specified for TDS and hardness by the manufacturers, the operating pressure of the boiler, the extent of make-up water used, and the quality of raw water at the site. For small-capacity and low-pressure boilers, water treatment is carried out by adding chemicals to the boiler to prevent the formation of scale, and by converting the scale-forming compounds to free-flowing sludge, which can be removed by blowdown.

**Limitations:**

Treatment is applicable to boilers where feed water is low in hardness salts, where low pressure – high TDS content in boiler water is tolerated, and where only small quantities of water need to be treated. If these conditions are not met, then high rates of blowdown are required to dispose of the sludge, and treatment become uneconomical based on heat and water loss considerations.

**Chemicals Used:**

Sodium carbonate, sodium aluminate, sodium phosphate, sodium sulphite, and compounds of vegetable or inorganic origin are used for treatment. Internal treatment alone is not recommended.

## 2.6 ENERGY EFFICIENCY OPPORTUNITIES IN BOILERS

The various energy efficiency opportunities in boiler systems can be related to combustion, heat transfer, avoidable losses, high auxiliary power consumption, water quality, and blowdown, and are discussed below.

### 2.6.1 Reduce excess air

To minimize escape of heat through flue gases, reducing excess air (the air quantity over and above the theoretical amount needed for combustion) is one of the most important methods of improving boiler efficiency.

- **Perfect combustion** is achieved when all the fuel is burned using only the theoretical amount of air, but perfect combustion can rarely be achieved in practice.
- **Good/complete combustion** is achieved when all the fuel is burned using the minimal amount of excess air (over and above the theoretical amount of air needed to burn the fuel). Complete combustion with minimum excess air is always our goal since heat losses due to high excess air in flue gases are unaffordable and unacceptable from the point of view of efficiency.
- **Incomplete combustion** occurs when all the fuel is not completely burned and escapes as CO in flue gases or as unburnts in refuse, both of which result in higher losses and low efficiency.
- **Flue gas analysis** of combustion is important as it helps to achieve efficient combustion conditions by excess air control and reduction of CO in flue gases.

Using gas analyzers, the excess air quantity can be established from measurement of oxygen or carbon dioxide. Based on oxygen value in flue gas, excess air is given as:

% of excess air = 100 *% of O2 /(21-% of $O_2$).

The relation between % $O_2$ and flue gas and excess air is illustrated in Table 2-1. The advantage of oxygen based analysis is that it is the same for any fuel or fuel combination:

Table 2-1 Oxygen content and excess air

| **% $O_2$** | **% excess air** |
|---|---|
| 1 | 5 |
| 2 | 10.52 |
| 3 | 16.67 |
| 4 | 23.53 |
| 5 | 31.25 |
| 6 | 40 |
| 7 | 50 |
| 8 | 61.7 |
| 9 | 77 |
| 10 | 90.9 |
| 11 | 110 |

The effort, therefore, should be to operate the boiler with minimum % $O_2$ in flue gases (excess air), eliminating all avenues of excess air used for combustion and in the flue gas path.

### 2.6.2 Minimize stack temperature

The stack temperature should be as low as possible, since it carries all the heat from the fuel. However, it should not be so low that water vapor from exhaust condenses on the stack walls. This is important in fuels containing significant sulphur, as low temperature can lead to sulphur dew point corrosion and acid attack effects on metallic parts in the flue gas path. A stack temperature greater than 200°C indicates potential for recovery of waste heat. It also sometimes indicates the fouling and scaling of heat transfer/recovery equipment. Boiler users must monitor stack temperature and compare it with design value. When it has increased over time, maintenance of heat transfer surfaces is called for. If the design value itself is high, the stack temperature can be reduced by adopting one of the following waste heat recovery methods. Waste heat recovery systems are typically shell and tube type heat exchangers and heat transfer area, and other design features depend on flow rates, temperature drop considered, etc.

#### *2.6.2.1 Feed water preheating from waste heat of stack gases*

Where feasible, adoption of feed water heating, using economizer from flue gases with economizer application, gives the highest fuel economy, as one can pre-heat feed water almost up to the saturation temperature of steam. The economizer is a pressure vessel.

A lower order and cheaper alternative for achieving fuel economy through flue gas waste heat recovery would be a non-pressurized feed water heater, which allows feed water pre-heating up to a maximum of 100°C only.

Every rise of 6°C in boiler feed water temperature through waste heat recovery would offer about 1% fuel savings.

#### *2.6.2.2 Combustion air preheating from waste heat of stack gases*

Combustion air preheating is an alternative to feed water heating, and can be adopted, if no further scope for feed water pre-heating exists and where stack gases still have waste heat potential left to be tapped.

Shell and tube type and rotary regenerative type air pre-heaters and regenerative burners are some of the options that can be adopted for waste heat recovery.

For every reduction in flue gas temperature by 22°C for heat recovery, fuel savings of about 1% can be achieved.

The combustion air pre-heat temperature limiting value is decided by permissible exit flue gas temperature for avoiding chimney corrosion on the one hand, and recommended limits of pre-heat temperature by burner manufacturers on the other.

### 2.6.3 Avoid incomplete combustion

Incomplete combustion can arise from a shortage of air or sulphur of fuel or poor distribution of fuel. It is usually obvious from the color or smoke, and must be corrected immediately. In the case of oil and gas-fired systems, CO or smoke (for oil-fired system only) with normal and high excess air indicates burner system problems like poor mixing of fuel air at the burner. Incomplete combustion can result from high viscosity, worn burner tips, carbonization on burner tips, and deterioration of diffusers or spinner plates.

With coal firing, unburnt carbon can escape through fly ash or bottom ash and can lead to 2% to 3% heat loss. Coal preparation, sizing, and air supply should be looked into, in order to avoid this loss.

### 2.6.4 Reduce scaling and soot losses

In oil and coal-fired boilers, soot buildup on tubes acts as an insulator against heat transfer. Any such deposits should be removed on a regular basis. Elevated stack temperatures may indicate excessive soot buildup. The same result will also occur due to scaling on the water side. High exit gas temperatures at normal excess air indicate poor heat transfer performance. This condition can result from a gradual build-up of gas-side or water-side deposits. Water-side deposits require a review of water treatment procedures and tube cleaning, to remove the deposits. Incorrect water treatment, poor combustion, and poor cleaning schedules can easily reduce overall thermal efficiency. However, the additional cost of maintenance and cleaning must be taken into consideration when assessing savings.

Every millimeter thickness of soot coating increases the stack temperature by about 55°C. A deposit of 3mm of soot can cause an increase in fuel consumption by 2.5%. A 1mm thick scale (deposit) on the water side could increase fuel consumption by 5% to 8%.

Stack temperature should be checked and recorded regularly as an indicator of soot deposits and soot removal frequencies decided by trends of temperature rise of flue gas. Fire-side (fuel additives) and water-side additives may be judiciously adopted where justified.

### 2.6.5 Minimize radiation and convection losses

The boiler's exposed surfaces lose heat to the surroundings depending on the surface area and the difference in temperature between the surface and the surroundings. The heat loss from the boiler shell is normally assumed as fixed energy loss, irrespective of the boiler output. With modern boiler designs, this may represent only 1.5% of the gross calorific value at full rating, but it will increase to around 6% if the boiler operates at only 25% output. Repairing or augmenting insulation can reduce heat loss through boiler walls.

### 2.6.6 Adopt automatic blowdown controls

As a first choice, ensure maximum condensate recovery, since condensate is the purest form of water, and this would help reduce dependence on make-up water and also blowdown requirements. Uncontrolled, continuous blowdown is very wasteful. For optimizing blowdown, automatic controls can be installed, which can sense and respond to boiler water conductivity and pH. Relate blowdown to TDS limits/Conductivity of boiler and feed water TDS/Conductivity, by online monitoring.

### 2.6.7 Optimize boiler steam pressure

Wherever permissible, operating a boiler at lower steam pressure (a lower saturated steam temperature, higher latent heat of steam, and a similar reduction in the temperature of the flue gas temperature) helps to achieve fuel economy. In some cases, the process demands are not continuous, and there are periods when the boiler pressure could be reduced. Pressure could be reduced in stages, and no more than a 20% reduction should be considered. Care should be taken that adverse effects, such as an increase in water carryover from the boiler owing to pressure reduction, do not negate any potential savings.

### 2.6.8 Variable speed control for fans, blowers, and pumps

Generally, combustion air control in boilers is achieved by throttling dampers fitted at forced and induced draft fans. Though dampers are a simple means of control, they are an inefficient means of capacity control as they lack accuracy, giving poor control characteristics at the top and bottom of the operating range. If the steam demand characteristic of the boiler is variable, the possibility of replacing an inefficient damper and throttling controls by electronic Variable Speed Drives should be considered for reducing auxiliary power consumed in boiler fans and pumps.

### 2.6.9 Effect of boilder loading on efficiency

Optimum boiler efficiency occurs at 65%–85% of full load. As the steam demand falls, so does the value of the mass flow rate of the flue gases through the tubes. This reduction in flow rate for the available heat transfer area helps to reduce the exit flue gas temperature by a small extent, reducing the sensible heat loss. However, at below 50% load, most combustion appliances need more excess air to burn the fuel completely, and this would increase the sensible heat loss. Operation of a boiler at low loading should be avoided.

### 2.6.10 Boiler replacement

If the existing boiler is old and inefficient, not capable of firing cheaper substitute fuels, over or under-sized for present requirements, not designed for ideal loading conditions, or not responsive to load changes, replacement by a more efficient one needs to be explored.

## 2.7 CASE STUDY

**Installing Economizer for Heat Recovery:**
A paper mill retrofitted an economizer to existing boiler. The general specifications of the boiler are given in Table 2-2:

Table 2-2 Boiler specifications

| Boiler Capacity (T/h) | Feed Water Temp. (°C) | Steam Pressure (bar) | Fuel Oil |
|---|---|---|---|
| 8 | 110 | 18 | Furnace oil |

The thermal efficiency of the boiler was measured and calculated by the indirect method using a flue gases analyzer and a data log. The result is summarized below:

Thermal efficiency : 81%
Flue gas temperature : 315°C
$CO_2$ % : 13CO (ppm) : 167

The temperature in the flue gas was in the range of 315 to 320°C. The waste heat in the flue gas was recovered by installing an economizer, which transfers waste heat from the flue gases to the boiler feed water. This resulted in a rise in feed water temperature by about 26°C.

**Basic data:**

- Average quantity of steam generated.... : 5T/hr
- Average flue gas temperature.... : 315°C
- Average steam generation/kg of fuel oil : 14 kg
- Feed water inlet temperature.... : 110°C
- Fuel of supply rate : 314 kg/hr
- Flue gas quantity : 17.4 kg/kg of fuel

**Fuel savings achieved:**

- Quantity of fuel gases : 314x17.4 = 5463.6 kg/hr
- Quantity of recovered heat in the flue gases
  : 5463.6x0.24x(315-200)=150795 kCal/hr
- Raise in the feed water temperature : 26°C
- Savings in fuel oil : 16.3 kg/h
- Annual operating hours : 8600
- Annual fuel oil savings : 8600x16.3 = 140,180 kg

Through recovery of waste heat by installation of an economizer, the paper mill was thus able to achieve fuel savings of 16.3kg/h (in other words 5.19% of previous fuel consumption).

## 2.8 TIPS FOR ENERGY EFFICIENCY IN BOILERS

- Establish a boiler efficiency-maintenance program. Start with an energy audit and follow-up, then make a boiler efficiency-maintenance program a part of your continuous energy management program.
- Preheat combustion air with waste heat. Add an economizer to preheat boiler feed water using exhaust heat.

  *(Every 22°C reduction in flue gas temperature increases boiler efficiency by 1%.)*
- Use variable speed drives on large boiler combustion air fans with variable flows instead of damper controls.
- Insulate exposed hot oil tanks.
- Clean burners, nozzles, and strainers regularly.
- Inspect oil heaters to ensure proper oil temperature.
- Close burner air and/or stack dampers when the burner is off, to minimize heat loss up the stack.
- Introduce oxygen trim controls (limit excess air to less than 10% on clean fuels).

  *(Every 5% reduction in excess air increases boiler efficiency by 1%; every 1% reduction of residual oxygen in stack gas increases boiler efficiency by 1%.)*
- Automate/optimize boiler blowdown. Recover boiler blowdown heat.
- Optimize de-aerator venting to minimize steam losses.
- Inspect door gaskets for leakage avoidance.
- Inspect for scale and sediment on the water side.

  *(Every 1mm-thick scale (deposit) on the water side could increase fuel consumption by 5%–8 %.)*
- Inspect heating surfaces for soot, fly-ash, and slag deposits on the fire side.

  *(A 3mm-thick soot deposition on the heat transfer surface can cause an increase in fuel consumption of 2.5%.)*
- Optimize boiler water treatment.
- Recycle steam condensate to the maximum extent.
- Study part–load characteristics and cycling costs to determine the most efficient combination for operating multiple boiler installations.
- Consider using multiple units instead of one or two large boilers, to avoid partial load inefficiencies.

# 3. ENERGY EFFICIENCY IN STEAM DISTRIBUTION AND UTILIZATION

## 3.1 INTRODUCTION

Steam is used for generating power as well as for process heating applications in industries such as sugar, paper, fertilizer, refineries, petrochemicals, chemicals, food, synthetic fiber and textiles. 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.

## 3.2 IMPORTANT PROPERTIES OF STEAM

**Liquid enthalpy (also known as "Sensible Heat")**

When water is first heated to the boiling point, it is called sensible heat addition (with change in temperature); liquid enthalpy (hf) is the "enthalpy" (heat energy) available when it is in the water form, and is typically represented in kCal/kg.

**Enthalpy of evaporation (also known as "Latent Heat")**

Once water reaches its boiling point, the enthalpy of evaporation (hfg) is the additional heat energy to be added to this hot water in order to change it into steam. There is no change in temperature during evaporation, hence the name latent heat.

The temperature at which water boils is also called the boiling point or **saturation temperature**. This value depends on the steam pressure and increases as the steam pressure increases. As the steam pressure increases, the useful latent heat energy in the steam (enthalpy of evaporation) actually decreases.

The total heat carried by dry saturated steam or enthalpy of saturated steam is given by the sum of these two enthalpies ($h_f + h_{fg}$).

If the heat energy added is less than required latent heat, **wet steam** is produced, which contains partial water content, and the total heat carried by such wet steam will be lower than that of **dry saturated steam**. It is detrimental to use wet steam for process and steam distribution. **Dryness fraction** is the property which tells us how dry the steam is.

If saturated steam is heated further to a still higher temperature, it starts behaving like a hot gas, and this steam is called **superheated steam**. Superheating is the addition of heat to dry saturated steam without an increase in pressure. The temperature of superheated steam, expressed as degrees above saturation corresponding to the pressure, is known as the **degree of superheat**.

## 3.3 THE TEMPERATURE–ENTHALPY RELATIONSHIP

The properties of steam provided in the steam tables can also be expressed in a graphic form. Figure 3-1 shows the relationship between the enthalpy and the temperature at different pressures, and is known as a phase diagram. This is also called the Mollier diagram, and it helps us to understand the conditions and transition zones of water to steam and to superheated steam.

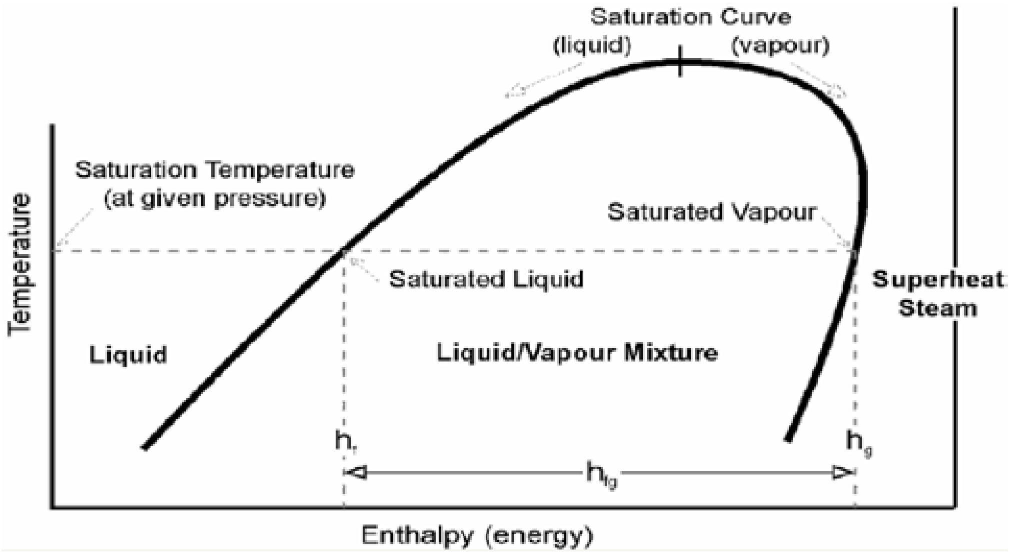


Figure 3-1 Phase diagram

## 3.4 STEAM TABLES

The steam tables (see Table 3-1) present various steam parameters at different pressure and temperature state points and are a helpful tool for design and analysis of steam systems.

Table 3-1 Extract from the steam table

| **Pressure ($kg/cm^2$)** | **Temperature °C** | **Enthalpy in Kcal/kg** | | | **Specific Volume ($m^3/kg$)** |
|---|---|---|---|---|---|
| | | **Water ($h_f$)** | **Evaporation ($h_{fg}$)** | **Steam ($h_g$)** | |
| 1 | 100 | 100.09 | 539.06 | 639.15 | 1.673 |
| 2 | 120 | 119.92 | 526.26 | 646.18 | 0.901 |
| 3 | 133 | 133.42 | 517.15 | 650.57 | 0.616 |
| 4 | 143 | 143.70 | 509.96 | 653.66 | 0.470 |
| 5 | 151 | 152.13 | 503.90 | 656.03 | 0.381 |
| 6 | 158 | 159.33 | 498.59 | 657.92 | 0.321 |
| 7 | 164 | 165.67 | 493.82 | 659.49 | 0.277 |
| 8 | 170 | 171.35 | 489.46 | 660.81 | 0.244 |

## 3.5 STEAM DISTRIBUTION SYSTEM

For efficient steam distribution, an adequate quantity of steam that is dry and free of air must reach the plant at correct pressure; the diameter of steam piping should be optimum, in order to minimize pressure drops and reduce investment and operating costs.

## 3.6 STEAM PIPING: GOOD PRACTICES

- While laying new pipes, it is often necessary to compromise between aesthetics and the architect’s plans.
- Steam pipes should be laid along the shortest possible distance.
- Provisions need to be made for proper draining of condensate. For example, a 100mm well-lagged pipe 30 meters in length, carrying steam at 7kg/cm$^2$ pressure, can condense nearly 10kg of water in the pipe in one hour unless it is removed from the pipe through traps.
- The pipes should run with a fall (slope) of not less than 12.5mm for every 3 meters distance, in the direction of flow.
- Drain pockets should be provided every 30–50 meters and at any low point in the pipe network.
- Expansion loops are required to take care of the expansion of pipes when they get heated up.
- Automatic air vents should be fixed at the dead ends of steam mains, to allow removal of air, which will tend to accumulate.

## 3.7 TIPS ON STEAM PIPING SIZING AND LAYOUT

### Pipe sizing

Proper sizing of steam pipelines helps in minimizing pressure drop. The velocities for various types of steam are:

- Superheated: 50–70 m/sec
- Saturated: 30–40 m/sec
- Wet or Exhaust: 20–30 m/sec

The steam piping should be sized based on permissible velocity and the available pressure drop in the line. A higher pipe size will reduce the pressure drop and thus the energy cost. However, higher pipe size will increase the initial installation cost. By use of smaller pipe size, even though the installation cost can be reduced, the energy cost will increase due to higher-pressure drop. Thus, optimum sizing is necessary. (Pressure drop change is inversely proportional to the 5th power of diameter change.)

### Pipe redundancy

Pipe redundancy is to be avoided in steam distribution since it leads to significant losses. All redundant pipelines must be eliminated; this could reduce steam distribution losses significantly

### Drain points

Drain points help in removing water in the pipes due to condensation of steam. The presence of water in steam is undesirable as it causes water hammer, leading to damage to steam pipes and eventually leakages. Steam traps must be provided at the drain points to avoid leakage of steam.

## 3.8 MAINTENANCE OF STEAM TRAPS

The key functions of steam traps are:

- to discharge condensate once it is formed;
- to prevent steam from escaping; and
- to discharge air and non-condensable gases.

Steam trap performance is very important for fuel economy in all steam-use systems and is one of the major energy efficiency opportunities which can yield surprising results.

- Traps that are open, meaning those draining steam and condensate, result in loss of energy and direct loss of condensate (the purest form of water) and significant economic loss as boiler operating costs increase.
- Traps that are closed, or become blocked, result in reduced heating capacity of steam heating equipment, and direct loss of production, which is undesirable.

Some tips for steam trap monitoring and maintenance are presented here:

- Dirt is one of the most common problem areas. Dirt, scale, or foreign material finds its way to the traps and often damages the valve seat, preventing it from closing properly and leading to leakages.
- Strainers provided for handling dirt and other material before it reaches the traps must be maintained properly.
- Sight glasses, fitted after the traps, permit visual identification of blowing traps and need to be properly taken care of.
- If the trap selected is not the appropriate type and size for the given application, significant losses take place.
- Inverted bucket and thermodynamic traps should have intermittent condensate discharge.
- Float and thermostatic traps should have a continuous condensate discharge.
- Flash steam and leaking steam are not the same. Leaking steam is continuous, like an exhaust, while flash steam is intermittent and like a cloud.
- A regular schedule of maintenance should be adopted, to repair and replace defective traps in the interest of fuel economy.
- Mechanisms within the traps produce sonic and ultrasonic sounds due to passage of condensate and steam. Using suitable listening devices, ranging from a simple screwdriver, a mechanic's stethoscope, or an ultrasonic trap tester, a trap monitoring system can be established in an industry.
- Similarly, temperature sensing by contact and non-contact devices can help to monitor trap performance.

## 3.9 GOOD PRACTICES FOR EFFICIENT STEAM UTILIZATION

### 3.9.1 Steam leakage quantification

Steam leakage is a visible indicator of waste and must be avoided. Regular leakage monitoring and rectification is one of the major steam economy measures.

A simple graph (see Figure 3-2) can be used for estimating steam leakage. The plume is the visible jet of steam issuing from the point of leakage. And, irrespective of pressure, the length of plume helps us to quantify steam loss in kg per hour.

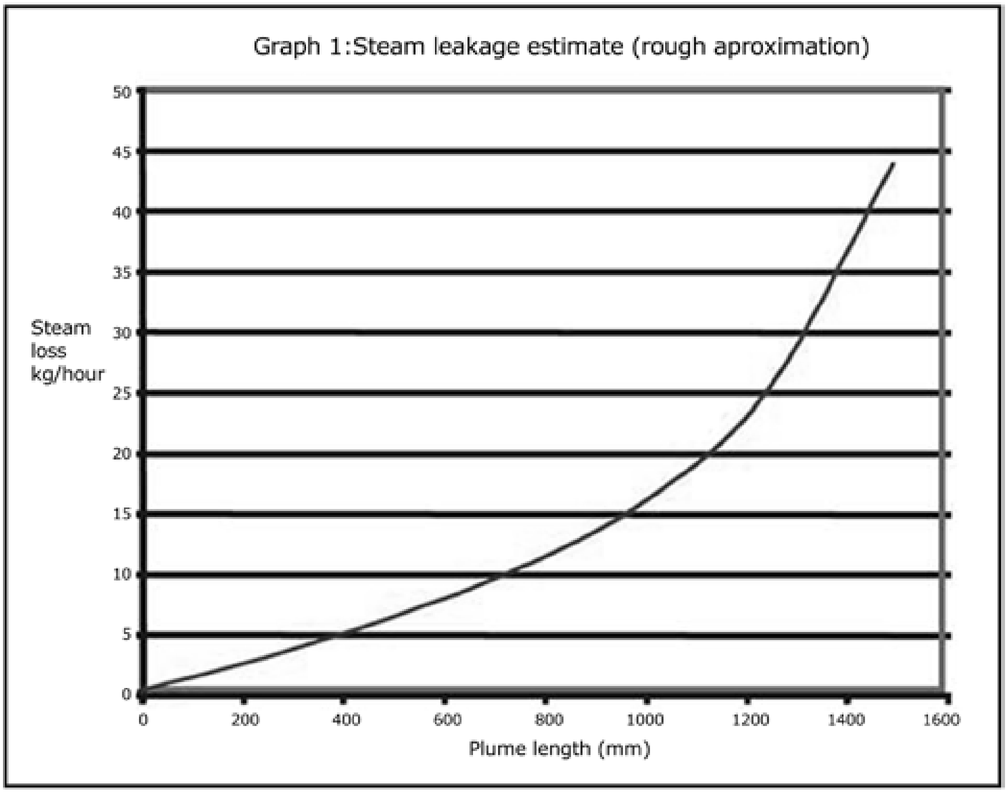


Figure 3-2  Eestmating steam leakage

Example: For a plume length of 700 mm, steam loss is 10 kg/hr.

### 3.9.2 Providing dry steam for the process

Almost all heat transfer processes call for dry steam, and it is necessary to ensure dry steam conditions for efficient use. Wet steam can reduce plant productivity and product quality, and can cause damage to most items of equipment.

Disadvantages of allowing wet steam include lower heat content, extended process time, irregular heating, creation of barriers to heat transfer, and overloading of steam traps. At the same time, superheated steam is not desirable for process heating because of its poor heat transfer coefficient; and it also takes time to give up superheat by conduction. The benefit of using dry steam is that heat transfer is rapid.

To ensure dry steam for processing, steam separators may be fitted appropriately at the steam head and near steam use equipment.

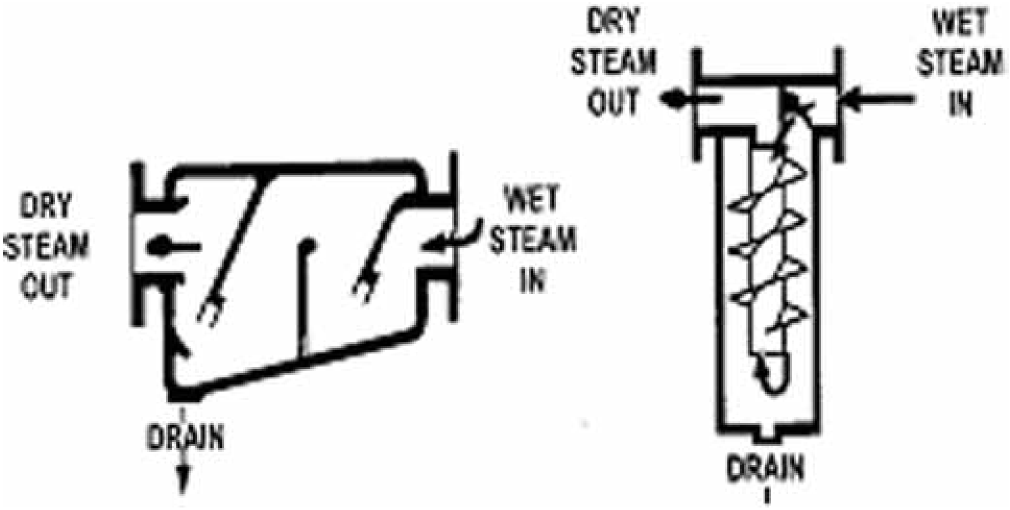


Figure 3-3 Dry steam

### 3.9.3 Utilizing steam at the lowest acceptable pressure for the process

The latent heat in steam reduces as the steam pressure increases. It is this latent heat of steam that takes part in the heating process when applied to a direct heating system. Thus, it is important that its value be kept as high as possible. This can only be achieved if we try to obtain 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 can 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 pressure, 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 items of equipment with which one can profitably go in for lower pressures and realize economy in steam consumption without materially affecting production time. Depending on the equipment design, the lowest possible steam pressure with which the equipment can work should be selected without sacrificing either production time or steam consumption.

### 3.9.4 Insulation of steam pipelines and hot process equipment

Heat can be lost due to radiation from steam pipes. For example, while lagging steam pipes, it is common to see flanges uncovered. An uncovered flange is equivalent to leaving 0.6m of pipeline unlagged. If a steam pipe 0.15m in diameter has 5 uncovered flanges, there would be a loss of heat equivalent to wasting 5 tons of coal or 3000 liters of oil a year. Uncovering is usually done to facilitate checking the condition of the flange, but at the cost of considerable heat loss. The remedy is to provide prefabricated insulation covers, which can be easily removed when necessary. The insulating materials used are cork, glass wool, rock wool, and asbestos.

Table 3-2 indicates the heat loss from a hot uninsulated surface to the environment:

Table 3-2 Quantity of heat lost at different temperatures

| **Difference in Temperature between Ambient and Hot Surfaces (°C)** | **Heat Loss (kCal/m² /hr)** |
|---|---|
| 50 | 500 |
| 100 | 1350 |
| 200 | 3790 |
| 400 | 13640 |

This is based on 35°C ambient temperature, 0.9 emissivity factor, and still-wind conditions. The effective insulation of a steam system can bring down the heat losses to less than 75 kCal/m$^2$/hr.

It is desirable to limit hot surface temperature to not more than 20°C above ambient temperature, by insulation, for fuel economy.

### 3.9.5 Minimizing heat transfer barriers

In indirect heating, a temperature difference is required to transfer heat from steam to the material. The main barrier to heat transfer is the thermal conductivity of the pipe carrying steam. Other impediments include the heat transfer barrier of an air film as well as scaling on the steam side, and scaling as well as a stagnation product film on the product side.

For instance, it has been estimated that air is 1500 times more resistant to heat transfer than steel and 13,000 times more resistant than copper.

Air is probably the best heat insulator ever known. It is also the most likely material to be trapped in all steam supplies, because when steam condenses, air always tries to take its place, on account of the partial vacuum created. Air is also carried into the steam space by incoming steam during startup. It is, therefore, essential that steam-heated equipment should be so designed that all trapped air is pumped out automatically using proper air venting systems. Similarly, scaling of heat transfer areas should be regularly monitored and taken care of by measures like cleaning and de-scaling.

### 3.9.6 Condensate recovery

Steam condenses after giving off its latent heat in the heating coil or the jacket of the process equipment. A sizable portion (about 25%) of the total heat contained in the steam leaves the process equipment as condensate (hot water). If this hot condensate is returned to the boiler house, it will reduce the fuel requirements in the boiler.

For every 6°C rise in the feed water temperature, there will be approximately 1% saving of fuel in the boiler.

Further, in most cases, the boiler water has to be chemically treated to prevent or reduce scale formation, whereas condensate is almost entirely pure water, which needs no treatment. With a high share of the condensate returning to the boiler house, the expenses involved for water treatment can therefore be reduced by an appreciable amount.

### 3.9.7 Flash steam recovery

Flash steam is produced when high pressure condensate is flashed in an enclosure to produce low pressure steam, and can be used for heating application. The specially designed enclosure is called a flash vessel, which is available with most steam equipment suppliers.

The flash steam quantity can be calculated by the following formula with the help of steam tables:

Flash steam is calculated in % = $S_1 - S_2) / L_2$

where

$S_1$ is the sensible heat of higher pressure condensate,

$S_2$ is the sensible heat of steam at lower pressure (at which it has been flashed),

and $L_2$ is the latent heat of flash steam (at lower pressure)

Thus, higher the steam pressure and lower the flash steam pressure, the greater is the quantity of flash steam that can be generated. In many cases, flash steam from high-pressure equipment is made use of directly by the low-pressure equipment, to reduce the use of fresh steam, through pressure-reducing valves.

Flash steam can also be used on low-pressure applications like direct injection and can replace an equal quantity of fresh steam that would otherwise be required.

### 3.9.8 Reducing the work to be done by steam

All the equipment should be supplied with dry saturated steam. To reduce the work done by steam, if any product is to be dried, a press could be used to squeeze as much water as possible, before being heated up in a dryer using steam, which is a more efficient method.

Always use the most economical way to remove the bulk of water from the wet material. Steam can then be used to complete the process. For this reason, hydro extractors, spin dryers, squeeze or calendar rolls, presses, and other equipment are initially used in many drying processes to remove the mass of water. The efficiency with which this operation is carried out is most important.

For example, in a laundry for finishing sheets, the normal moisture content of the sheets as they leave the hydro extractor is 48% by weight. Thus, the steam heated iron has to evaporate nearly 48% of water. This requires 62kg of steam. If, due to inefficient drying in the hydro-extractor, finishing sheets arrive at the iron with 52% moisture content, 52kg of water has to be evaporated; the steam quantity required is 67 kg. So, for the same quantity of finished product, the steam consumption increases by 8%.

When steam reaches the place where its heating is required, it must be ensured that the steam has no more work to do than is absolutely necessary. Air–heater batteries, for example, which provide hot air for drying, will use the same amount of steam whether the plant is fully or partly loaded. So, if the plant is running only at 50% load, it is wasting twice as much steam (or twice as much fuel) as is necessary.

By reducing work done by steam, energy saving can be achieved by the following measures:

- Reduction in operating hours;
- Reduction in steam quantity required per hour;
- Use of more efficient technologies;
- Avoiding part load operations; and
- Minimizing wastage.

### 3.9.9 Proper utilization of directly injected steam

Where feasible, the heating of a liquid by direct injection of steam is often desirable. 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 of the steam is used up along with the latent heat, making the process thermally efficient. If the dilution of the tank contents and agitation are not acceptable in the process (i.e., if direct steam agitation is not acceptable), indirect steam heating is the only answer.

Ideally, the injected steam should be condensed completely as the bubbles rise through the liquid. This is possible if the inlet steam pressures are kept very low, around 0.5 kg/cm$^2$ to 1.0 kg/cm$^2$. If pressures are high, the velocity of the steam bubbles will also be high, and they will not have sufficient time condense before they reach the surface.

A large number of small-diameter holes (2–5mm), facing downwards, may be drilled on the steam distributor pipe. This will help in dissipating the velocity of bubbles in the liquid. Adopting thermostatic control of steam admitted is highly desirable.

### 3.9.10 Proper air venting

A 0.25mm thick air film offers the same resistance to heat transfer as a 330mm thick copper wall. The presence of air inside the process equipment will reduce the partial pressure of steam in the steam air mixture, thus dropping the overall temperature of the steam air mixture, which is the heating medium.

However, it is impossible to avoid the entry of air into a steam system that is working intermittently. If the steam condenses during the shutdowns, air enters the process equipment from the steam mains at the time of startup.

Adequate air venting provision should be made at appropriate positions in the pipelines, to purge air as quickly as possible from the equipment, making heat transfer more efficient.

# 4. ENERGY EFFICIENCY IN FURNACES

## 4.1 INTRODUCTION

A furnace is a piece of equipment used to melt metal for casting or to heat materials in order to change their shape (rolling, forging, etc.) or their properties (heat treatment).

## 4.2 TYPES AND CLASSIFICATION OF FURNACES

Furnaces can be broadly classified into three categories based on mode of heat transfer, mode of charging, and mode of heat recovery. The furnace classification is given in Figure 4-1.

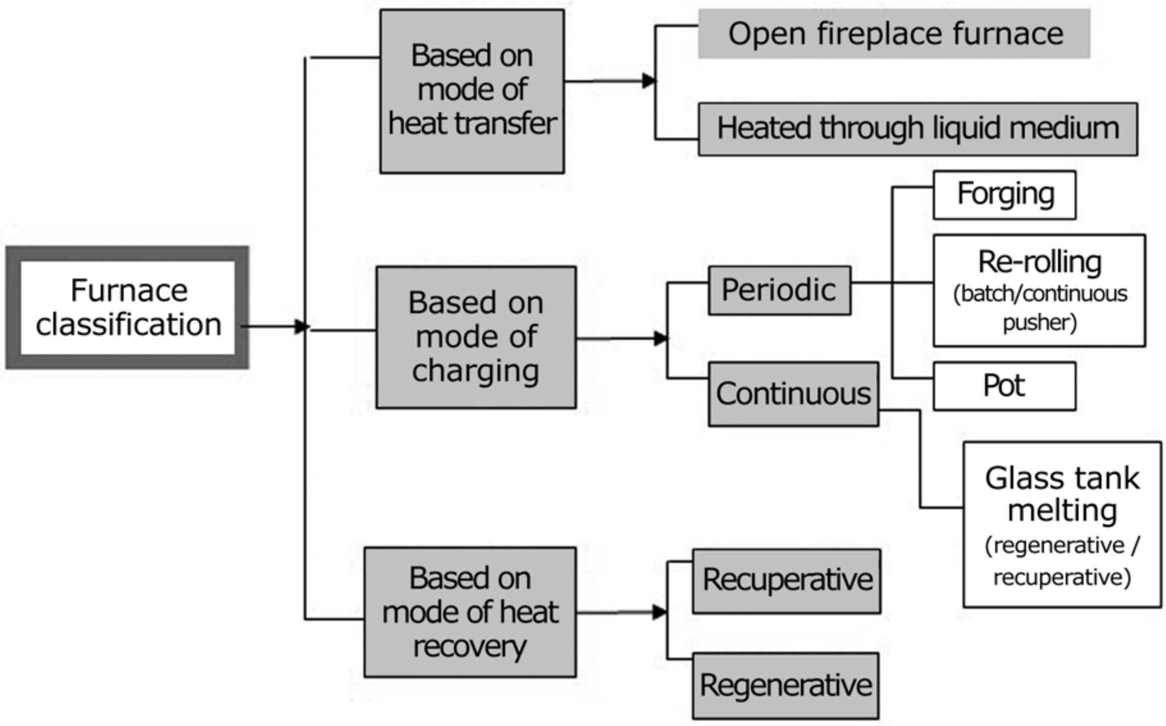


Figure 4-1 Furnace classification

## 4.3 CHARACTERISTICS OF AN EFFICIENT FURNACE

A furnace should be designed so that in a given time, as much of the material as possible can be heated to as uniform a temperature as possible with the least possible fuel and labor.

## 4.4 FURNACE ENERGY SUPPLY

The products of flue gases directly contact the stock, so the type of fuel chosen is of importance. For example, some materials will not tolerate sulphur in the fuel. In addition, use of solid fuels will generate particulate matter, which may affect the stock placed inside the furnace. Hence, the majority of furnaces use liquid fuel, gaseous fuel, or electricity as energy input. Melting furnaces for steel and cast iron use electricity in induction and arc furnaces. Non-ferrous melting furnaces utilize oil as fuel.

## 4.5 OIL-FIRED FURNACES

Furnace oil is the major fuel used in reheating and heat treatment furnaces. LDO is used in furnaces where the presence of sulphur is undesirable. Some furnaces operate with efficiencies as low as 7% as against up to 90% achieved in other combustion equipment such as boilers. Factors reducing efficiency include the high temperatures at which the furnaces have to operate, huge thermal masses, high exit flue gas temperatures, standing losses during soaking, partial load operations, losses due to lack of temperature controls, opening losses, delays in stock removal even after heating has been achieved, and others. For example, a furnace heating the stock to 1200°C will have its exhaust gases leaving at least at 1200°C if no heat recovery is installed, resulting in a huge heat loss through the stack.

## 4.6 TYPICAL FURNACE SYSTEMS

### 4.6.1. Forging furnaces

Forging furnaces use an open fireplace system, and most of the heat is transmitted by radiation. It is used for preheating billets and ingots to attain forging temperature. Thus, furnace temperature is maintained at 1200–1250°C. The typical loading in a forging furnace is 5 to 6 tons, with the furnace operating for 16 to 18 hours daily. The total operating cycle can be divided into (i) heat-up time (ii) soaking time, and (iii) forging time. Specific fuel consumption depends upon the type of material and number of such “reheats” required.

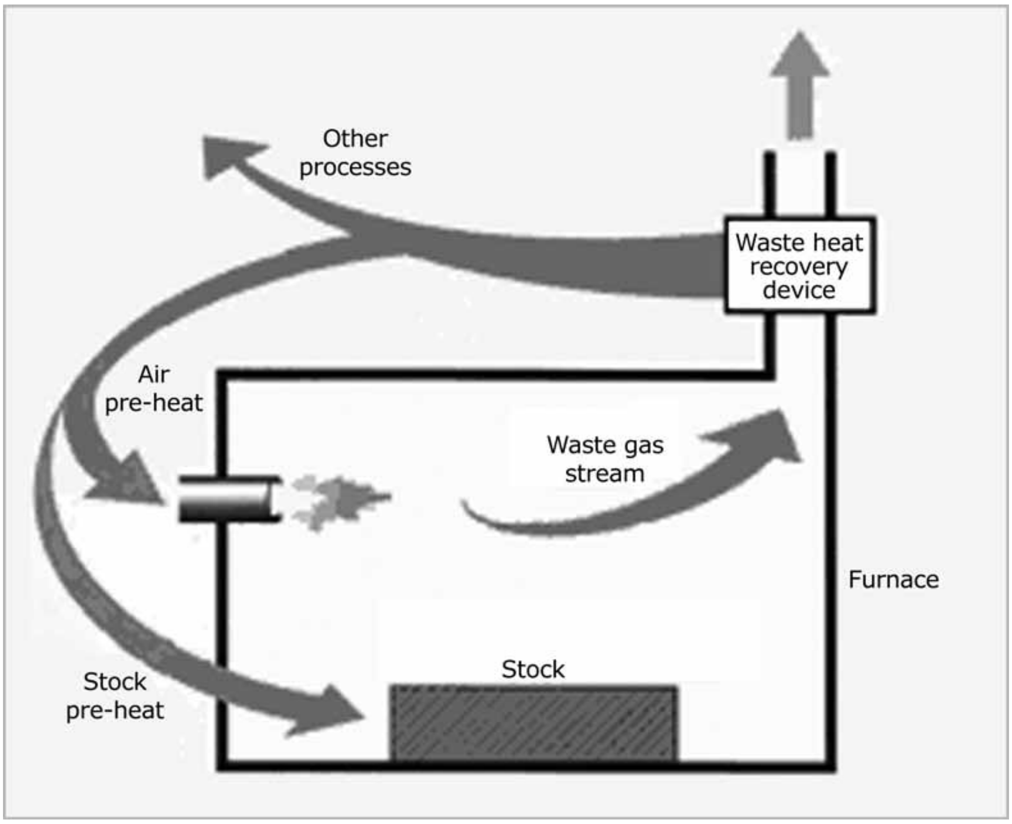


Figure 4-2 Basic diagram of furnace operation

### 4.6.2 Rerolling mill furnaces

#### i) Batch type furnaces

Batch type furnaces are used for heating scrap, small ingots, and billets weighing 2–20 kg. For batch type rerolling, charging and discharging of the "material" is done manually, and the final product is in the form of rods, strips, etc. The operating temperature is 1200°C. The total cycle time can be divided into heat-up time and rerolling time.

#### ii) Continuous pusher type furnaces

The process flow and operating cycles of a continuous pusher type of furnace is the same as that of a batch furnace. The operating temperature is 1250°C. The material or stock recovers a part of the heat in flue gases as it moves down the length of the furnace. Heat absorption by the material in the furnace is slow, steady, and uniform throughout the cross-section compared with a batch type furnace.

## 4.7 PERFORMANCE EVALUATION OF A TYPICAL FURNACE

A furnace heat balance will have the components shown in Figure 4-3. It can be seen that some of these losses do not exist in equipment like boilers, which is the reason why boilers are often much more efficient than furnaces.

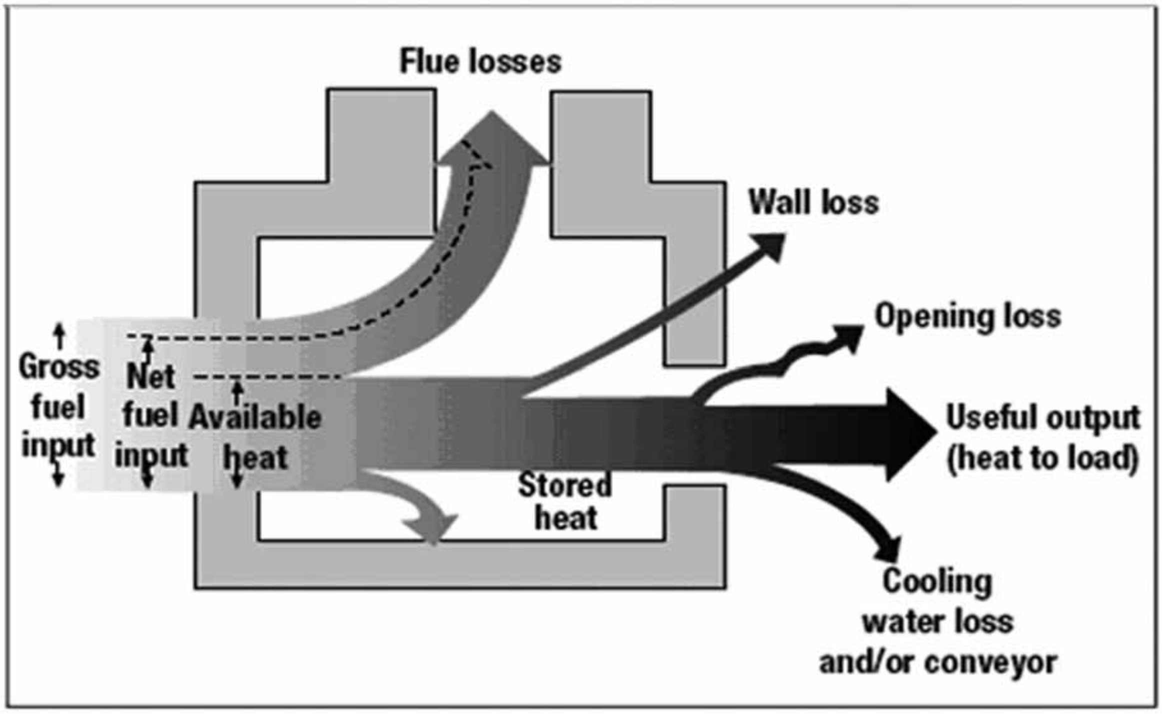


Figure 4-3 Furnace efficiency

Normal furnace losses include the following:

- Heat storage in the furnace structure;
- Losses from the furnace outside walls or structure;
- Heat transported out of the furnace by the load conveyors, fixtures, trays;
- Radiation losses from openings, hot exposed parts, etc.;
- Heat carried by cold air infiltration into the furnace; and
- Heat carried by the excess air used in the burners.

### 4.7.1 Furnace efficiency

The efficiency of a furnace is the ratio of useful output to heat input. The furnace efficiency can be determined by both a direct and an indirect method.

**Direct method testing**

The efficiency of the furnace can be computed by measuring the amount of fuel consumed per unit weight of material produced from the furnace.

$$\text{Thermal efficiency of the fumance} = \frac{\text{Heat in the stock}}{\textit{Heat in the fuel consumed}}$$

The quantity of heat to be imparted (Q) to the stock can be found from the formula

$$Q = m \times C_p \times (t_2 - t_1)$$

where

Q = Quantity of heat in kCal

m = Weight of the material in kg

$C_p$ = Mean specific heat, in kCal/kg°C

$t_2$ = Final temperature desired, in °C

$t_1$ = Initial temperature of the charge before it enters the furnace, in °C

**Indirect method testing**

Similar to the method of evaluating boiler efficiency by indirect methods, furnace efficiency can also be calculated by an indirect method. Furnace efficiency is calculated after subtracting sensible heat loss in flue gas, loss due to moisture in flue gas, heat loss due to openings of the furnace, heat loss through the furnace skin, and other unaccounted losses from the input to the furnace.

The parameters that must be taken into account in order to calculate furnace efficiency using the indirect method include hourly furnace oil consumption, material output, excess air quantity, temperature of flue gas, temperature of the furnace at various zones, skin temperature. and hot combustion air temperature. Efficiency is determined by subtracting all the heat losses from 100.

**Measurement parameters**

The following measurements should be made to calculate the energy balance in oil-fired reheating furnaces (e.g. heating furnaces):

i) Weight of stock / Number of billets heated;
ii) Temperature of furnace walls, roof, etc,;
iii) Flue gas temperature;
iv) Flue gas analysis; and
v) Fuel oil consumption.

Instruments like infrared thermometer, fuel consumption monitor, surface thermocouple and other measuring devices are required to measure the above parameters. Reference manuals should be referred to for data like specific heat, humidity, etc.

### 4.7.2 Useful data

- In addition to conventional methods, Japanese Industrial Standard (JIS) GO 702: "Method of heat balance for continuous furnaces for steel" is used for the purpose of establishing the heat losses and efficiency of reheating furnaces.
- Heat transfer by radiation is proportional to the absolute temperature to the power of 4. Consequently, the radiation losses increase exponentially as temperature increases. Table 4-1 illustrates the observation.

Table 4-1 Radiant heat loss comparison at various temperatures

| **C1 (°C)** | **C2 (°C)** | **K1 (C1 +273)** | **K2 (C2 +273)** | **$(K1/K2)^4$** | **Relative Radiant Heat Transfer** |
|---|---|---|---|---|---|
| 700 | 20 | 973 | 293 | 122 | 1.0 (baseline value) |
| 900 | 20 | 1173 | 293 | 255 | 2.1 |
| 1100 | 20 | 1373 | 293 | 482 | 3.96 |
| 1300 | 20 | 1573 | 293 | 830 | 6.83 |
| 1500 | 20 | 1773 | 293 | 1340 | 11.02 |
| 1700 | 20 | 1973 | 293 | 2056 | 16.91 |

(Note: C1 is hot body temperature and C2 is ambient air temperature)

In other words, the radiation losses from an open furnace door at 1500°C are 11 times greater than the losses of the same furnace at 700°C. A good practice for iron and steel melters is to keep the furnace lid closed at all times and maintain a continuous feed of cold charge onto the molten bath.

### 4.7.3 Determining black body radiation at a particular temperature

If a furnace body has an opening, the heat in the furnace escapes to the outside as radiant heat. Heat loss due to openings can be calculated by computing black body radiation at furnace temperature, and multiplying these values by emissivity (usually 0.8 for furnace brick work), and the factor of radiation through openings. The black body radiation losses can be directly computed from the curves as given in Figure 4-4.

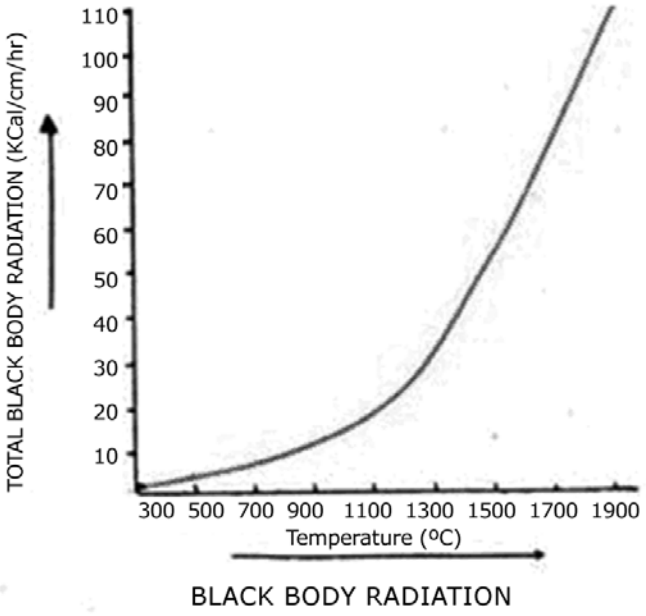


Figure 4-4 Black body radiation

**Furnace utilization factor**

Utilization has a critical effect on furnace efficiency and is a factor that is often ignored or underestimated. If the furnace is at temperature, then standby losses occur whether or not a product is in the furnace.

**Standby losses**

Energy is lost from the charge or its enclosure in the forms of heat:
(a) conduction, (b) convection; and/or (c) radiation.

**Furnace draft control**

Furnace pressure control has a major effect on fuel-fired furnace efficiency. Running a furnace at a slight positive pressure reduces air ingress and can increase its efficiency.

**Theoretical heat**

In the example of melting one ton of steel from an ambient temperature of 20℃:

Specific heat of steel = 0.186 Wh/kg/℃.

Latent heat for melting of steel = 40 Wh/kg/℃.

The melting point of steel = 1600 ℃.

Theoretical total heat = Sensible heat + Latent heat

Sensible heat = 1000 kg x 0.186 Wh/kg℃ x (1600-20)℃ = 294 kWh/T

Latent heat = 40 Wh/kg x 1000 kg = 40 kWh/T

Total heat = 294 + 40 = 334 kWh/T

So the theoretical energy needed to melt one ton of steel from 20℃ = 334 kWh.

Actual energy used to melt to 1600℃ is 700 kWh.

$$\text{Efficiency} = \frac{334\ \text{kWh}}{700\ \text{kWh}} \times 100 = 48\%$$

Typical furnace efficiency values for reheating and forging furnaces (as observed in few trials undertaken by an Energy Auditing Agency on such furnaces) are given in Tables 4-2 and 4-3.

Table 4-2  Pusher type billet reheating furnaces (for rolling mills)

| **Furnace Capacity** | **Specific Fuel Consumption** | **Thermal Efficiency Achieved** |
|---|---|---|
| Upto 6 T/hr | 40-45 Ltrs/ton | 52% |
| 7-8 T/hr | 35-40 Ltrs/ton | 58.5% |
| 10-12 T/hr | 33-38 Ltrs/ton | 63% |
| 15-20 T/hr | 32-34 Ltrs/ton | 66.6% |
| 20 T/hr & above | 30-32 Ltrs/ton | 71% |

Table 4-3  Pusher type forging furnaces

| **Furnace Capacity** | **Specific Fuel Consumption** | **Thermal Efficiency Achieved** |
|---|---|---|
| 500-600 kg/hr | 80-90 Ltrs/ton | 26% |
| 1.0 T/hr | 70-75 Ltrs/ton | 30% |
| 1.5-2.0 T/hr | 65-70 Ltrs/ton | 32.5% |
| 2.5-3.0 T/hr | 55-60 Ltrs/ton | 38% |

The fuel consumption figures in the tables correspond to conditions when the furnaces were operating continuously at their rated capacity.

Note: These are trial figures and cannot be presumed as standards for the furnaces concerned.

## 4.8 GENERAL FUEL ECONOMY MEASURES IN FURNACES

### 4.8.1 Combustion with minimum excess air

To obtain complete combustion of fuel with the minimum amount of air, it is necessary to control air infiltration, maintain the pressure of combustion air, and monitor fuel quality and excess air. Higher excess air will reduce flame temperature, furnace temperature, and heating rate.

A simple equation to calculate excess air from the percentage of oxygen in flue gases for any fuel in a combustion system is:

% excess air = (% Oxygen)*100/ (21 – % Oxygen).

On the other hand, if the excess air is reduced, then unburnt components in flue gases will increase and will be carried away in the flue gases through the stack. Therefore 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 the furnace is high.

The amount of heat lost in the flue gases depends upon amount of excess air. In the case of a furnace carrying away flue gases at 900°C, percentage of heat lost is shown in Table 4-4.

Table 4-4 Heat loss in flue gas based on excess air level

| **Excess Air** | **% of total heat in the fuel carried away by waste gases (flue gas temp. 900°C)** |
|---|---|
| 25 | 48 |
| 50 | 55 |
| 75 | 63 |
| 100 | 71 |

### 4.8.2 Correct heat distribution

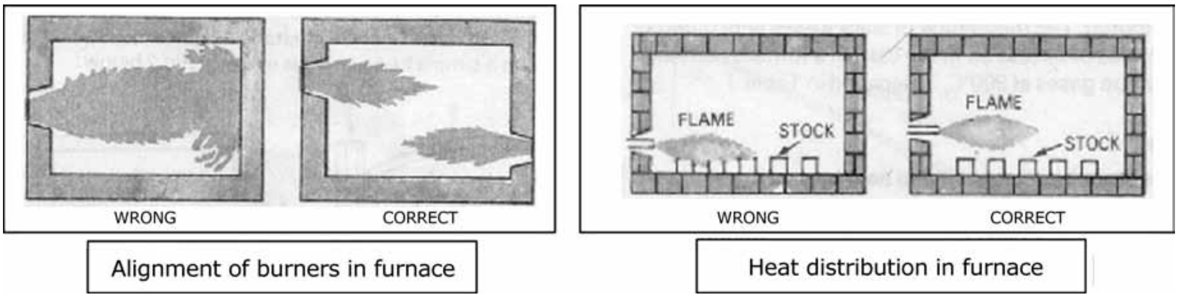
For proper heat distribution, when using oil burners, the following measures should be taken:

i) Prevent flame impingement by aligning the burner properly to avoid touching the material. The flame should not touch any solid object and should propagate clear of any solid object. Any obstruction will disturb the atomized fuel particles, thus affecting combustion and creating black smoke. If flame impinges on the stock, there will be an increase in scale losses, which are often hidden in nature but precious in value.

ii) If the flames impinge on refractories, the incomplete combustion products can settle and react with the refractory constituents at high flame temperatures.

iii) The flames of different burners in the furnace should stay clear of each other. If they intersect, inefficient combustion will occur. It is desirable to stagger the burners on the opposite sides.

iv) The burner flame has a tendency to travel freely in the combustion space just above the material. In small reheating furnaces, the axis of the burner is never placed parallel to the hearth but always at an upward angle. Flames should not hit the roof.



Alignment of burners in furnace

Heat distribution in furnace

Figure 4-5 Burner alignment and heat distribution

v) Designs with few large-capacity burners produce a long flame, which may be difficult to contain within the furnace walls. More burners of less capacity give a better distribution of heat in the furnace and also increase furnace life.

vi) For small reheating furnaces, it is desirable to have a long flame with golden yellow color while firing furnace oil for uniform heating. The flame should not be so long that it enters the chimney and comes out through the top or through the doors. This will happen if excess oil is fired. In such cases, a major portion of additional fuel is carried away from the furnace.

## 4.9 FURNACE WASTE HEAT RECOVERY

Since furnaces operate in high temperature domains; the stack temperatures are very high, and waste heat recovery is a major energy efficiency opportunity in furnaces. The recovered waste heat is conventionally used for either pre-heating of combustion air or to heat he material itself.

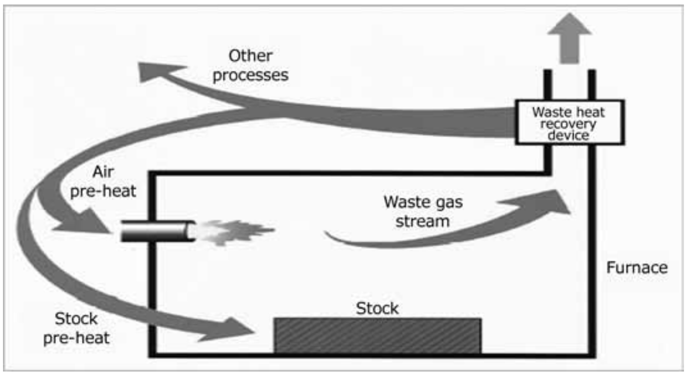


Figure 4-6 Waste heat diagram

## 4.9.1 Some common waste heat recovery systems

### Simple double pipe type heat exchangers

These **generally** take the form of concentric cylinders, in which the combustion air passes through the annulus and the exhaust gases from the furnace pass through the center. Such recuperators are very cheap to make, are suitable for use with dirty gases, have a negligible resistance to flow, and can replace the flue or chimney if space is limited.

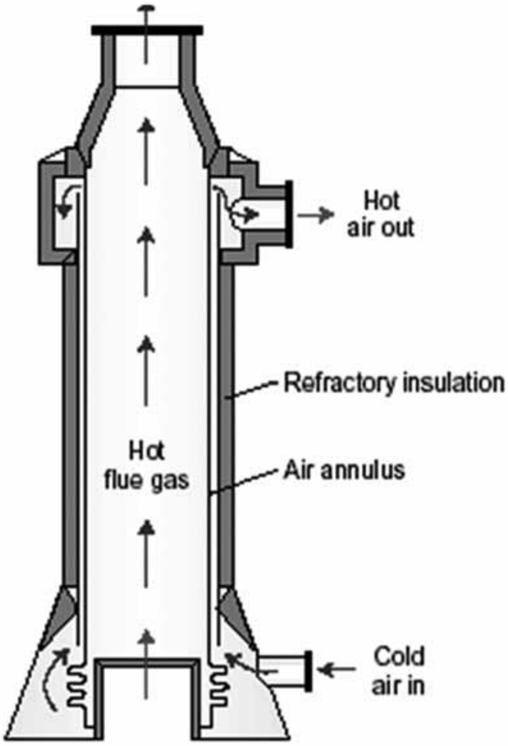


Figure 4-7 Heat exchanger

### Convection recuperators

Convection recuperators consist essentially of bundles of drawn or cast tubes. Internal and/or external fins can be added to assist with heat transfer. The combustion air normally passes through the tubes and the exhaust gases outside the tubes, but there are some applications where this is reversed. For example, with dirty gases, it is easier to keep the tubes clean if the air flows on the outside. Design variations include 'U' tube and double pass systems. Convection recuperators are more suitable for exhaust gas temperatures of less than about 900°C. Beyond 900°C, ceramic recuperators can be used which can withstand higher temperatures.

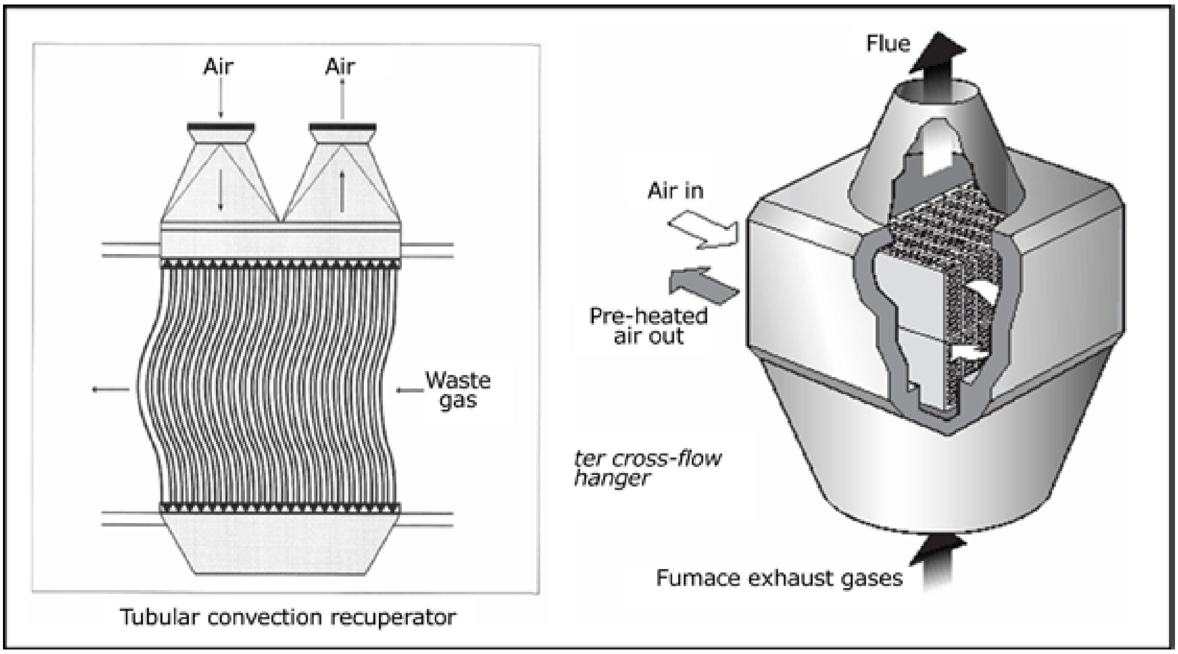


Figure 4-8 Convection recuperators

### Regenerative burners

In regenerative burners, the heat of the gases is stored before they exit and incoming combustion air is preheated from this stored heat, switching between two chambers alternately. The cycle time is accurately controlled for switchover. Options include regenerative burners and regenerative air pre-heaters for heat recovery.

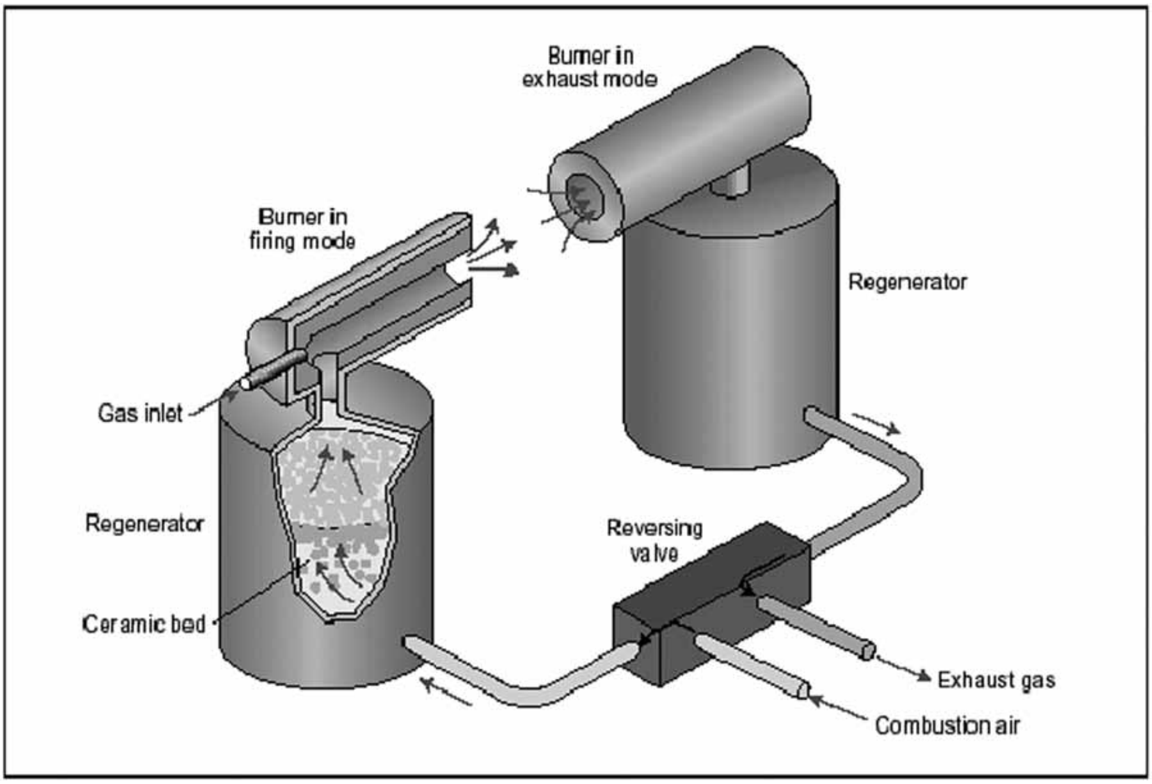


Figure 4-9 Regenerative burners

### 4.9.2 Ceramic fiber for reducing thermal mass

Thermal mass in a furnace contributes significantly to storage heat loss, especially in those batch furnaces with huge refractory brickwork. Every time the furnace goes through a heating cycle, the whole refractory mass needs to be heated all over. Introduction of ceramic fiber to replace conventional fire brick lining helps to reduce thermal mass to almost 15% of the original, helping to lower fuel consumption and batch time reduction as well.

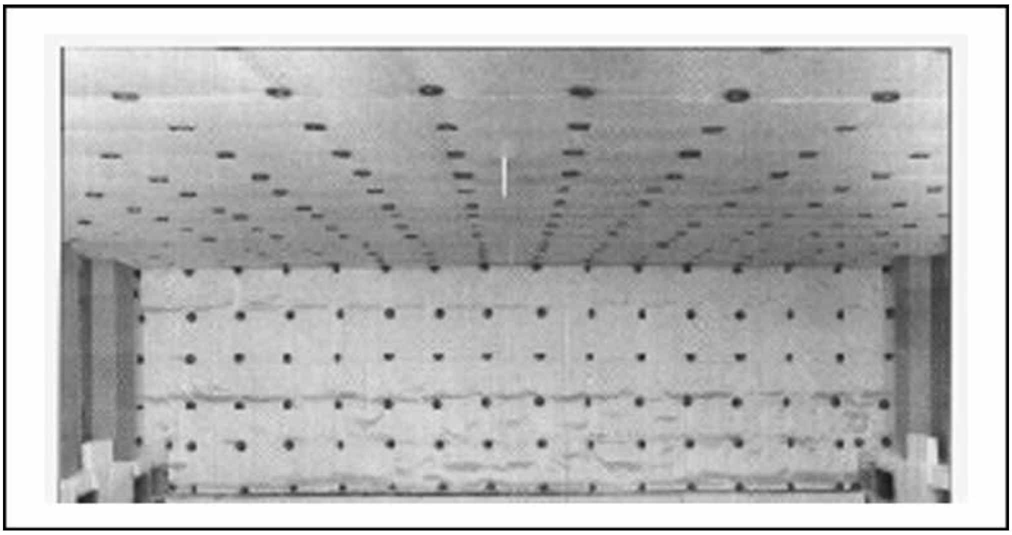


Figure 4-10 Use of ceramic fiber

### 4.9.3 Ceramic coatings to improve emissivity

Heat transfer in a furnace depends mainly on radiation, which in turn depends on emissivity. At higher temperatures, the emissivity decreases and is on the order of 0.3. High emissivity refractory coating, if applied on the internal surface of the furnace, increases the emissivity to 0.8, thus contributing to increased heat transfer. The application of high-emissivity coatings in furnace chambers promotes rapid and efficient transfer of heat, uniform heating, and extended life of refractories and metallic components such as radiant tubes and heating elements. For intermittent furnaces or where rapid heating is required, use of such coatings is found to reduce fuel consumption up to 10%. Other benefits are temperature uniformity and increased refractory life.

## 4.10 TIPS FOR IMPROVING ENERGY EFFICIENCY IN FURNACES

**General**

- Establish a management information system on loading, efficiency, and specific fuel consumption.
- Prevent infiltration of air, using doors or air curtains.
- Monitor $O_2/CO_2/CO$ ratios and control excess air level.
- Improve burner design, combustion control, and instrumentation.
- Ensure that the furnace combustion chamber is under slight positive pressure.
- Use ceramic fiber linings in the case of batch operations.
- Match the load to the furnace capacity.
- Retrofit with heat recovery devices.

- Investigate cycle times and avoid extended hours of runtime and excess heating.
- Provide temperature controllers.
- Ensure that the flame does not touch the stock.

**Insulation**

- Repair damaged insulation.
- Use an infrared gun to check for hot wall areas during hot weather.
- Ensure that all insulated surfaces are clad with aluminum lining.
- Insulate all flanges, valves, and couplings.

**Waste heat recovery**

- Recover maximum heat from flue gases.
- Ensure upkeep of heating surfaces by regular cleaning.

# 5. ELECTRICAL LOAD MANAGEMENT

## 5.1 INTRODUCTION

In industrial type electricity billing, where mostly a two-part tariff is adopted, the consumer pays for two components:

- For the maximum demand (kVA) recorded during billing duration; and
- For the energy (kWh) consumed during billing duration.

Electrical load management for a company involves measures to reduce maximum demand and to improve power factors so that the maximum demand charges are minimized. Energy consumption mainly relates to end-use equipment efficiency and can be reduced by various relevant measures.

## 5.2 MAXIMUM DEMAND BASICS

Maximum demand charges relate to the fixed cost of capacity blocked to be provided for serving a consumer's needs.

A tri-vector meter installed at the consumer end records the maximum demand registered by a consumer during billing duration, apart from other important consumption features like active power (kWh), reactive power (kVarh), apparent power (kVah), and power factor (PF).

At present many utilities have a "time of day tariff" in place, and charge a consumer variable rates for maximum demand drawn during different times of day. For instance, there could be lower rates for night hours when the utility is lightly loaded and higher rates during evening hours when utilities are stretched to meet maximum load demands. It would thus help to study the load curve patterns and, based on prevalent tariff structure provisions, optimize maximum demand to save on maximum demand charges.

### 5.2.1 Load curve of a plant

From Figure 5-1, one can see that demand varies from time to time, due to the combination of users and consumption of electricity changing all the time. The demand is measured over a predetermined time interval and averaged out for the interval as shown by the horizontal dotted line.

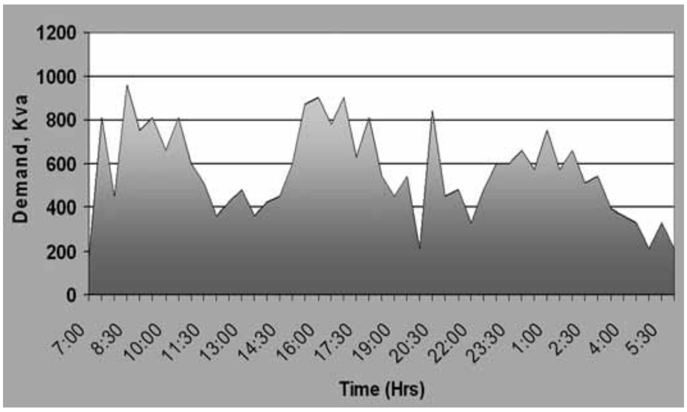


Figure 5-1 Maximum demand curve

### 5.2.2 MD recording

It is important to note that while maximum demand is recorded, it is not the instantaneous demand drawn, as is often misunderstood, but rather is the time-integrated demand over the duration of the recording cycle.
As example, in an industry, if the draw over a recording cycle of 30 minutes is:

2500 kVA for 4 minutes

3600 kVA for 12 minutes

4100 kVA for 6 minutes

3800 kVA for 8 minutes,

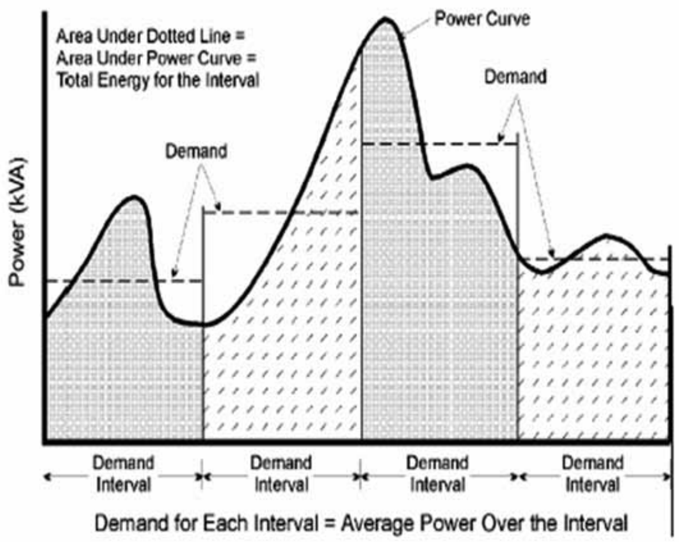


Figure 5-2 Time-integrated demand

the MD recorder will be computing MD for the duration of 30 minutes as:

$$\mathbf{\frac{(2500 \times 4) + (3600 \times 12) + (4100 \times 6) + (3800 \times 8)}{30} = 3606.7\ kVA}$$

## 5.3 LOAD MANAGEMENT STRATEGIES

Various techniques applicable to optimize maximum demand of an industry include:

- Rescheduling loads;
- Staggering of motor loads;
- Storage of products/in process material/process utilities like refrigeration;
- Shedding of non-essential loads;
- Operation of captive power generation; and
- Reactive power compensation.

### 5.3.1 Rescheduling and staggering loads

In Figure 5-3 the left side shows the demand curve of a consumer before load shifting, and the right side shows the demand curve of a unit after load shifting (leading to kVA reduction).

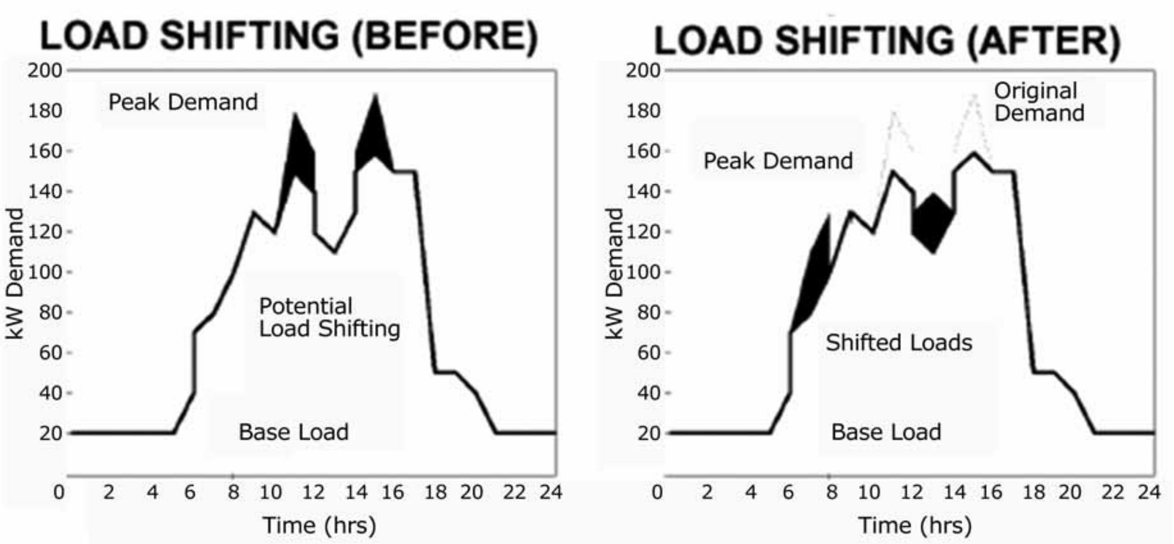


Figure 5-3 Load shifting

### 5.3.2 Storage of products in process materials and process utilities like refrigeration

In many plants, studies reveal extra capacity available, for producing certain products, in process material and utilities like pumps and refrigeration, all of which consume electricity. Using these capacities during lean demand durations like late night hours, the maximum demand during peak hours can be optimized. One example may be pumping and storing all water needs during off-peak hours in overhead tanks and reducing corresponding demand during peak hours.

### 5.3.3 How ice storage helps in demand control

In order for 1kg of ice to form, about 80kcals must be rejected from water at 0°C, and forming 38kg of ice will require around one TR of refrigeration. Thus, making ice during low peak demand night hours and using this stored refrigeration capacity during daytime helps to reduce corresponding peak demand. Dairy plants, pharmaceuticals, bulk drugs, and processing industries with massive refrigeration capacities can adopt refrigeration storage for MD control since every TR of load shifted means 1.2 to 2.5 kW per TR demand shifting.

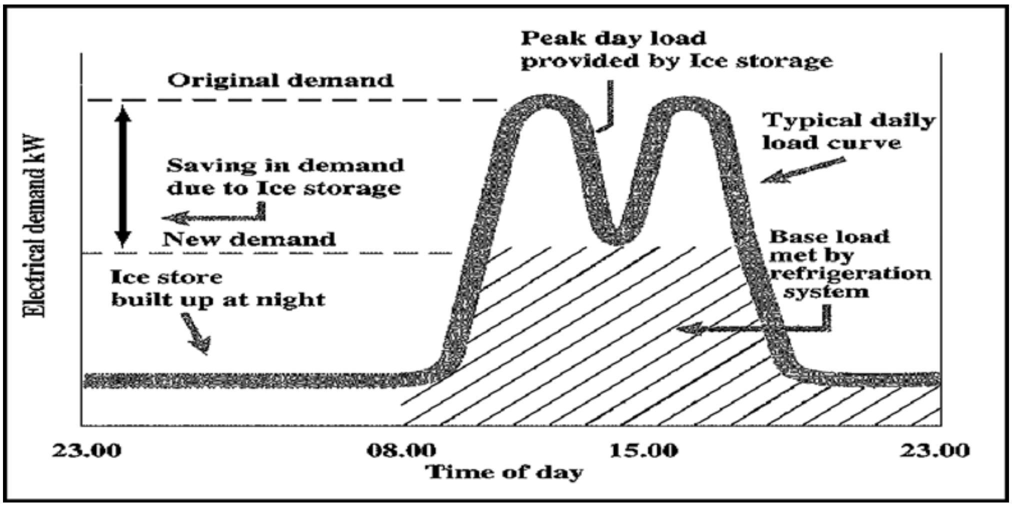


Figure 5-4 Using ice storage to reduce peak demand

## 5.4 POWER FACTOR (PF) IMPROVEMENT

In most modern electrical distribution systems, the predominant loads are resistive and inductive.

- Typical resistive loads are incandescent lighting and resistance heating.
- Typical inductive loads are A.C. Motors, induction furnaces, transformers and ballast-type lighting.

**Inductive loads require two kinds of power:**

- Active (or working) power to perform the work (motion), and
- Reactive power to create and maintain electromagnetic fields.

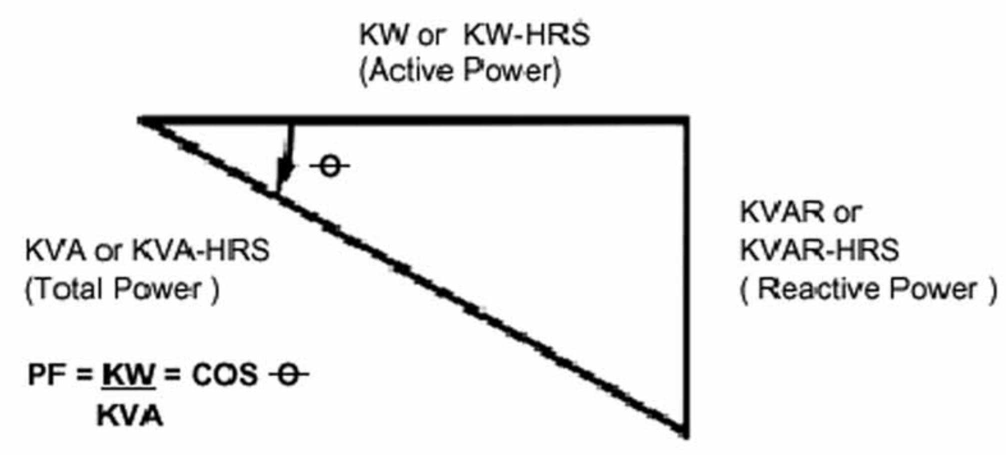


Figure 5-5 Maximizing capacity

The vector sum of the active power and reactive power make up the total (or apparent) power used. This is the power to be supplied by the utility for meeting all active and reactive power needs of users and utility electrical generation and distribution systems are designed accordingly.

Since it is only the active power or kilowatts that are of real use, there is an advantage in operating with a power factor close to unity—that is, drawing close to zero reactive power from the utility. In this way, the capacity of a utility electrical network can be optimally used, with minimum losses. In fact, the utilities penalize users for low power factors and sometimes incentivize high power factors at the user end, in their tariff structures. Installing and maintaining capacitors helps industry to balance the reactive power of inductive loads and to improve power factors at the user end, which also offers benefits of better voltage, reduced maximum demand, and lower distribution losses within the industry premises.

**Capacitor locations:**

For motors of 50 hp and above, it is best to install power factor correction capacitors at the motor terminals since distribution circuit loading is reduced. Figure 5-6 shows capacitor banks connected at the bus for each motor control centre. This compromise to Method 1 will reduce installation costs. The least expensive method shows capacitor banks connected at the service entrance. However, the disadvantage is that higher feeder currents still flow from the service entrance to the end-of-line equipment and will only benefit the utility in a real sense.

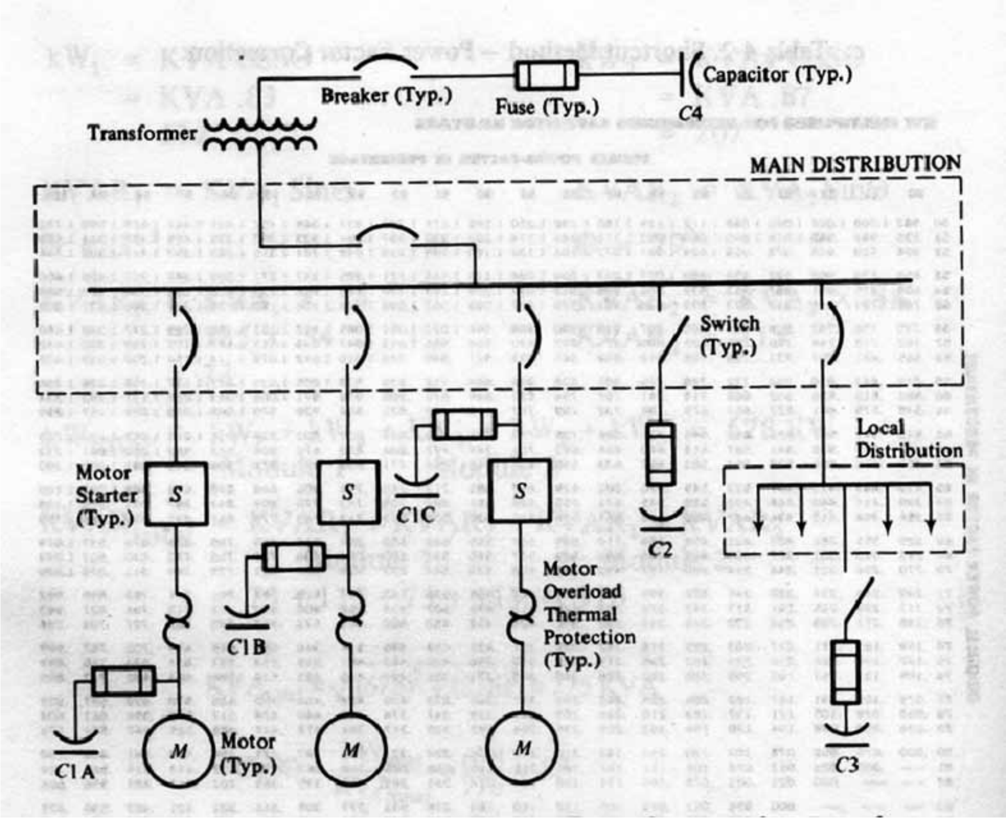


Figure 5-6 Capacitor array

PF improvement can significantly reduce distribution loads and maximum demand within the facility.

As current flows through conductors, the conductors are heated up due to resistance property; this is called distribution loss. In industry this loss can be anywhere from less than 1% to as high as 6%. Distribution loss is proportional to square of current handled, which declines as the power factor is improved, especially at use end locations.

$$\% \text{ Loss Reduction} = 100 \times 1 - \frac{(\text{Original P.F.})^2}{(\text{Desired P.F.})^2}$$

We know that active power is the product of apparent power and power factor; to reduce the maximum demand, it would help to keep the power factor close to unity. Reduced maximum demand charges are evaluated against investment for capacitors, for payback analysis. Tariff structure data and monthly bill analysis can help the utility to figure out cost benefits.

For maximum demand optimization, it would be desirable to adopt automatic PF controls.

### 5.4.1 Example problem:

If the maximum demand is 1500 kVA at 0.85 PF, calculate the reduction in demand with improved PF to 0.95, and work out the cost benefits of PF improvement.

*Active power kW which is being presently served = 1500 x 0.85 = 1275*

*New kVA for serving same 1275 kW of active power at 0.95 PF = 1275/0.95 = 1342*

*Reduction in maximum demand with higher PF =1500 kVA – 1342 kVA =158 kVA.*

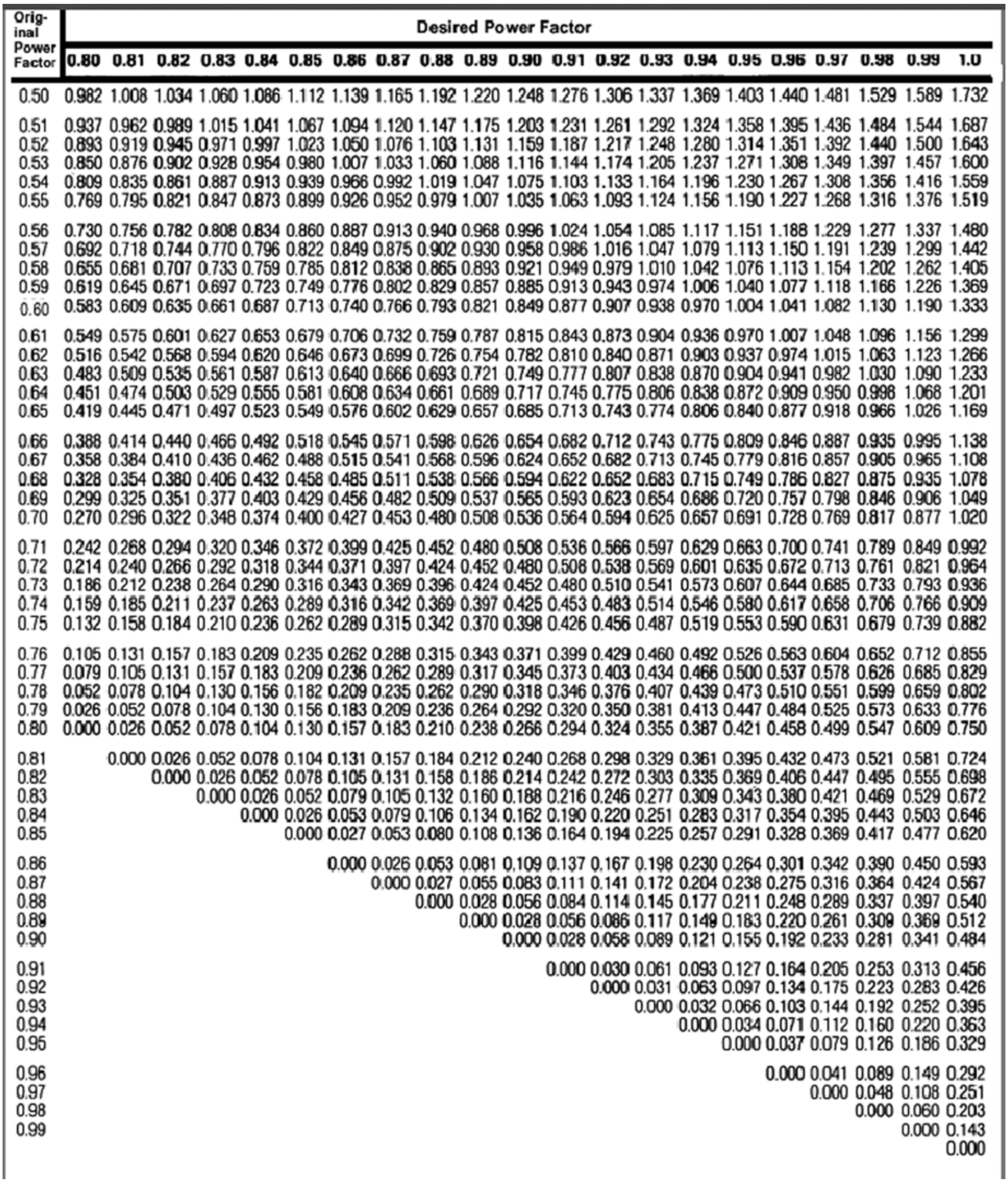
*At USD8 per kVA, MD reduction would help to reduce monthly demand charges by USD1264 or annual savings of USD15168.*

*Applying relevant multiplying factor of 0.291 from following table, the kVAr rating works out to 371.*

*The investment for capacitors @ USD6 per kVAr works out to USD2226. Against savings of USD15168 per annum, the measure thus offers a simple payback period of 0.15 years, a hugely attractive opportunity.*

Table 5-1 is useful for sizing capacitor banks.

Table 5-1 Multipliers to determine capacitor KVAR required for power factor correction



| Original Power Factor | Desired Power Factor | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **0.80** | **0.81** | **0.82** | **0.83** | **0.84** | **0.85** | **0.86** | **0.87** | **0.88** | **0.89** | **0.90** | **0.91** | **0.92** | **0.93** | **0.94** | **0.95** | **0.96** | **0.97** | **0.98** | **0.99** | **1.0** |
| 0.50 | 0.982 | 1.008 | 1.034 | 1.060 | 1.086 | 1.112 | 1.139 | 1.165 | 1.192 | 1.220 | 1.248 | 1.276 | 1.306 | 1.337 | 1.369 | 1.403 | 1.440 | 1.481 | 1.529 | 1.589 | 1.732 |
| 0.51 | 0.937 | 0.962 | 0.989 | 1.015 | 1.041 | 1.067 | 1.094 | 1.120 | 1.147 | 1.175 | 1.203 | 1.231 | 1.261 | 1.292 | 1.324 | 1.358 | 1.395 | 1.436 | 1.484 | 1.544 | 1.687 |
| 0.52 | 0.893 | 0.919 | 0.945 | 0.971 | 0.997 | 1.023 | 1.050 | 1.076 | 1.103 | 1.131 | 1.159 | 1.187 | 1.217 | 1.248 | 1.280 | 1.314 | 1.351 | 1.392 | 1.440 | 1.500 | 1.643 |
| 0.53 | 0.850 | 0.876 | 0.902 | 0.928 | 0.954 | 0.980 | 1.007 | 1.033 | 1.060 | 1.088 | 1.116 | 1.144 | 1.174 | 1.205 | 1.237 | 1.271 | 1.308 | 1.349 | 1.397 | 1.457 | 1.600 |
| 0.54 | 0.809 | 0.835 | 0.861 | 0.887 | 0.913 | 0.939 | 0.966 | 0.992 | 1.019 | 1.047 | 1.075 | 1.103 | 1.133 | 1.164 | 1.196 | 1.230 | 1.267 | 1.308 | 1.356 | 1.416 | 1.559 |
| 0.55 | 0.769 | 0.795 | 0.821 | 0.847 | 0.873 | 0.899 | 0.926 | 0.952 | 0.979 | 1.007 | 1.035 | 1.063 | 1.093 | 1.124 | 1.156 | 1.190 | 1.227 | 1.268 | 1.316 | 1.376 | 1.519 |
| 0.56 | 0.730 | 0.756 | 0.782 | 0.808 | 0.834 | 0.860 | 0.887 | 0.913 | 0.940 | 0.968 | 0.996 | 1.024 | 1.054 | 1.085 | 1.117 | 1.151 | 1.188 | 1.229 | 1.277 | 1.337 | 1.480 |
| 0.57 | 0.692 | 0.718 | 0.744 | 0.770 | 0.796 | 0.822 | 0.849 | 0.875 | 0.902 | 0.930 | 0.958 | 0.986 | 1.016 | 1.047 | 1.079 | 1.113 | 1.150 | 1.191 | 1.239 | 1.299 | 1.442 |
| 0.58 | 0.655 | 0.681 | 0.707 | 0.733 | 0.759 | 0.785 | 0.812 | 0.838 | 0.865 | 0.893 | 0.921 | 0.949 | 0.979 | 1.010 | 1.042 | 1.076 | 1.113 | 1.154 | 1.202 | 1.262 | 1.405 |
| 0.59 | 0.619 | 0.645 | 0.671 | 0.697 | 0.723 | 0.749 | 0.776 | 0.802 | 0.829 | 0.857 | 0.885 | 0.913 | 0.943 | 0.974 | 1.006 | 1.040 | 1.077 | 1.118 | 1.166 | 1.226 | 1.369 |
| 0.60 | 0.583 | 0.609 | 0.635 | 0.661 | 0.687 | 0.713 | 0.740 | 0.766 | 0.793 | 0.821 | 0.849 | 0.877 | 0.907 | 0.938 | 0.970 | 1.004 | 1.041 | 1.082 | 1.130 | 1.190 | 1.333 |
| 0.61 | 0.549 | 0.575 | 0.601 | 0.627 | 0.653 | 0.679 | 0.706 | 0.732 | 0.759 | 0.787 | 0.815 | 0.843 | 0.873 | 0.904 | 0.936 | 0.970 | 1.007 | 1.048 | 1.096 | 1.156 | 1.299 |
| 0.62 | 0.516 | 0.542 | 0.568 | 0.594 | 0.620 | 0.646 | 0.673 | 0.699 | 0.726 | 0.754 | 0.782 | 0.810 | 0.840 | 0.871 | 0.903 | 0.937 | 0.974 | 1.015 | 1.063 | 1.123 | 1.266 |
| 0.63 | 0.483 | 0.509 | 0.535 | 0.561 | 0.587 | 0.613 | 0.640 | 0.666 | 0.693 | 0.721 | 0.749 | 0.777 | 0.807 | 0.838 | 0.870 | 0.904 | 0.941 | 0.982 | 1.030 | 1.090 | 1.233 |
| 0.64 | 0.451 | 0.474 | 0.503 | 0.529 | 0.555 | 0.581 | 0.608 | 0.634 | 0.661 | 0.689 | 0.717 | 0.745 | 0.775 | 0.806 | 0.838 | 0.872 | 0.909 | 0.950 | 0.998 | 1.068 | 1.201 |
| 0.65 | 0.419 | 0.445 | 0.471 | 0.497 | 0.523 | 0.549 | 0.576 | 0.602 | 0.629 | 0.657 | 0.685 | 0.713 | 0.743 | 0.774 | 0.806 | 0.840 | 0.877 | 0.918 | 0.966 | 1.026 | 1.169 |
| 0.66 | 0.388 | 0.414 | 0.440 | 0.466 | 0.492 | 0.518 | 0.545 | 0.571 | 0.598 | 0.626 | 0.654 | 0.682 | 0.712 | 0.743 | 0.775 | 0.809 | 0.846 | 0.887 | 0.935 | 0.995 | 1.138 |
| 0.67 | 0.358 | 0.384 | 0.410 | 0.436 | 0.462 | 0.488 | 0.515 | 0.541 | 0.568 | 0.596 | 0.624 | 0.652 | 0.682 | 0.713 | 0.745 | 0.779 | 0.816 | 0.857 | 0.905 | 0.965 | 1.108 |
| 0.68 | 0.328 | 0.354 | 0.380 | 0.406 | 0.432 | 0.458 | 0.485 | 0.511 | 0.538 | 0.566 | 0.594 | 0.622 | 0.652 | 0.683 | 0.715 | 0.749 | 0.786 | 0.827 | 0.875 | 0.935 | 1.078 |
| 0.69 | 0.299 | 0.325 | 0.351 | 0.377 | 0.403 | 0.429 | 0.456 | 0.482 | 0.509 | 0.537 | 0.565 | 0.593 | 0.623 | 0.654 | 0.686 | 0.720 | 0.757 | 0.798 | 0.846 | 0.906 | 1.049 |
| 0.70 | 0.270 | 0.296 | 0.322 | 0.348 | 0.374 | 0.400 | 0.427 | 0.453 | 0.480 | 0.508 | 0.536 | 0.564 | 0.594 | 0.625 | 0.657 | 0.691 | 0.728 | 0.769 | 0.817 | 0.877 | 1.020 |
| 0.71 | 0.242 | 0.268 | 0.294 | 0.320 | 0.346 | 0.372 | 0.399 | 0.425 | 0.452 | 0.480 | 0.508 | 0.536 | 0.566 | 0.597 | 0.629 | 0.663 | 0.700 | 0.741 | 0.789 | 0.849 | 0.992 |
| 0.72 | 0.214 | 0.240 | 0.266 | 0.292 | 0.318 | 0.344 | 0.371 | 0.397 | 0.424 | 0.452 | 0.480 | 0.508 | 0.538 | 0.569 | 0.601 | 0.635 | 0.672 | 0.713 | 0.761 | 0.821 | 0.964 |
| 0.73 | 0.186 | 0.212 | 0.238 | 0.264 | 0.290 | 0.316 | 0.343 | 0.369 | 0.396 | 0.424 | 0.452 | 0.480 | 0.510 | 0.541 | 0.573 | 0.607 | 0.644 | 0.685 | 0.733 | 0.793 | 0.936 |
| 0.74 | 0.159 | 0.185 | 0.211 | 0.237 | 0.263 | 0.289 | 0.316 | 0.342 | 0.369 | 0.397 | 0.425 | 0.453 | 0.483 | 0.514 | 0.546 | 0.580 | 0.617 | 0.658 | 0.706 | 0.766 | 0.909 |
| 0.75 | 0.132 | 0.158 | 0.184 | 0.210 | 0.236 | 0.262 | 0.289 | 0.315 | 0.342 | 0.370 | 0.398 | 0.426 | 0.456 | 0.487 | 0.519 | 0.553 | 0.590 | 0.631 | 0.679 | 0.739 | 0.882 |
| 0.76 | 0.105 | 0.131 | 0.157 | 0.183 | 0.209 | 0.235 | 0.262 | 0.288 | 0.315 | 0.343 | 0.371 | 0.399 | 0.429 | 0.460 | 0.492 | 0.526 | 0.563 | 0.604 | 0.652 | 0.712 | 0.855 |
| 0.77 | 0.079 | 0.105 | 0.131 | 0.157 | 0.183 | 0.209 | 0.236 | 0.262 | 0.289 | 0.317 | 0.345 | 0.373 | 0.403 | 0.434 | 0.466 | 0.500 | 0.537 | 0.578 | 0.626 | 0.685 | 0.829 |
| 0.78 | 0.052 | 0.078 | 0.104 | 0.130 | 0.156 | 0.182 | 0.209 | 0.235 | 0.262 | 0.290 | 0.318 | 0.346 | 0.376 | 0.407 | 0.439 | 0.473 | 0.510 | 0.551 | 0.599 | 0.659 | 0.802 |
| 0.79 | 0.026 | 0.052 | 0.078 | 0.104 | 0.130 | 0.156 | 0.183 | 0.209 | 0.236 | 0.264 | 0.292 | 0.320 | 0.350 | 0.381 | 0.413 | 0.447 | 0.484 | 0.525 | 0.573 | 0.633 | 0.776 |
| 0.80 | 0.000 | 0.026 | 0.052 | 0.078 | 0.104 | 0.130 | 0.157 | 0.183 | 0.210 | 0.238 | 0.266 | 0.294 | 0.324 | 0.355 | 0.387 | 0.421 | 0.458 | 0.499 | 0.547 | 0.609 | 0.750 |
| 0.81 | | 0.000 | 0.026 | 0.052 | 0.078 | 0.104 | 0.131 | 0.157 | 0.184 | 0.212 | 0.240 | 0.268 | 0.298 | 0.329 | 0.361 | 0.395 | 0.432 | 0.473 | 0.521 | 0.581 | 0.724 |
| 0.82 | | | 0.000 | 0.026 | 0.052 | 0.078 | 0.105 | 0.131 | 0.158 | 0.186 | 0.214 | 0.242 | 0.272 | 0.303 | 0.335 | 0.369 | 0.406 | 0.447 | 0.495 | 0.555 | 0.698 |
| 0.83 | | | | 0.000 | 0.026 | 0.052 | 0.079 | 0.105 | 0.132 | 0.160 | 0.188 | 0.216 | 0.246 | 0.277 | 0.309 | 0.343 | 0.380 | 0.421 | 0.469 | 0.529 | 0.672 |
| 0.84 | | | | | 0.000 | 0.026 | 0.053 | 0.079 | 0.106 | 0.134 | 0.162 | 0.190 | 0.220 | 0.251 | 0.283 | 0.317 | 0.354 | 0.395 | 0.443 | 0.503 | 0.646 |
| 0.85 | | | | | | 0.000 | 0.027 | 0.053 | 0.080 | 0.108 | 0.136 | 0.164 | 0.194 | 0.225 | 0.257 | 0.291 | 0.328 | 0.369 | 0.417 | 0.477 | 0.620 |
| 0.86 | | | | | | | 0.000 | 0.026 | 0.053 | 0.081 | 0.109 | 0.137 | 0.167 | 0.198 | 0.230 | 0.264 | 0.301 | 0.342 | 0.390 | 0.450 | 0.593 |
| 0.87 | | | | | | | | 0.000 | 0.027 | 0.055 | 0.083 | 0.111 | 0.141 | 0.172 | 0.204 | 0.238 | 0.275 | 0.316 | 0.364 | 0.424 | 0.567 |
| 0.88 | | | | | | | | | 0.000 | 0.028 | 0.056 | 0.084 | 0.114 | 0.145 | 0.177 | 0.211 | 0.248 | 0.289 | 0.337 | 0.397 | 0.540 |
| 0.89 | | | | | | | | | | 0.000 | 0.028 | 0.056 | 0.086 | 0.117 | 0.149 | 0.183 | 0.220 | 0.261 | 0.309 | 0.369 | 0.512 |
| 0.90 | | | | | | | | | | | 0.000 | 0.028 | 0.058 | 0.089 | 0.121 | 0.155 | 0.192 | 0.233 | 0.281 | 0.341 | 0.484 |
| 0.91 | | | | | | | | | | | | 0.000 | 0.030 | 0.061 | 0.093 | 0.127 | 0.164 | 0.205 | 0.253 | 0.313 | 0.456 |
| 0.92 | | | | | | | | | | | | | 0.000 | 0.031 | 0.063 | 0.097 | 0.134 | 0.175 | 0.223 | 0.283 | 0.426 |
| 0.93 | | | | | | | | | | | | | | 0.000 | 0.032 | 0.066 | 0.103 | 0.144 | 0.192 | 0.252 | 0.395 |
| 0.94 | | | | | | | | | | | | | | | 0.000 | 0.034 | 0.071 | 0.112 | 0.160 | 0.220 | 0.363 |
| 0.95 | | | | | | | | | | | | | | | | 0.000 | 0.037 | 0.079 | 0.126 | 0.186 | 0.329 |
| 0.96 | | | | | | | | | | | | | | | | | 0.000 | 0.041 | 0.089 | 0.149 | 0.292 |
| 0.97 | | | | | | | | | | | | | | | | | | 0.000 | 0.048 | 0.108 | 0.251 |
| 0.98 | | | | | | | | | | | | | | | | | | | 0.000 | 0.060 | 0.203 |
| 0.99 | | | | | | | | | | | | | | | | | | | | 0.000 | 0.143 |
| | | | | | | | | | | | | | | | | | | | | | 0.000 |

This table can be used for selecting capacitor ratings. Based on present Power Factor on Y axis and desirable Power Factor on X axis, this table gives the multiplying factor to be applied to measured kilowatt value, to arrive at the rating in kVAr of the capacitor to be installed.

## 5.5 TIPS FOR ENERGY-EFFICIENT ELECTRICAL LOAD MANAGEMENT

- Review the tariff agreement with the utility supplier to meet requirements at optimum cost.
- Balance kilowatt loads on three phases of supply.
- Schedule plant operations to maintain a high load factor.
- Shift loads to off-peak times where possible.
- Minimize maximum demand by controlling loads through an automatic demand controller.
- Stagger start-up times for equipment with large starting currents to minimize load peaking.
- Use standby electric generation equipment for on-peak high load periods.
- Correct power factor to well above 0.90 by installing additional capacitors and automatic power factor controllers, avoid motor under-load conditions, and take advantage of PF improvement incentives if any are available.
- Ensure that all capacitors are in line and functional, by checking charging current.
- Relocate transformers close to main loads.
- Set transformer taps to optimum settings.
- Disconnect primary power to transformers that do not serve any active loads.
- Consider on-site captive generation or cogeneration as a cheaper/efficient alternative.
- Export power to grid if there is any surplus in captive generation.
- Periodically, calliberate the utility’s electricity meter with your own meter for accuracy.
- Shut off unnecessary and idle process equipment, utilities, and office equipment like computers, printers, and copiers at night.

# 6. ENERGY EFFICIENCY IN ELECTRIC MOTORS

## 6.1 INTRODUCTION

Motors convert electrical energy into mechanical energy by the interaction between the magnetic fields set up in the stator and rotor windings. Industrial electric motors can be broadly classified as induction motors, direct current motors, or synchronous motors. All motor types have the same four operating components: stator (stationary windings), rotor (rotating windings), bearings, and frame (enclosure). Squirrel cage induction motors account for over 90% of the population.

Figure 6-1 Induction motor

## 6.2 SALIENT ASPECTS OF MOTOR PERFORMANCE

**Motor speed**

The speed of a motor is the number of revolutions in a given time frame, typically revolutions per minute (RPM). The synchronous speed in RPM is given by the following equation, where the frequency is in hertz or cycles per second:

$$\text{Synchronous Speed (RPM)} = \frac{120 \text{ x Frequency}}{\text{Poles}}$$

It can also be shown that the speed of an AC motor can be varied infinitely by changing the frequency. The actual speed at which the motor operates will be less than the synchronous speed. The difference between synchronous and full load speed is called slip and is measured in as a percentage. It is calculated using the following equation:

$$\text{Slip (\%)} = \frac{\text{Synchronous Speed-Full Load Speed}}{\text{Synchronous Speed}} \times 100$$

**Voltage frequency relation**

Impedance of an inductor is proportional to frequency. At low frequencies, this impedance approaches zero, making the circuit appear to be a short-circuit. To maintain a constant flux in the motor, the voltage to the motor must also be changed. This ratio is constant over most of the entire speed range By keeping the ratio constant, a fixed speed induction motor can be made to run at variable speed offering constant torque. At low speeds, due to the motor having inherent resistance in the windings, the ratio must be altered to provide enough magnetizing flux to spin the motor. The VFD allows this relationship to be altered by changing the voltage boost parameter.

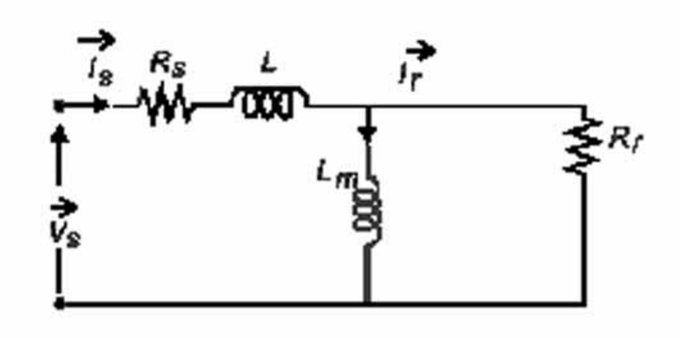


Figure 6-2 Boosting voltage

Application of variable frequency drives and variable speed drives, for capacity control of pumps, fans, compressors, process control, as against other conventional methods, is the most relevant energy conservation opportunity in the electric motor industry.

**Load versus power factor**

As the load on the motor is reduced, the magnitude of the **active current** declines. However, there is not a corresponding reduction in the **magnetizing current**, with the result that the motor power factor declines, or gets worse, with a reduction in applied load.

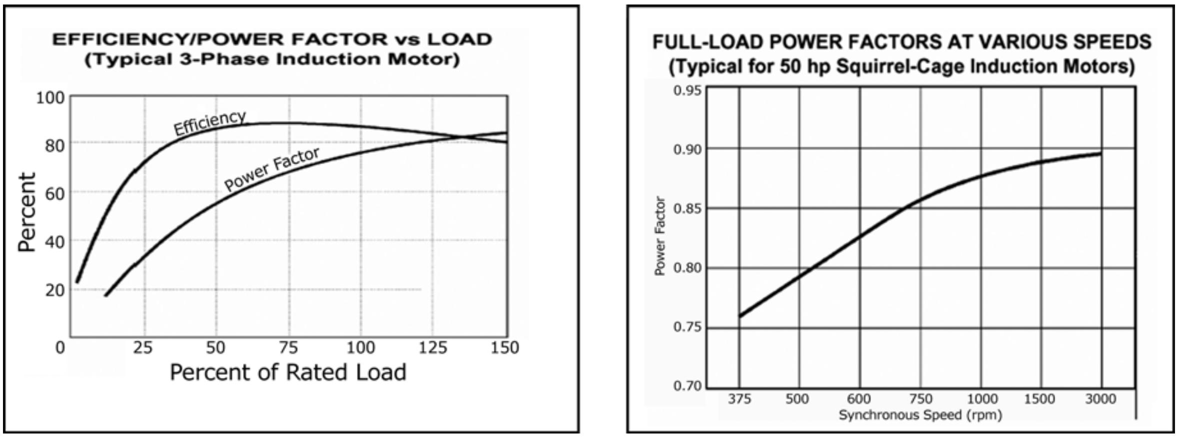


Figure 6-3 Load and power

**Motor efficiency versus load**

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} \times 100 = \frac{\text{Input} - \text{Losses}}{\text{Input}} \times 100 = \frac{746 \times \text{HP Output}}{\text{Watts Input}} \times 100$$

Electric motors are electromagnetic energy converters whose function is based on the force exerted between electrical currents and magnetic fields, which are usually electrically excited as well. Due to their principle of functioning, electric motors have a relatively high efficiency. A typical efficiency value for an 11 kW standard motor is around 90%, for 100 kW, up to 94%. The efficiency levels of large motors are higher than those of smaller motors.

It should be noted that peak efficiency occurs at about 75% loading and drops significantly when loading is below about 30%.

## 6.3 THE TYPES OF MOTOR LOSS

**Core losses:**

Core loss is around 22% of total loss at full load. Core losses represent the energy required to magnetize the core material (hysteresis) and are expended by small electric currents that flow in the core (eddy currents). Core loss of a motor is constant and is independent of the motor load current, and thus it accounts for a much higher percentage of the losses at low motor loads.

**Stator and rotor resistance losses:**

Loss due to stator and rotor resistance is about 56% of total loss at full load. It occers due to the current flow (I) through the motor conductors of resistance (R). Loss is proportional to the square of the stator and rotor current and is also called I2R loss; it is influenced largely by loading on motor.

**Friction and windage losses:**

Loss due to friction and wind represents about 11% of total loss at full load. This loss results from friction within the shaft bearings and from the resistance to air being circulated through the motor by cooling fans. It depends on bearing quality and condition to a great extent.

**Stray load losses:**

Stray load loss is about 11% of total loss at full load. Stray load loss results from leakage of magnetic flux, and depends on the rotor slot design. Like I2R losses, it is dependent on the square of the load current and tends to increase with motor load.

## 6.4 ENERGY EFFICIENCY OPPORTUNITIES IN MOTORS

Two approaches, namely a systems approach and operational measures, can be adopted for energy efficiency improvements in motors.

### 6.4.1 Systems approach

The key to systematic or large energy savings in motors involves several fundamental procedures:

- Switching off equipment when not needed.
- Providing energy-efficient capacity controls (variable frequency drives or VFDs) instead of throttling.
- Process re-engineering for reducing work done.

### 6.4.2 Operational measures

Operational measures for energy efficiency include the following:

**Maintain voltage close to rating:**

Although motors are designed to operate within 10% of nameplate voltage, large variations significantly reduce efficiency, power factor, and service life. When operating at less than 95% of design voltage, motors typically lose 2 to 4 points of efficiency, and service temperatures increase up to 20°F, greatly reducing insulation life. Running a motor above its design voltage also reduces power factor and efficiency.

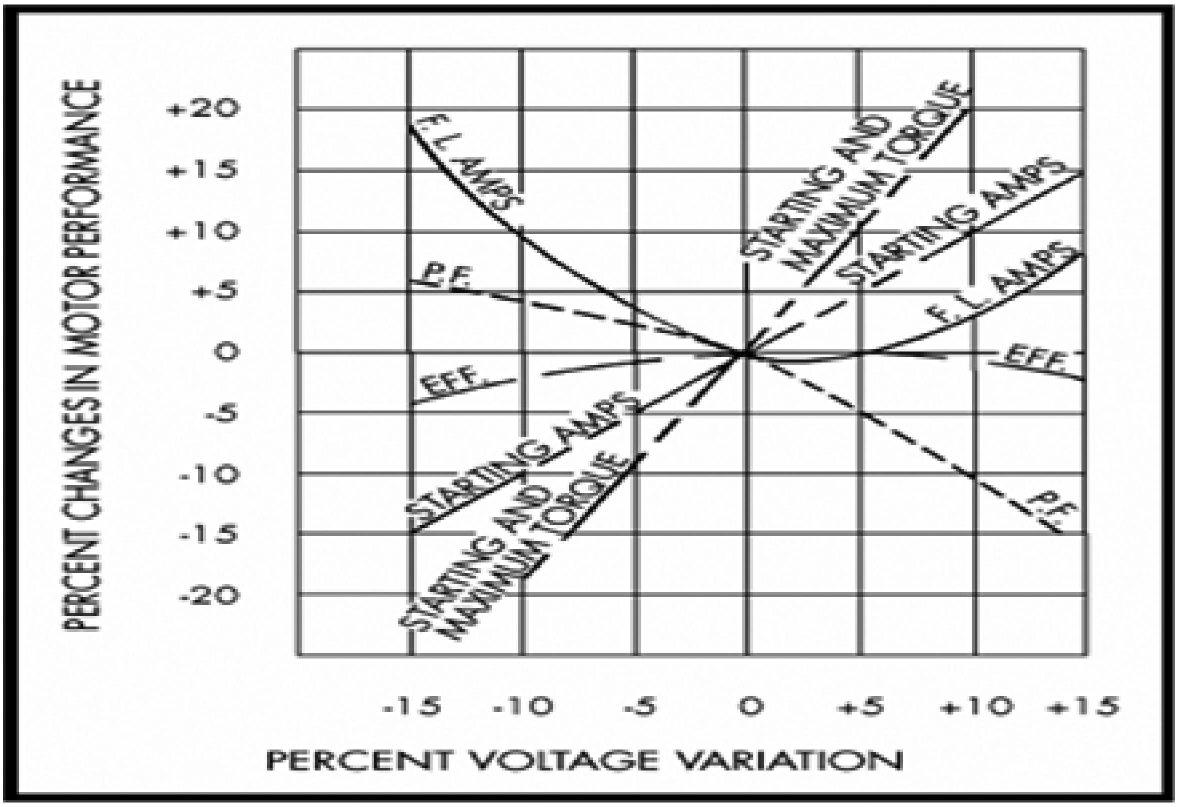


Figure 6-4 Voltage variation effect on motor performance

**Minimize phase imbalance:**

The voltage of each phase in a three-phase system should be of equal magnitude, symmetrical, and separated by 120°. Phase balance should be within 1% to avoid derating of the motor. Several factors can affect voltage balance: single-phase loads on any one phase, different cable sizing, or faulty circuits. An unbalanced system increases distribution system losses and reduces motor efficiency.

Voltage imbalance is defined as 100 times the maximum deviation of the line voltage from the average voltage on a three-phase system divided by the average voltage. If line voltages measured are 431, 438, and 427, the average is 432. The voltage imbalance is given by

$$\left[\frac{432-427}{432}\right]\times 100 = 1.1\%$$

**Minimize rewind losses:**

Rewinding can reduce motor efficiency and reliability. A rewind-versus-replace decision is quite complicated and depends on such variables as the rewind cost, expected rewind loss, energy-efficient motor purchase price, motor size and original efficiency, load factor, annual operating hours, electricity price, and others. The majority of users would wish to rewind the motor rather than replace it, because it is a cheaper option; but the disadvantage is that there is not much quality assurance. During a motor failure, or in the stripping of the winding from the stator core prior to rewinding, heating involved causes exposure to high temperatures. These temperatures can, in many cases, affect the electrical characteristics of the stator core steel and result in increased iron losses and lower motor efficiency.

The only area of possible loss reduction available during the rewinding process is the copper (I2r) losses in the motor. Reduction is achieved by rewinding the motor with a larger-diameter wire so that the effective conductor area is increased, where slot area permits, resulting in a lower winding resistance. The effect is to lower the stator copper loss.

Rewinding for lower copper losses is possible only if additional slot space is available in the original stator slot, often released by use of new, higher class of insulating material replacing older, lower grade insulation. It follows that not all motors are candidates for efficiency improvement by rewinding.

Many industries operate with a population of 40%–50% rewound motors, and it would be useful to evaluate all such motors and introduce a phasing-out program and a quality assurance program for motor efficiency based on measurement of load losses, stator resistance values, etc.

**Optimize transmission efficiency:**

Motor power transmission equipment, including shafts, belts, chains, and gears, should be properly installed and maintained. When possible, use flat belts in place of V-belts. Helical gears are more efficient than worm gears; use worm gears only with motors under 10hp. As far as possible, it is better to have a direct drive, thus avoiding losses in the transmission system.

**Operate motors loaded in star mode:**

When a delta motor is connected in star mode, the voltage across the windings is reduced with a corresponding reduction in flux produced, current drawn, and torque produced; in essence, the motor is de-rated electrically, with least cost.

Star mode operation is applicable as an energy-saving opportunity with motors loaded to less than 50% of rating, as a low-cost alternative to replacement.

**Use soft starters for induction motors:**

AC induction motors are frequently used at fixed speeds, and the overwhelming majority of these are powered by direct on-line (DOL) starters and Star Delta starters which are characterized by jerky startup operations, high transient currents, maximum demand surges, and possible damage to motor windings and insulation. Soft starters use electronic controls, PLC, to gradually increase the voltage applied to the motor, starting slowly and limit start up currents. Since voltage is reduced, current also comes down, and there is reduction in iron and copper losses. Power factor is improved as the reactive current is reduced due to lower flux strength requirements, which in turn results in a higher power factor. (The starting current with a soft starter is only 1.5 to 2 times the full load current as against 5–7 times in the case of other conventional starters). With soft starters, cable sizes, contactors, and motors can be sized lower during the initial selection.

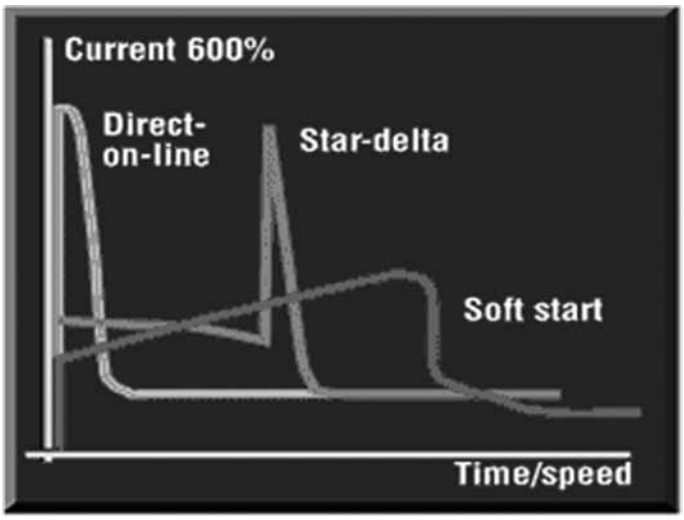


Figure 6-5 Effect of energy-saving operation

**Conduct a motor load survey and performance assessment:**

A motor load survey is a very useful audit step to bring out saving opportunities in electric motors. The steps involved are:

Inventory and list all motors by plant, department, and type of equipment, using an hour basis.

Document all name plate data.

Measure run values of input power parameters, alongside machine side parameters.

Document and record the following:

1. Cases of repeated motor burnout.
2. Motors with high no-load losses.
3. Percentage of motors loading in kW as against rated input kW.
4. Occurrences of voltage unbalance, low power factor, loose connections, and low terminal voltage.
5. Occurrences of any mechanical problems like slippages, local heating, vibration, mis-alignment, poor ventilation, and dusty conditions.
6. Machine-side inefficiencies like idle operations, throttling of pumps, damper operations in fans, leakages, etc.

Research candidate areas for VFD application for energy efficiency.

The margins in motor efficiency may often be less than 5% of consumption, but the load survey can help to make changes in driven machines or systems, which can yield 30%–40% energy savings.

## 6.5 TIPS FOR ENERGY EFFICIENCY IN MOTORS AND DRIVES

- Properly size to the load for optimum efficiency. (High-efficiency motors offer 4%–5% higher efficiency than standard motors.)
- Use energy-efficient motors where economical.
- Use synchronous motors to improve power factor.
- Check alignment.
- Provide proper ventilation. (For every 10°C increase in motor operating temperature over the recommended peak, the motor life is estimated to be halved.)
- Check for under-voltage and over-voltage conditions.
- Balance the three-phase power supply. (An umbalanced voltage can reducemotor input power by 3%–5%.)
- Demand efficiency restoration after motor rewinding. (If rewinding is not done properly, the efficiency can be reduced by 5%–8%.)

**Drives:**

- Use variable-speed drives for large variable loads.
- Use high-efficiency gear sets.
- Use precision alignment.
- Check belt tension regularly.
- Eliminate variable-pitch pulleys.
- Use nylon sandwich type energy efficient flat belts as alternatives to old v-belts.
- Eliminate inefficient couplings.
- Shut them off when not needed adopting interlocks, controls.

# 7. ENERGY EFFICIENCY IN PUMPS

## 7.1 PUMP CHOICES

Pumps come in a variety of sizes for a wide range of applications. They 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.

In principle, any liquid can be handled by any of the pump designs. Where different pump designs could be used, the centrifugal pump is generally the most economical, followed by rotary and reciprocating pumps. Although positive displacement pumps are generally more efficient than centrifugal pumps, the benefit of higher efficiency tends to be offset by increased maintenance costs.

## 7.2 CENTRIFUGAL PUMPS IN BRIEF

A centrifugal pump has a very simple design, as shown in Figure 7-1. The two main parts of the pump are the impeller and the diffuser. The impeller, which is the only moving part, is attached to a shaft and driven by a motor. Impellers are generally made of bronze, polycarbonate, cast iron, or stainless steel, as well as other materials. The diffuser (also called a volute) houses the impeller and captures and directs the water off the impeller.

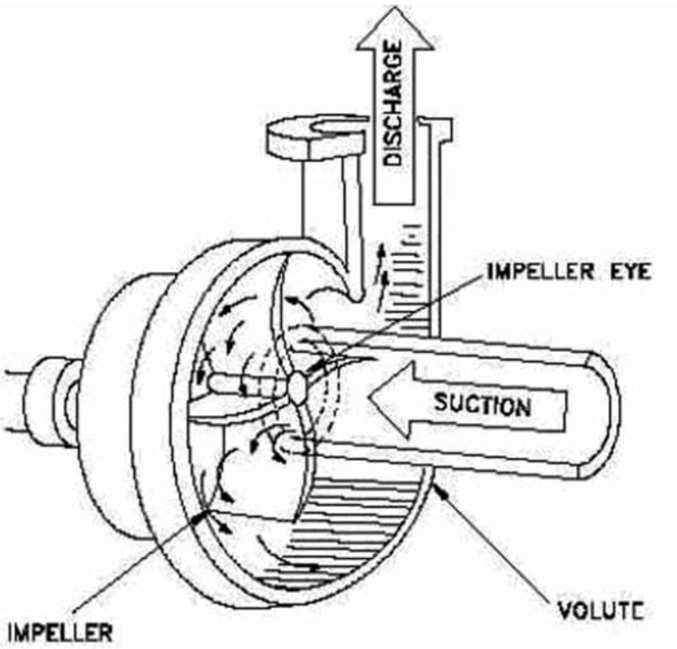


Figure 7-1  Design of centrifugal pump

Water enters the center (eye) of the impeller and exits the impeller with the help of centrifugal force. As water leaves the eye of the impeller a low-pressure area is created, causing more water to flow into the eye. Atmospheric pressure and centrifugal force cause this to happen. Velocity is developed as the water flows through the impeller, which is spinning at high speed. The water velocity is collected by the diffuser and converted to pressure by specially designed passageways that direct the flow to the discharge of the pump, or to the next impeller should the pump have a multi-stage configuration.

The pressure (head) that a pump will develop is in direct relationship to the impeller diameter, the number of impellers, the size of the impeller eye, and the shaft speed. Capacity is determined by the exit width of the impeller. The head and capacity are the main factors that affect the horsepower size of the motor to be used. The greater the quantity of water to be pumped, the more energy is required.

## 7.3 SYSTEM CHARACTERISTICS

In a pumping system, the objective, in most cases, is either to transfer a liquid from a source to a required destination (e.g. filling a high-level reservoir) or to circulate liquid around a system (e.g. as a means of heat transfer in heat exchanger).

### Head losses

Pressure is needed to make the liquid flow at the required rate, and this pressure must overcome head “losses” in the system. Losses are of two types: static head and friction head.

Static head is simply the difference in height of the supply and destination reservoirs, as shown on the left side in Figure 7-2. In this illustration, flow velocity in the pipe is assumed to be very small. Another example of a system with only static head is pumping into a pressurized vessel with short pipe runs. Static head is independent of flow and graphically would be shown as on the right side in Figure 7-2.

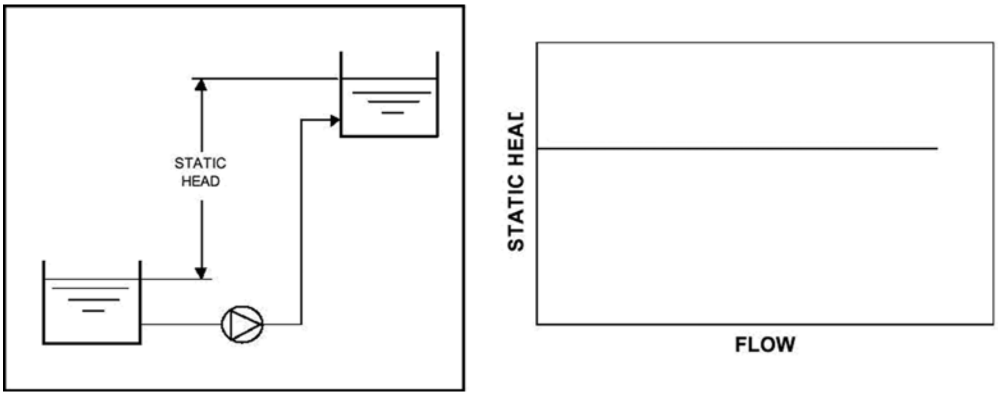


Figure 7-2 Static head

Friction head (sometimes called dynamic head loss) is the loss due to friction on the liquid being moved, in pipes, valves, and equipment in the system. Friction tables are universally available for various pipe fittings and valves. These tables show friction loss per 100 feet (or meters) of a specific pipe size at various flow rates. In the case of fittings, friction is stated as an equivalent length of pipe of the same size. The friction losses are proportional to the square of the flow rate. A closed loop circulating system, without a surface open to atmospheric pressure, would exhibit only friction losses and would have a system friction head loss vs. flow curve as shown in Figure 7-3.

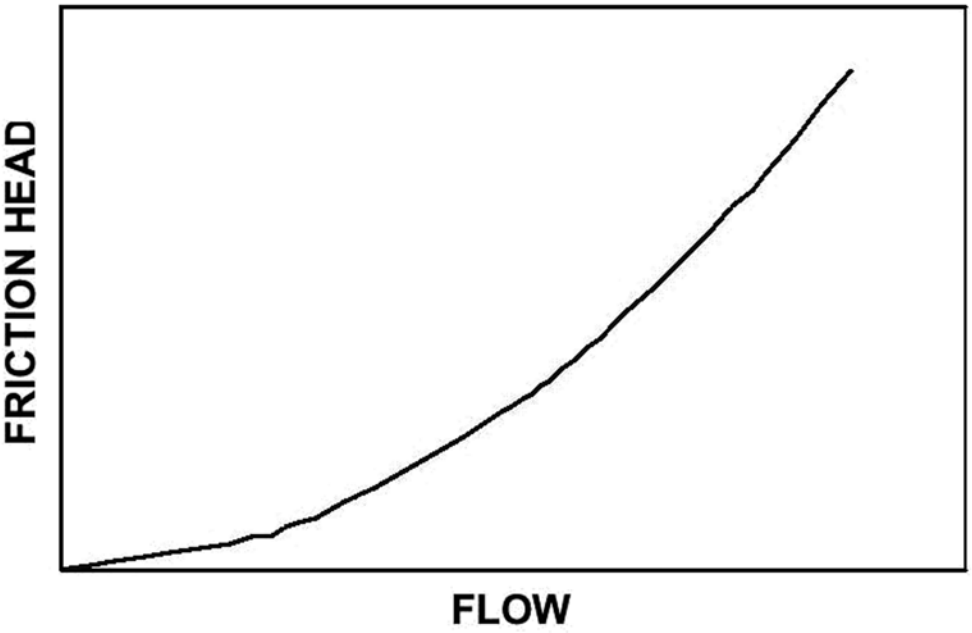


Figure 7-3 Friction head

Most systems have a combination of static and friction head, and the system curves for the two cases are shown in Figures 7-4 and 7-5. The ratio of static to friction head over the operating range influences the benefits achievable from variable speed drives.

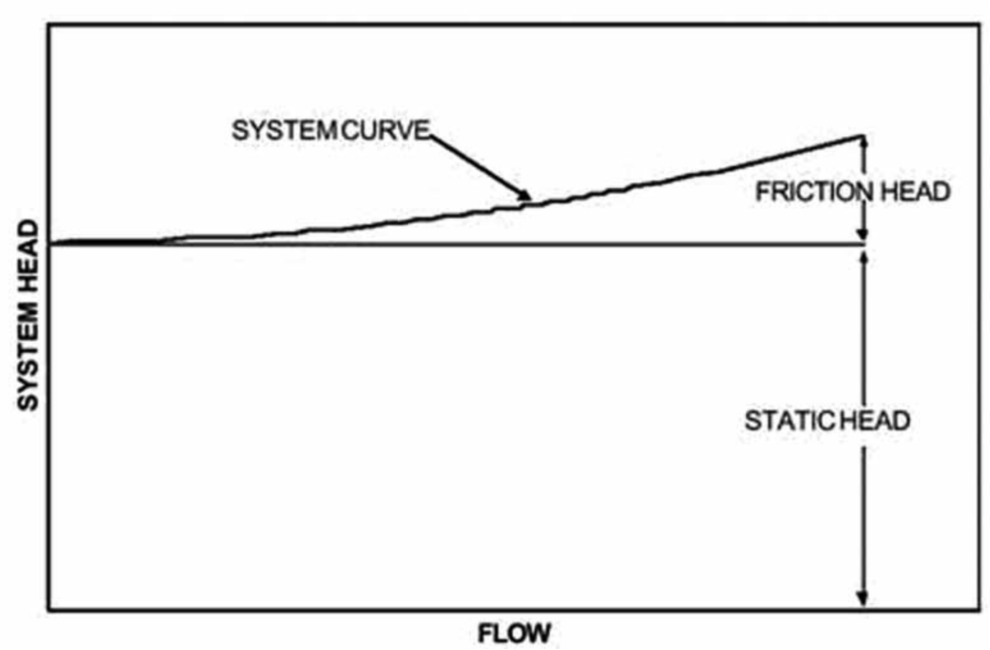


Figure 7-4 System with high static head

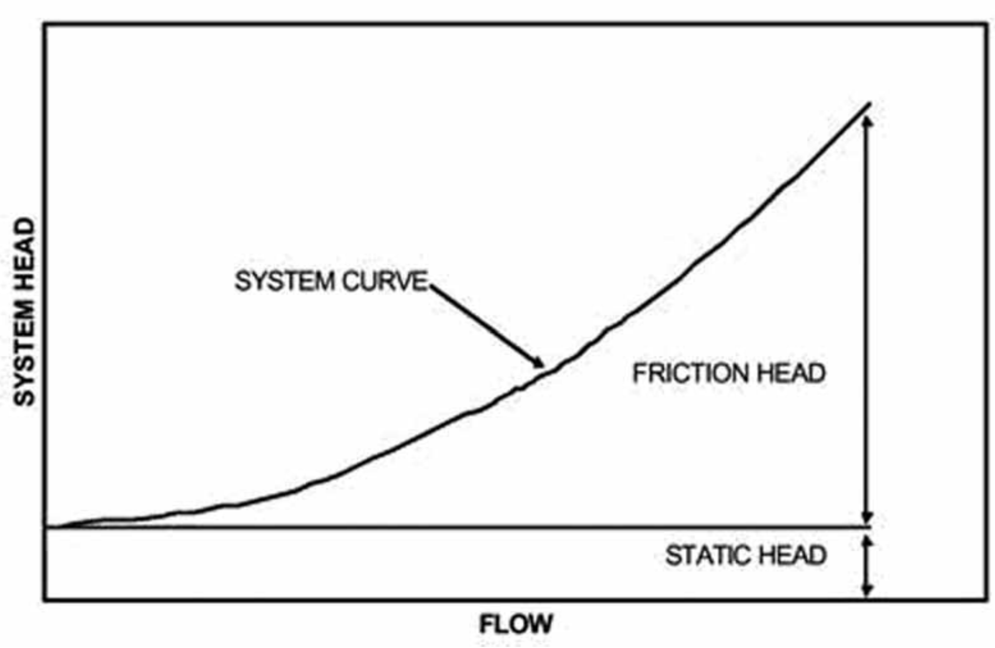


Figure 7-5 System with low static head

Static head is a characteristic of the specific installation, and reducing this head where it is possible generally reduces both the cost of the installation and the cost of pumping the liquid. Friction head losses must be minimized to reduce pumping cost, but after eliminating unnecessary pipe fittings and length, further reduction in friction head will require a larger-diameter pipe, which adds to installation cost.

**Pump operating point**

When a pump is installed in a system, the effect can be illustrated graphically by superimposing pump and system curves. The operating point will always be where the two curves intersect, as shown in Figure 7-6.

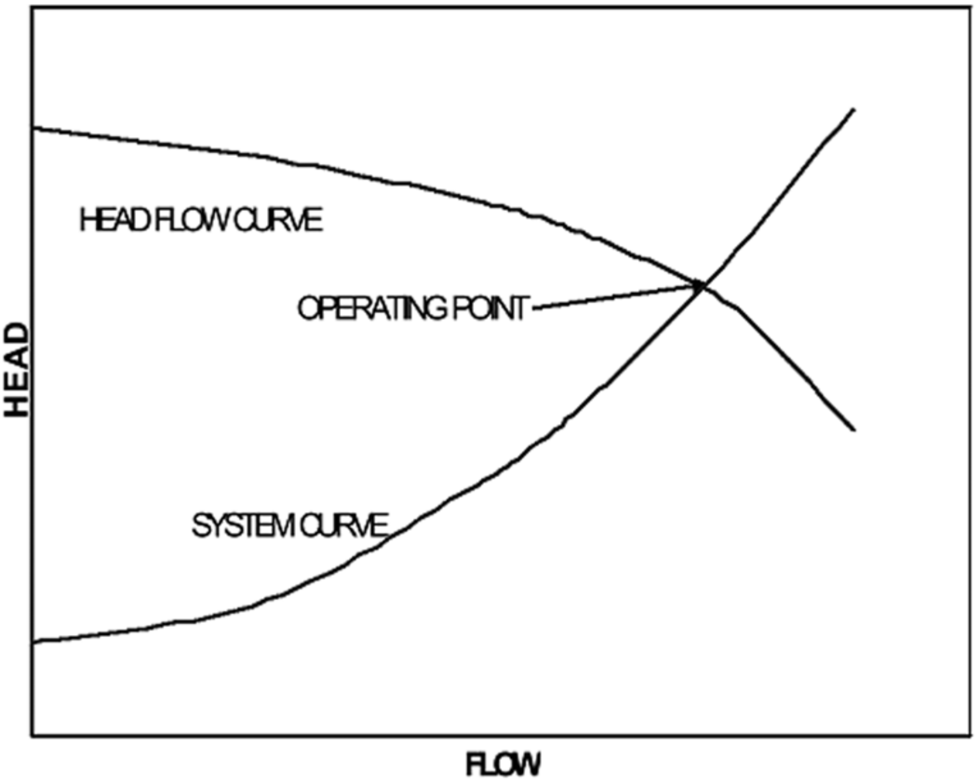


Figure 7-6 Pump operating point

It is ideal if the operating duty point of a pump is close to the design best efficiency point, which implies that careful attention is needed in sizing the pump for an application, as oversizing would lead to reduced operational efficiency.

## 7.4 TYPICAL PUMP CHARACTERISTIC CURVES

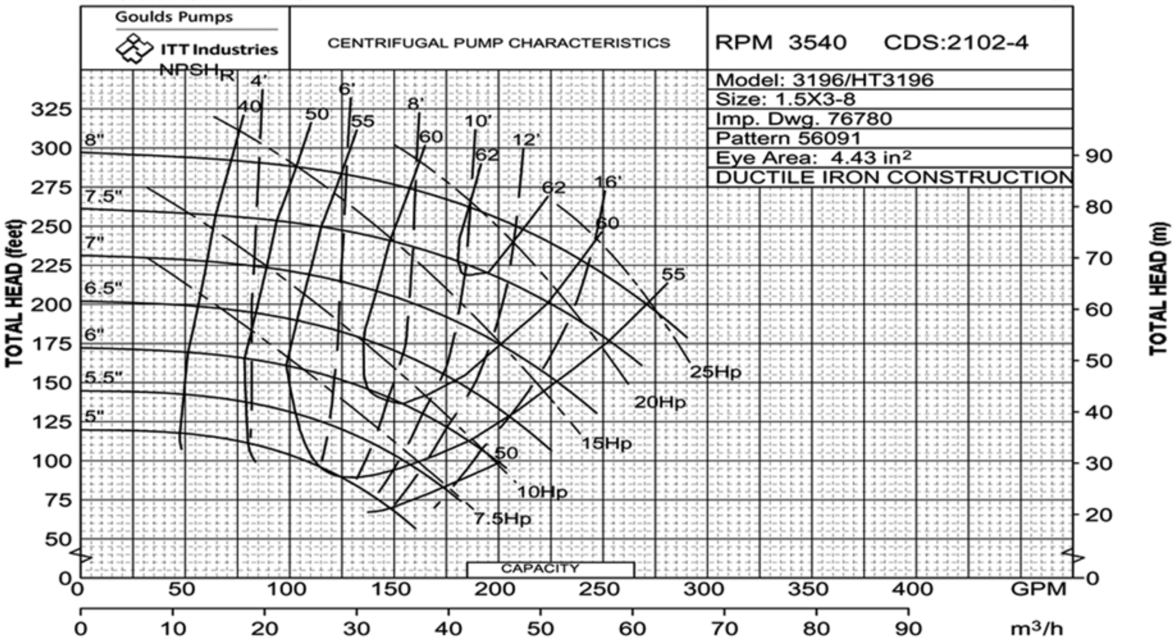


Figure 7-7 Pump operating curves

Pump operating curves as shown in Figure 7-7 relate to the head, flow, and efficiency values that can be obtained with various impellor diameter choices. The same analogy can also be applied for obtaining speed variation conditions.

Pump efficiency is linked to specific speed of the pump, and the above curves indicate constant efficiency attributes, also called iso-efficiency curves, at different head flow combinations. Once the the specific speed (which depends on head, flow, and RPM of a pump) is known, achievable pump efficiency can be predicted from standard curves.

## 7.5 FLOW CONTROL METHODS AND ENERGY EFFICIENCY

### 7.5.1 Flow control by valve control

With the valve control method, the pump runs continuously, and a valve in the pump discharge line is opened or closed to adjust the flow to the required value.

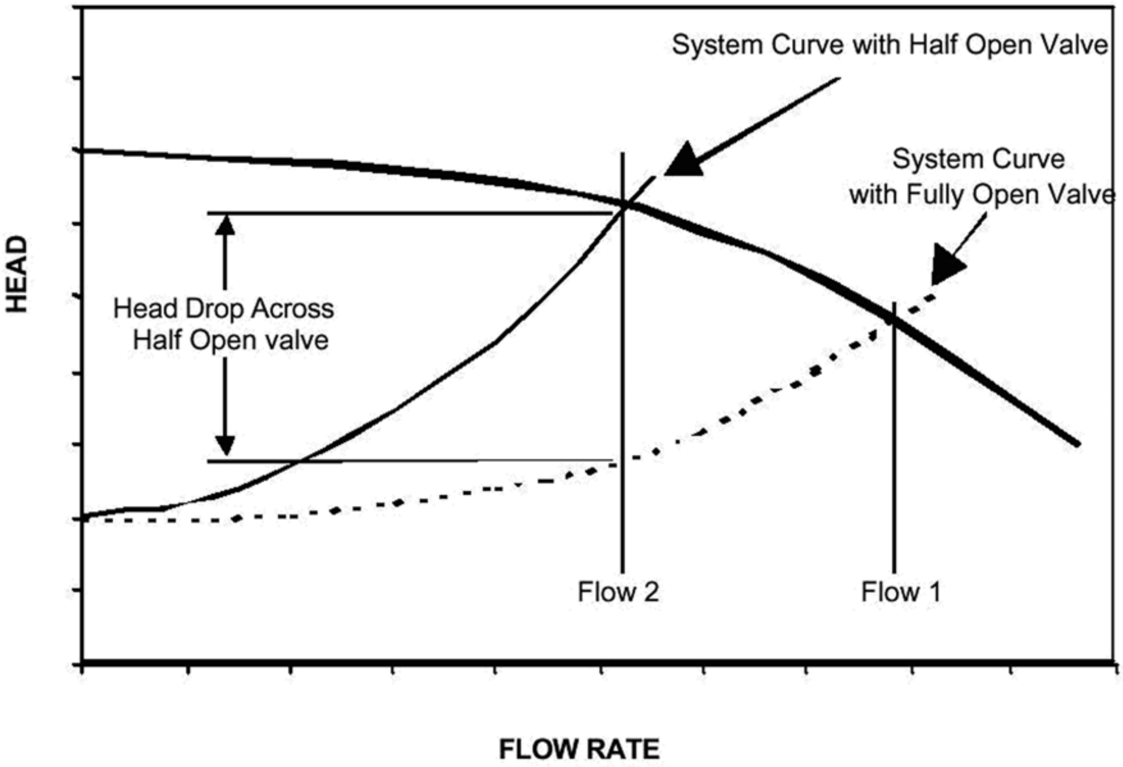


Figure 7-8 Valve control method

As shown in Figure 7-8, with the valve fully open, the pump operates at 'Flow 1.' When the valve is partially closed it introduces an additional friction loss in the system, which is proportional to flow squared. The new system curve cuts the pump curve at 'Flow 2,' which is the new operating point. The head difference between the two curves is the pressure drop across the valve.

It is usual practice with valve control to have the valve 10% shut, even at maximum flow. Energy is therefore wasted overcoming the resistance through the valve at all flow conditions. There is some reduction in pump power absorbed at the lower flow rate, but the flow multiplied by the head drop across the valve is wasted energy.

It should also be noted that, while the pump will accommodate changes in its operating point as far as it is able within its performance range, it can be forced to operate high on the curve, where its efficiency is low, and its reliability is affected.

Maintenance cost of control valves can be high, particularly with corrosive and solids-containing liquids. Therefore, the lifetime cost could be unnecessarily high.

### 7.5.2 Bypass control

With the bypass control approach, the pump runs continuously at the maximum process demand level, with a permanent bypass line attached to the outlet. When a lower flow is required, the surplus liquid is bypassed and returned to the supply source.

An alternative configuration may have a tank supplying a varying process demand, which is kept full by a fixed-duty pump running at the peak flow rate. Most of the time the tank overflows and recycles back to the pump suction. This is even less energy-efficient than a control valve because there is no reduction in power consumption with a reduction in process demand.

The small bypass line sometimes installed to prevent a pump running at zero flow is not a means of flow control, but is required for the safe operation of the pump.

### 7.5.3 Fixed flow reduction by impeller trimming

Impeller trimming refers to the process of machining the diameter of an impeller to reduce the energy added to the system fluid, and it offers a useful correction to pumps that, through overly conservative design practices or changes in system loads, are oversized for their application.

Trimming an impeller provides a lesser level of correction than buying a smaller impeller from the pump manufacturer. In many cases, the next smaller size impeller is too small for the pump load. Also, smaller impellers may not be available for the pump size in question, and impeller trimming is the only practical alternative short of replacing the entire pump/motor assembly.

Impeller trimming reduces tip speed, which in turn directly lowers the amount of energy imparted to the system fluid and lowers both the flow and pressure generated by the pump (see Figure 7-9).

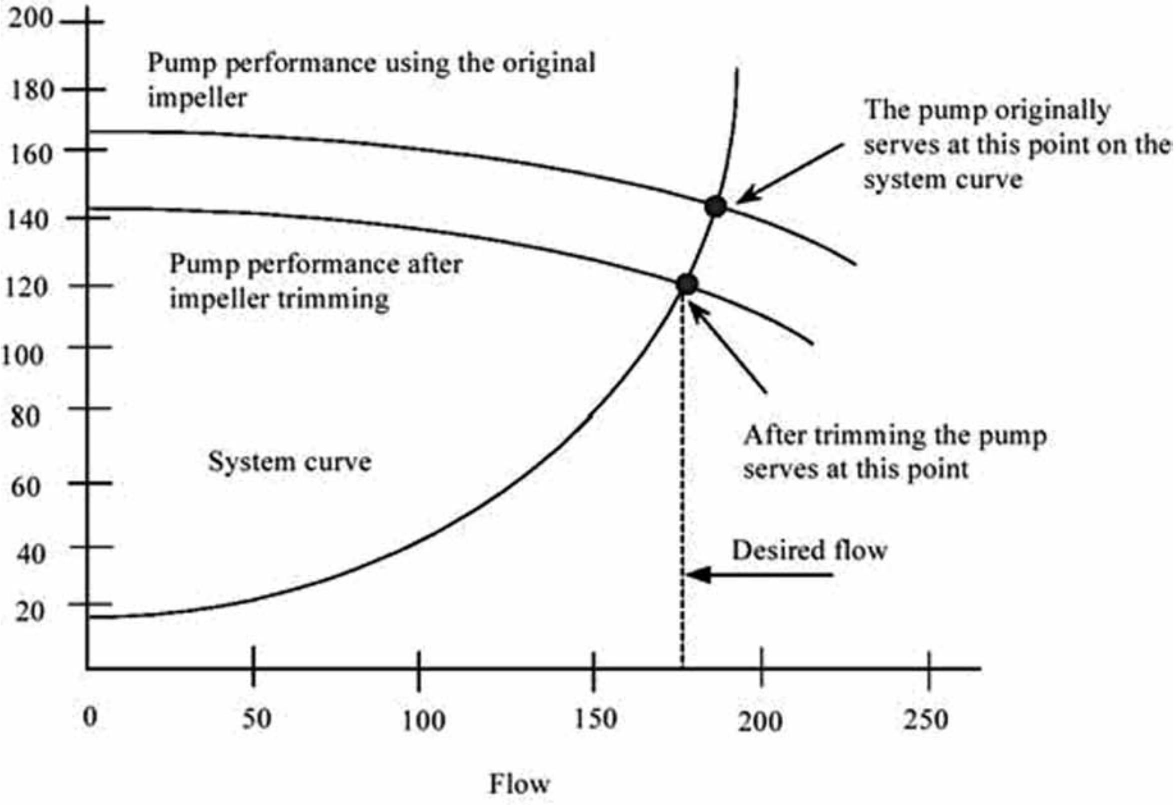


Figure 7-9 Impeller trimming to reduce flow

The Affinity Laws, which describe centrifugal pump performance, provide a theoretical relationship between impeller size and pump output (assuming constant pump speed):

where

Q = flow

H = head

BHP = brake horsepower of the pump motor

Subscript 1 = original pump,

Subscript 2 = pump after impeller trimming

D = diameter

$$Q_2 = \frac{D_2}{D_1} Q_1$$

$$H_2 = \left[\frac{D_2}{D_1}\right]^2 H_1$$

$$BHP_2 = \left[\frac{D_2}{D_1}\right]^3 BHP_1$$

Trimming an impeller changes its operating efficiency, and the non-linearities of the Affinity Laws with respect to impeller machining complicate the prediction of pump performance. Consequently, impeller diameters are rarely reduced below 70% of their original size.

### 7.5.4 Meeting variable flow needs by speed reduction

Pump speed adjustments provide the most efficient means of controlling pump flow. When pump speed is reduced, less energy is imparted to the fluid and less energy needs to be throttled or bypassed. There are two primary methods of reducing pump speed: multiple-speed pump motors and variable speed drives (VSDs).

Although both directly control pump output, multiple-speed motors and VSDs serve entirely separate applications. Multiple-speed motors contain a different set of windings for each motor speed; consequently, they are more expensive and less efficient than single-speed motors. Multiple-speed motors also lack subtle speed-changing capabilities within discrete speeds.

VSDs allow pump speed adjustments over a continuous range, avoiding the need to jump from speed to speed as with multiple-speed pumps. VSDs control pump speeds using several different types of mechanical and electrical systems. Mechanical VSDs include hydraulic clutches, fluid couplings, and adjustable belts and pulleys. Electrical VSDs include eddy current clutches, wound-rotor motor controllers, and variable frequency drives (VFDs). VFDs adjust the electrical frequency of the power supplied to a motor to change the motor's rotational speed. VFDs are by far the most popular type of VSD.

However, pump speed adjustment is not appropriate for all systems. In applications with high static head, slowing a pump risks inducing vibrations and creating performance problems that are similar to those found when a pump operates against its shutoff head.

For systems in which the static head represents a large portion of the total head, caution should be used in deciding whether to use VFDs. Operators should review the performance of VFDs in similar applications and consult VFD manufacturers to avoid the damage that can result when a pump operates too slowly against high static head.

## 7.6 PUMP PERFORMANCE ASSESSMENT

The steps in assessing pump performance are as follows:

1. Select the pump or pumping station for which the audit/assessment is being carried out.
2. Collect specifications, design/performance guarantee test data, pump characteristic curves, and schematic diagrams of the pumping system.
3. Collect maintenance history and records of existing problems (if any) in the system.
4. Check the availability and functionality of various online and portable instruments to be used for observations during the trials.
5. Observations should be made by running the pumps in different combinations (if the pumps are connected in parallel).
6. Take an overall perspective of the pumping system comprising pumps, motors, coupling, suction/discharge valves, piping, flanges, pump seals/glands, etc., in order to check the general health of the pumping system: for example, note noticeable leakages of process fluid, thermal insulation deterioration if the fluid handled is hot or cold.
7. Carry out power measurements of pumps. In the absence of power analyzer/energy meter, use a tong tester and estimate power consumption from current, volts values.
8. Measure fluid flow (if available directly) or make arrangements to measure fluid flow by the tank filling method. Otherwise, estimate fluid flow by measuring suction pressure, discharge pressure, and power input, and use pump characteristic curves.
9. Perform calculations to draw conclusions based on the following parameters (formulae given in APO’s Energy Audit Manual):
   - Calculate combined efficiency of pump and motor.
   - Estimate of fluid flow (if flow is not measured directly).
   - Calculate specific power consumption (kWh/$M^3$).
   - Compare above values with performance guarantee/design values. If there is large variation, look for areas for improvement.
   - Suggest measures for energy savings.

Table 7-1 Calculating pump energy efficiency

| | | | |
|---|---|---|---|
| 1 | Energy consumption (P) in kW | = | $\sqrt{3VI \cos \Phi}$ |
| 2 | Combined efficiency of pump and motor (%)<br>Where<br>P<br>m<br>TDH | =<br>=<br>=<br>= | $\frac{M \times 9.81 \times TDH\ (mWC)}{P} \times 100$<br>power input (kW)<br>fluid flow ($m^3$/Sec)<br>Total differential head (mWC) |
| 3 | Pump efficiency | = | $\frac{\text{Combined efficiency}}{\text{motor efficiency}} \times 100$ |
| 4 | Fluid flow ($m^3$/hr)<br>Where<br>$\eta_p$<br>$\eta_m$ | =<br>=<br>= | $\frac{(P)\ (\eta_p)\ (\eta_m)\ (3600)}{(TDH)\ (9.81)}$<br>pump efficiency<br>motor efficiency |
| 5 | Specific power consumption | = | $\frac{\text{Power consumption (kWh)}}{(m^3/hr)\ \text{fluid flow}}$ |

10. Towards further diagnostics, one may conduct a shut-off head trial (maximum one-minute duration) to ensure that the discharge valve is fully closed and not passing. If head corresponds to less than 90%–95% of name plate value, look for pump internal problems like:
    - Gland seal leaking,
    - Shaft misalignment,
    - Impeller pitting or wearing out,
    - Casing wearing out, or
    - Bearing wearing out.
11. Based on existing pump efficiency, evaluate cost benefits for:
    - Pump replacement with higher efficiency pump or
    - Impeller replacement.
12. Based on % margins available on flow, head, motor input kW, and process demand variation, evaluate cost benefits for application of:
    - Variable speed drives,
    - Impeller size optimization, or
    - Smaller multi pump application.
13. Evaluate cost benefits of pipe size and pumping network optimization on both suction side and discharge side.
14. Identify the scope for improving NPSH and suction-side improvements like high-efficiency foot valves, high-efficiency strainers, and seamless pipelines.

## 7.7 TIPS FOR ENERGY CONSERVATION IN PUMPING SYSTEMS

1. Ensure adequate NPSH at site of installation. Site NPSH should always be higher than required NPSH.
2. Ensure availability of basic instruments at pumps like pressure gauges and flow meters.
3. Operate pumps near their best efficiency point.
4. Restore internal clearances if performance has changed.
5. Shut down unnecessary pumps.
6. Modify pumping system and pump losses to minimize throttling.
7. Adapt to wide load variation with variable speed drives or sequenced control of multiple units.
8. Stop running multiple pumps; add an auto-start for an available spare or add a booster pump where needed.
9. Use booster pumps for small loads requiring higher pressures.
10. Increase fluid temperature differentials to reduce pumping rates in case of heat exchangers.
11. Repair seals and packing to minimize water loss by dripping.
12. Balance the system to minimize flows and reduce pump power requirements.
13. Avoid pumping head with a free-fall return (gravity); use siphon effect to advantage:
14. Optimize the number of stages in a multi-stage pump in case of head margins.
15. Reduce system resistance by pressure drop assessment and pipe size optimization.

# 8. ENERGY EFFICIENCY IN FANS

## 8.1 INTRODUCTION

Fans and blowers provide air for ventilation and industrial process requirements. Fans generate a pressure to move air (or gases) against resistance caused by ducts, dampers, or other components in a fan system. The fan rotor receives energy from a rotating shaft and transmits it to the air as pressure energy.

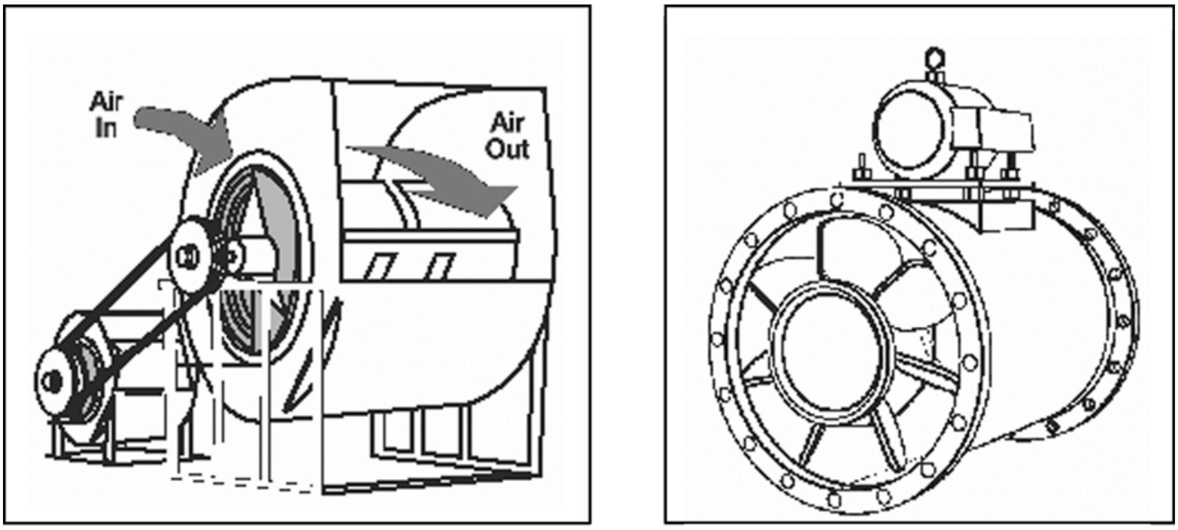
Figure 8-1 Basic diagram of a fan

**Difference between fans, blowers, and 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 the American Society of Mechanical Engineers (ASME), the specific ratio—the ratio of the discharge pressure over the suction pressure—is used for fans, blowers, and compressors. Accordingly, fans offer a pressure rise up to 1136 mmWg, blowers offer from 1136 to 2066 mmWg, and compressors offer pressure rises even higher than blowers.

## 8.2 FAN TYPES

Fans fall into two general categories: centrifugal flow and axial flow. In centrifugal flow, airflow changes direction twice: once when entering the fan and again when leaving (forward-curved, backward-curved or -inclined, and radial types). In axial flow, air enters and leaves the fan with no change in direction (propeller, tube axial, vane axial).



Centrifugal Fan

Axial Fan

Figure 8-2 Types of fans

The major types of centrifugal fan by type of impellors adopted *are radial forward curved and backward curved:*

***Radial fans*** are industrial workhorses because of their high static pressures (up to 1400mm WC) and ability to handle heavily contaminated airstreams. Because of their simple design, radial fans are well suited for high temperatures and medium blade tip speeds.

***Forward-curved fans*** are used in clean environments and operate at lower temperatures. They are well suited for low tip speed and high-airflow work: they are best suited for moving large volumes of air against relatively low pressures.

***Backward-inclined fans*** are more efficient than forward-curved fans. Backward-inclined fans reach their peak power consumption and then power demand drops off well within their usable airflow range. Backward-inclined fans are known as “non-overloading” because changes in static pressure do not overload the motor.

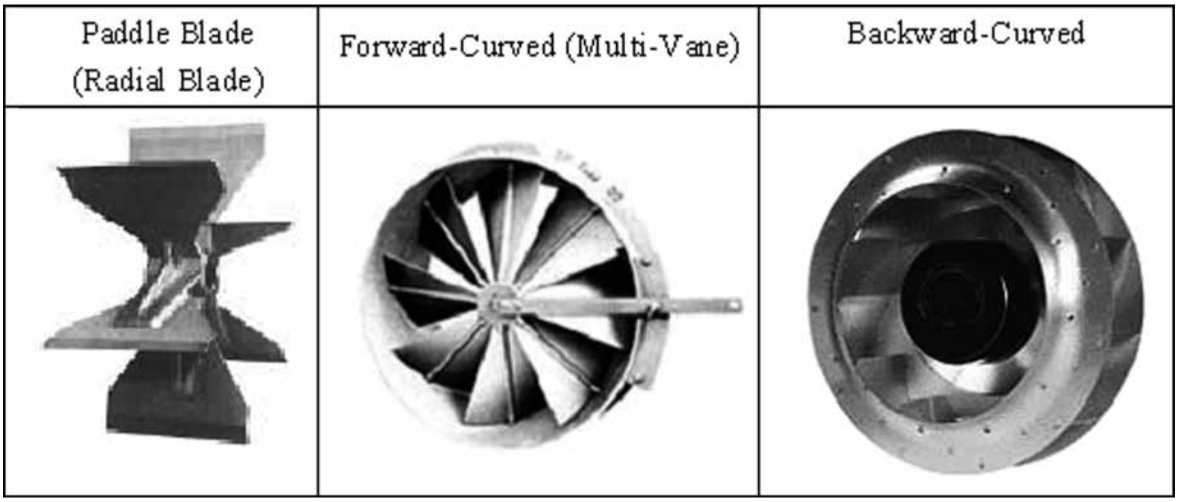


Figure 8-3 Types of fan blades

The major types of axial flow fans are *tube axial, vane axial, and propeller:*

***Tube axial* fans** have a wheel inside a cylindrical housing, with close clearance between blade and housing to improve airflow efficiency. The wheels turn faster than propeller fans, enabling operation under high pressures of 250–400mm WC. The efficiency is up to 65%.

***Vane axial* fans** are similar to tube axial fans, but with the addition of guide vanes that improve efficiency by directing and straightening the flow. As a result, they have a higher static pressure with less dependence on the duct static pressure. Such fans are used generally for pressures up to 500mm WC. Vane axial are typically the most energy-efficient fans available and should be used whenever possible.

***Propeller* fans** usually run at low speeds and moderate temperatures. They experience a large change in airflow with small changes in static pressure. They handle large volumes of air at low pressure or free delivery. Propeller fans are often used indoors as exhaust fans. Outdoor applications include air-cooled condensers and cooling towers.

Application choices for fans are summarized in Table 8-1.

Table 8-1 Types of fans, characteristics, and typical applications

| **Centrifugal Fans** | | |
|---|---|---|
| **Type** | **Characteristics** | **Typical Applications** |
| Radial | High pressure, medium flow; efficiency close to that of tube-axial fans; power increases continuously | Various industrial applications; suitable for dust-laden, moist air/ gases |

*(Continued on next page)*

*( ... Continued)*

| | | |
|---|---|---|
| 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 |
| 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. |
| Airfoil type | Same as backward-curved type; highest efficiency | Same as backward-curved type, but for clean air applications |

| **Axial-flow Fans** | | |
|---|---|---|
| **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 |
| 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 |
| Vane-axial | High pressure, medium flow, dip in pressure-flow curve; use of guide vanes improves efficiency | High-pressure applications including HVAC systems, exhausts |

## 8.3 SYSTEM RESISTANCE

The term “system resistance” is used when referring to the static pressure. The system resistance is the sum of static pressure losses in the system. System resistance is a function of the configuration of ducts, pickups, and elbows, and the pressure drops across equipment—for example, a bag filter or cyclone. *The system resistance varies with the square of the volume of air flowing through the system.* For a given volume of air, the fan in a system with narrow ducts and multiple short radius elbows is going to have to work harder to overcome a greater system resistance than it would in a system with larger ducts and a minimum number of long radius turns. Long narrow ducts with many bends and twists will require more energy to pull the air through them. Consequently, for a given fan speed, the fan will be able to pull less air through this system than through a short system with no elbows. Thus, the system resistance increases substantially as the volume of air flowing through the system increases. Conversely, resistance decreases as flow decreases. To determine what volume the fan will produce, it is therefore necessary to know the system resistance characteristics.

In existing systems, the system resistance can be measured. In systems that have been designed, but not built, the system resistance must be calculated. Typically a system resistance curve is generated for various flow rates on the x-axis and the associated resistance on the y-axis.

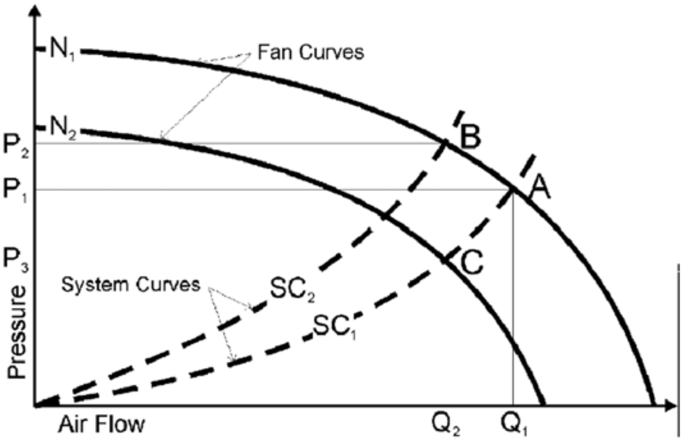


Figure 8-4 System resistance

## 8.4 FAN PERFORMANCE ASSESSMENT

Fans are tested for field performance by measurement of air flow, head (pressure developed, also sometimes called draft), and temperature on the fan side and electrical motor kW input on the motor side.

### 8.4.1 Air flow measurement

**Static pressure:**

Static pressure is the potential energy put into the system by the fan. It is given up to friction in the ducts, and at the duct inlet as it is converted to velocity pressure. At the inlet to the duct, the static pressure produces an area of low pressure

**Velocity pressure:**

Velocity pressure is the pressure along the line of the flow that results from the air flowing through the duct. The velocity pressure is used to calculate air velocity.

**Total pressure:**

Total pressure is the sum of the static and velocity pressure. Velocity pressure and static pressure can change as the air flows though different size ducts while accelerating, but the total pressure stays constant, changing only with friction losses.

The fan flow is measured using Pitot tube manometer combination or a flow sensor (differential pressure instrument) or an accurate anemometer. Care must be taken regarding number of traverse points in a straight length section (to avoid turbulent flow regimes of measurement) upstream and downstream of measurement location. The measurements can be on the suction or discharge side of the fan, and preferably both where feasible.

**Measurement by Pitot tube:**

Total pressure is measured using the inner tube of the Pitot tube, and static pressure is measured using the outer tube of the Pitot tube, as indicated in Figure 8-5. When the inner and outer tube ends are connected to a manometer, we get the velocity pressure. For measuring low velocities, it is preferable to use an inclined tube manometer instead of a U tube manometer.

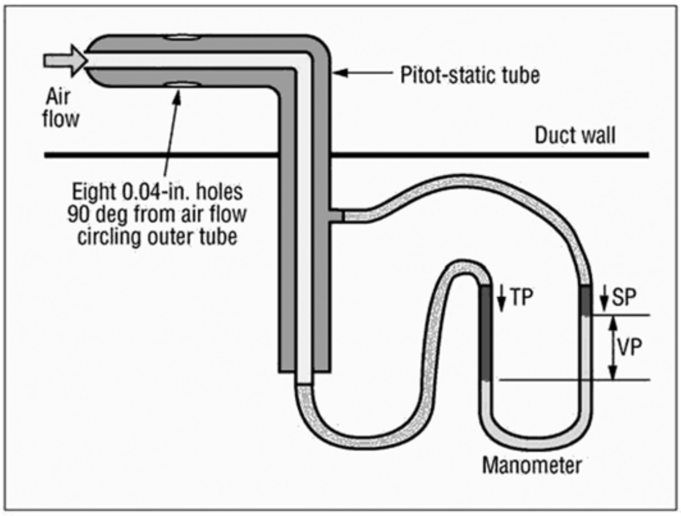


Figure 8-5 Pitot tube measurement

## 8.4.2 Velocity pressure/velocity calculation

When measuring velocity pressure, the duct diameter (or the circumference from which to calculate the diameter) should be measured as well. This will allow us to calculate the velocity and the volume of air in the duct. In most cases, pressure (head) must be measured at several places in the same system. A typical format is presented in Table 8-2.

Table 8-2 Measurements of air flow

| Duct Ref. | Duct Cross-sectional Area ($M^2$) | Dynamic Head (dp) at 10 Points along Duct Diameter/Length or Width | | | | | | | | | | Pitot-tube Constant | Temp. of Air at Measurement Point (°C) | Static Pressure in Duct at Measurement Point (mmWC) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | | | |
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- The velocity pressure varies across the duct. Friction slows the air near the duct walls, so the velocity is greater in the center of the duct. The velocity is affected by changes in the ducting configuration such as bends and curves. The best place to take measurements is in a section of duct that is straight for at least 3–5 diameters after any elbows, branch entries, or duct size changes.
- To determine the average velocity, it is necessary to take a number of velocity pressure readings across the cross-section of the duct. The velocity should be calculated for each velocity pressure reading, and the average of the velocities should be used. Do not average the velocity pressure; average the velocities.
- For best results, one set of readings should be taken in one direction and another set at a 90° angle to the first. For square ducts, the readings can be taken in 16 equally spaced areas. If it is impossible to traverse the duct, an approximate average velocity can be calculated by measuring the velocity pressure in the center of the duct and calculating the velocity. This value is reduced to an approximate average by multiplying by 0.9.

### 8.4.3 Air density calculation

The first calculation is to determine the density of the air. To calculate the velocity and volume from the velocity pressure measurements it is necessary to know the density of the air. The density is dependent on altitude and temperature:

$$\text{Gas Density}(\gamma) = \frac{273 \text{x} 1.293}{273 + t^{\circ}\text{C}}$$

where t°C – temperature of gas/air at site condition.

### 8.4.4 Velocity calculation

Once the air density and velocity pressure have been established, the velocity can be determined from the equation:

$$\text{Velocity v, m/s} = \frac{C_p \text{ x } \sqrt{2 \times 9.81 \times \Delta p \times \gamma}}{\gamma}$$

where $C_p$ = Pitot tube constant, 0.85 (or) as given by the manufacturer;

p = Average differential pressure measured by Pitot tube by taking measurement at number of points over the entire cross section of the duct;

γ = Density of air or gas at test condition.

### 8.4.5 Volume calculation

The volume in a duct can be calculated for the velocity using the equation:

$$\text{Volumetric flow(Q)}, m^3/\text{sec} = \text{Velocity(m/sec)} \text{x} \text{Area}(m^2)$$

### 8.4.6 Fan efficiency

Fan manufacturers generally use two ways to mention fan efficiency: mechanical efficiency (sometimes called total efficiency) and static efficiency. Both measure how well the fan converts horsepower into flow and pressure.

The equation for determining mechanical efficiency is:

*Fan Mechanical Efficiency*$(\eta_{mechanical})$,%

$$= \frac{\textit{Valumein } m^3/\textit{sec}*\Delta p(\textit{total pressure}) \textit{ in mmWC}}{102*\textit{power input to fan shaft in kW}} \textit{x100}$$

The static efficiency equation is the same except that the outlet velocity pressure is not added to the fan static pressure:

Fan Static Efficiency$(\eta_{\text{Static}})$,%

$$= \frac{\textit{Valumein } m^3/\textit{sec}*\Delta p(\textit{static pressure}) \textit{ in mmWC}}{102*\textit{power input to fan shaft in kW}} \textit{x100}$$

Drive motor kW can be measured by a load analyzer. This kW multiplied by motor efficiency gives the shaft power to the fan.

For analysis, the reported parameters are:

- Actual flow and % loading w.r.t rated flow;
- Actual head and % loading w.r.t rated head;
- Actual motor kW and % loading w.r.t rated input;
- As run efficiency w.r.t. rated efficiency of fan;
- Damper settings on suction or discharge side observed.

## 8.5 ENERGY SAVINGS OPPORTUNITIES

The energy efficiency strategy in fan systems includes establishing a system curve accurately, selecting the correct operating point of the fan and matching it with the best efficiency point, selecting the fan with highest efficiency for the application, achieving energy-efficient capacity controls, and adopting good O &M practices.

### 8.5.1 Flow control strategies and energy conservation

Typically, once a fan system is designed and installed, the fan operates at a constant speed. There may be occasions when a speed change is desirable, e.g., when adding a new run of duct that requires an increase in air flow (volume) through the fan. There are also instances when the fan is oversized and flow reductions are required. Various ways to achieve change in flow are: pulley change, damper control, inlet guide vane control, variable speed drives, and series and parallel operation of fans.

**Damper controls:**

Some fans are designed with damper controls. Dampers can be located at inlet or outlet. Dampers provide a means of changing air volume by adding or removing system resistance. This resistance forces the fan to move up or down along its characteristic curve, generating more or less air without changing fan speed. However, dampers provide a limited amount of adjustment, and they are not energy-efficient.

**Pulley change:**

When a fan volume change is required on a permanent basis, and the existing fan can handle the change in capacity, the volume change can be achieved with a speed change. The simplest and cheapest one-time way to change the speed is with a pulley change. For this, the fan must be driven by a motor through a V-belt system. The fan speed can be increased or decreased with a change in the drive pulley or the driven pulley or, in some cases, both pulleys. This method is normally applicable for de-rating, where a fan is oversized and damper operation (which is inefficient) is observed at all times.

**Inlet guide vanes:**

Inlet guide vanes are another mechanism that can be used to meet variable air demand. Guide vanes are curved sections that lie against the inlet of the fan when they are open. When they are closed, they extend out into the air stream. As they are closed, guide vanes pre-swirl the air entering the fan housing. This changes the angle at which the air is presented to the fan blades, which in turn changes the characteristics of the fan curve. Guide vanes are energy-efficient for modest flow reduction from 100% flow to about 80%. Below 80% flow, energy efficiency drops sharply.

Axial-flow fans can be equipped with variable pitch blades, which can be hydraulically or pneumatically controlled to change blade pitch while the fan is at stationary. Variable-pitch blades modify the fan characteristics substantially and thereby provide dramatically higher energy efficiency than the other options.

**Variable speed drives:**

Although variable speed drives are expensive, they provide almost infinite variability in speed control. Variable speed operation involves reducing the speed of the fan to meet reduced flow requirements. Fan performance can be predicted at different speeds using the fan laws. Since power input to the fan changes as the cube of the flow, this will usually be the most efficient form of capacity control. However, variable speed control may not be economical for systems which have infrequent flow variations. When considering variable speed drive, the efficiency of the control system (fluid coupling, eddy-current, VFD, etc.) should be accounted for in the analysis of power consumption.

Energy efficiency is achieved through right selection of flow control methods. Comparison of various volume control methods with respect to consumption (%) of required power is shown in Figure 8-6.

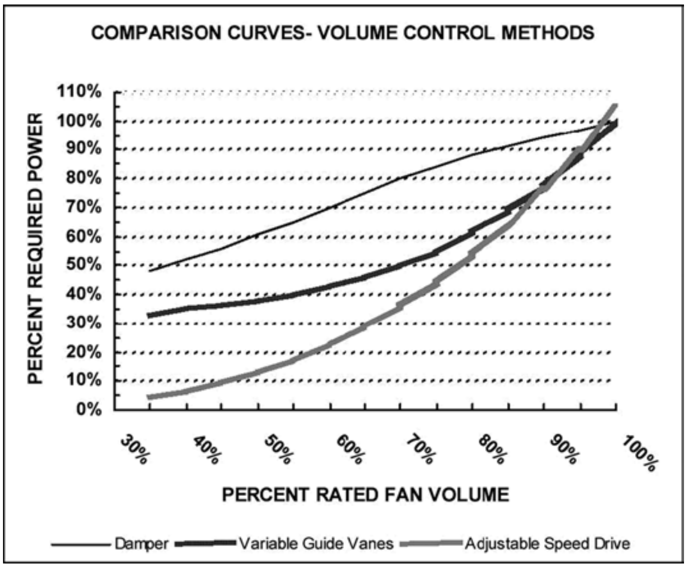

Figure 8-6  Power consumption of volume control methods

All the methods of capacity control presented above have turn-down ratios (ratio of maximum to minimum flow rate) determined by the amount of leakage (slip) through the control elements. For example, even with dampers fully closed, the flow may not be zero due to leakage through the damper. In the case of variable-speed drives the turn-down ratio is limited by the control system. In many cases, the minimum possible flow will be determined by the characteristics of the fan itself. Stable operation of a fan requires that it operate in a region where the system curve has a positive slope and the fan curve has a negative slope.

The range of operation and the time duration at each operating point also serves as a guide to selection of the most suitable capacity control system. Outlet damper control, with its simplicity, ease of operation, and low investment cost, is the most prevalent form of capacity control. However, it is the most inefficient of all methods and is best suited for situations where only small, infrequent changes are required (for example, minor process variations due to seasonal changes). The economic advantage of one method over another is determined by the time duration over which the fan operates at different operating points. The frequency of flow change is another important determinant. For systems requiring frequent flow control, damper adjustment may not be convenient. Indeed, in many plants, dampers are not easily accessible and are left at some intermediate position, to avoid frequent control.

The energy savings potential in fans and fan systems is maximized by reducing the loading on flow and head, eliminating inefficient capacity controls, and adopting need-based replacements for efficiency margins. These are summarized as type A, B, and C categories, as follows:

1. Minimizing excess air level in combustion systems to reduce forced draft fan and induced draft fan power consumption. (A)
2. Minimizing air in-leaks in hot flue gas path to reduce ID fan load, especially in kilns, boiler plants, furnaces, etc. Cold air in-leaks increase ID fan load tremendously, due to density increase of flue gases and in-fact choke up the capacity of fan, resulting in a bottleneck for the boiler/furnace itself. (A)
3. In-leaks/out-leaks in air conditioning systems also have a major impact on energy efficiency and fan power consumption and need to be minimized. (A)
4. The findings of fan performance assessment trials will indicate potential areas for improvement, which could be one or more of the following:

4.1. Replacement of impeller by a high-efficiency impeller along with a cone. (C)
4.2. Replacement of fan assembly as a whole by a higher-efficiency fan. (C)
4.3. Downsizing as needed by impeller de-rating (replacement with a smaller-diameter impeller). (B)
4.4 Replacement of a metallic/glass-reinforced plastic (GRP) impeller by the more energy-efficient hollow FRP impeller with aerofoil design, in case of axial flow fans, where significant savings have been reported. (C)

4.5. Fan speed reduction by pulley diameter modification for one-time de-rating. (C)
4.6. Option of two-speed motors or variable speed drives for variable duty conditions. (B)
4.7. Option of energy-efficient flat belts, or cogged raw edged V belts, in place of conventional V-belt systems, for reducing transmission losses. (C)
4.8. Adopting inlet guide vanes in place of discharge damper controls. (B)
4.9. Minimizing system resistance and pressure drops by improvements in duct system like larger ducts for lowering pressure drop, etc. (A)
4.10. Use of smooth, well-rounded air inlet cones for fan air intakes. (A)
4.11. Minimizing fan inlet and outlet obstructions. (A)

# 9. ENERGY EFFICIENCY IN COMPRESSED AIR SYSTEMS

## 9.1 INTRODUCTION

Air compressors account for significant amounts of the electricity used in industries. Air compressors are used in a variety of industries to supply process requirements, to operate pneumatic tools and equipment, and to meet instrumentation needs. Only 10%–30% of energy reaches the point of end-use; the remaining 70%–90% of energy of the power of the prime mover is converted to unusable heat energy and to a lesser extent is lost in the form of friction, misuse, and noise.

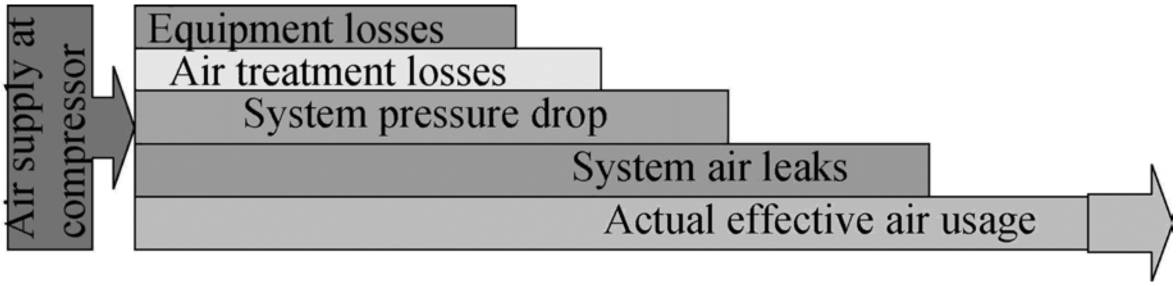

Figure 9-1 Losses in air compressor systems

## 9.2 COMPRESSOR TYPES

Compressors are broadly classified as positive displacement compressors and dynamic compressors.

**Positive displacement compressors** increase the pressure of the gas by reducing the volume. Positive displacement compressors are further sub-classified as reciprocating or rotary compressors.

**Dynamic compressors** increase the air velocity, which is then converted to increased pressure at the outlet. Dynamic compressors are basically centrifugal compressors and are further classified as radial and axial flow types.

The choice among types of compressors available is shown in Figure 9-2. They are distinctive by method of operation and have well-established niche areas of selection/application in industry.

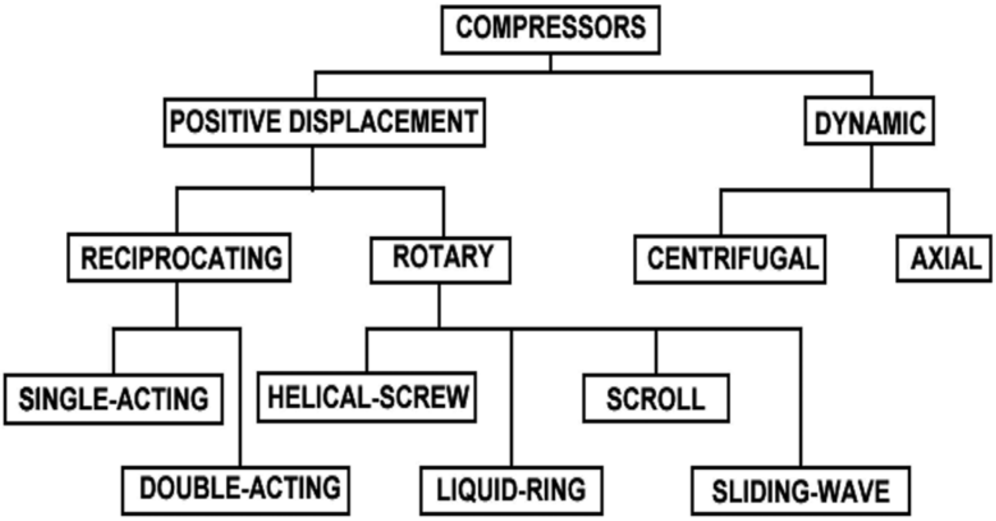

Figure 9-2 Types of compressors available

A simple selection help tool is shown in Figure 9-3. (Cfm stands for cubic feet output per minute, a well-accepted term in compressor systems.)

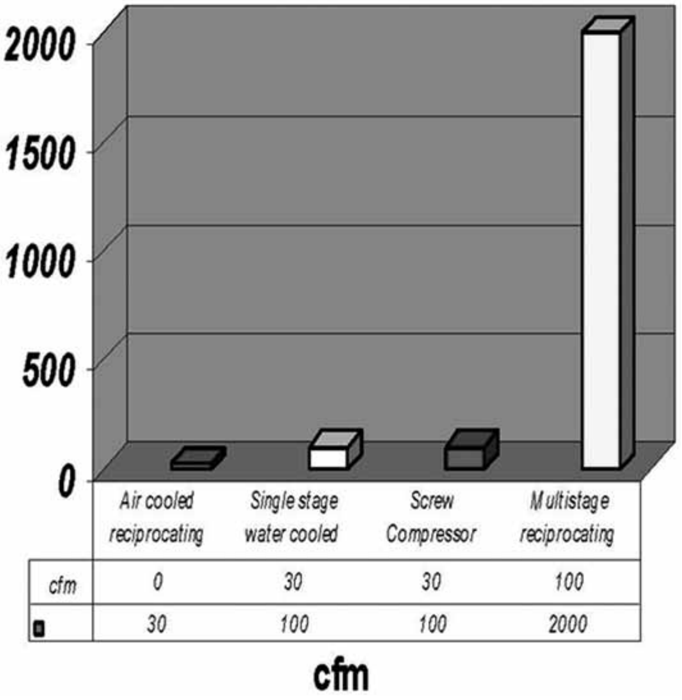

Figure 9-3 Compressor selection ratios

## 9.3 COMPRESSED AIR SYSTEM COMPONENTS

Compressed air systems consist of the following major components: intake air filters, inter-stage coolers, after-coolers, air dryers, moisture drain traps, receivers, piping network, filters, regulators, and lubricators.

**Intake air filters** prevent dust from entering the compressor. Dust causes sticking valves, scoured cylinders, excessive wear, etc.

**Inter-stage coolers** reduce the temperature of the air before it enters the next stage to reduce the work of compression and increase efficiency. They are normally water-cooled.

**After-coolers** work to remove the moisture in the air by reducing the temperature in a water-cooled heat exchanger.

**Air dryers:**

The traces of moisture remaining after the application of after-coolers are removed using air dryers, as air for instruments and pneumatic equipment has to be free of any moisture. The moisture is removed using adsorbents like silica gel/activated carbon, refrigerant dryers, or heat from compression dryers.

Table 9-1 Adsorbents used to dry air

| Type | Dew Point (°C) | Power Consumption (kW/1000 m3/hr) |
|---|---|---|
| Desiccant Regeneratives (Air purging) | –40 | 20.7 |
| Desiccant Regeneratives (Blowing) | –40 | 18 |
| Desiccant Regeneratives (Heat of compression) | –40 | 12 |
| Refrigerants (Drying) | –20 | 2.9 |

**Moisture drain traps:**

Moisture drain traps are used for removal of moisture in the compressed air. These traps resemble steam traps. The types of traps used include manual drain cocks, timer-based automatic drain valves, etc.

**Receivers:**

Air receivers are provided for storage and smoothening of pulsating air output, reducing variations in pressure of air from the compressor.

## 9.4 COMPRESSOR PERFORMANCE

### 9.4.1 Capacity of a compressor

Capacity of a compressor is the full rated volume of flow of gas compressed and delivered at conditions of total temperature, total pressure, and composition prevailing at the **compressor inlet**. It sometimes means actual flow rate, rather than rated volume of flow. This is also termed **Free Air Delivery (FAD)**—i.e., air at atmospheric conditions at any specific location. Because the altitude, barometer, and temperature may vary at different localities and at different times, it follows that this term does not mean air under identical or standard conditions.

### 9.4.2 Compressor efficiency definitions

Adiabatic and isothermal efficiencies are computed as the isothermal or adiabatic power divided by the actual power consumption. The figure obtained indicates the overall efficiency of compressor and drive motor. Isothermal compression is close to ideal, and with inter and after coolers, the work of compression is optimized with resulting power economy.

***Isothermal efficiency***

$$\text{Isothermal Efficiency} = \frac{\textit{Isothermal power}}{\text{Actual measured input power}}$$

$$\text{Isothermal power (kW)} = P_1 \times Q_1 \times \log_e r / 36.7$$

where

$P_1$ = Absolute intake pressure kg/ cm$^2$

$Q_1$ = Free air delivered m$^3$/hr.

$r$ = Pressure ratio $P_2/P_1$

The calculation of isothermal power does not include the power needed to overcome friction and generally gives an efficiency that is lower than adiabatic efficiency. The reported value of efficiency is normally the isothermal efficiency. This is an important consideration when selecting compressors based on reported values of efficiency.

As an easy reference, indicative specific power consumption values for various compressor types are presented in Figure 9-4.

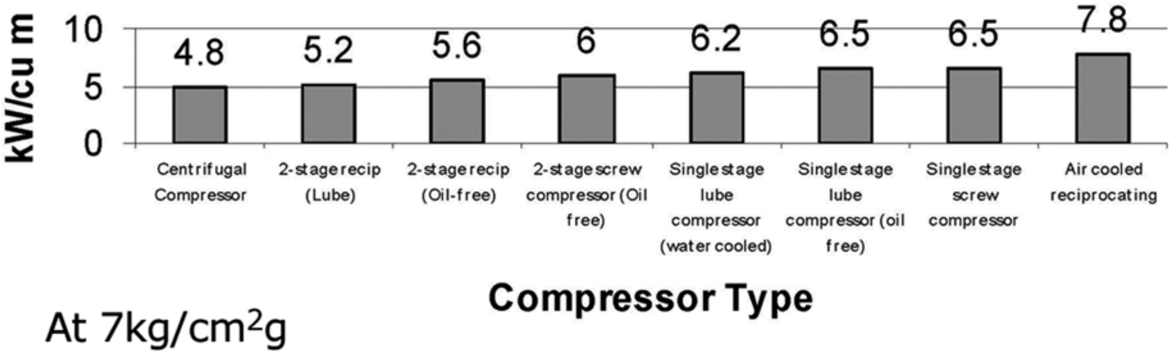

Figure 9-4 Power consumption values for compressors

## 9.5 SHOP FLOOR METHODS FOR ASSESSMENT AND FACTORS AFFECTING ENERGY EFFICIENCY

### 9.5.1 Compressor capacity assessment

Due to aging of the compressors and inherent inefficiencies in the internal components, the free air delivered may be less than the design value, despite good maintenance practices. Sometimes other factors such as poor maintenance, fouled heat exchangers, and effects of altitude also tend to reduce free air delivery. In order to meet the air demand, an inefficient compressor may have to run for a longer time, thus consuming more power than is actually required.

The power wastage depends on the deviation of FAD capacity. For example, a worn-out compressor valve can reduce the compressor capacity by as much as 20%. A periodic assessment of the FAD capacity of each compressor has to be carried out to check its actual capacity. If the deviations are more than 10%, corrective measures should be taken to rectify the situation.

The ideal method of compressor capacity assessment is through a nozzle test wherein a calibrated nozzle is used as a load, to vent out the generated compressed air. Flow is assessed based on the air temperature, stabilization pressure, and orifice constant.

### 9.5.2 Simple method of capacity assessment on the shop floor

1. Isolate the compressor along with the individual receiver being tested from the main compressed air system by tightly closing the isolation valve or blanking it, thus closing the receiver outlet.
2. Open the water drain valve, drain the water fully, and empty the receiver and the pipeline. Make sure that water trap line is tightly closed once again to start the test.
3. Start the compressor and activate the stopwatch.
4. Note the time taken to attain the normal operational pressure $P_2$ (in the receiver) from initial pressure $P_1$. The capacity is calculated as per the formula given below:

**Actual free air discharge**

$$Q=\frac{P_2-P_1}{P_0}\times\frac{V}{T}\text{Nm}^3\text{/Minute}$$

where

$P_2$ = Final pressure after filling (kg/cm$^2$ a)

$P_1$ = Initial pressure (kg/cm$^2$a) 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 taken to build up pressure to $P_2$ in minutes

The above equation is relevant where the compressed air temperature is the same as the ambient air temperature, i.e., perfect isothermal compression. In case the actual compressed air temperature at discharge, $t_2$°C is, higher than ambient air temperature $t_1$°C (as is usual), the FAD is to be corrected by a factor $(273 + t_1) / (273 + t_2)$.

## 9.5.3 Simple method of leak quantification on the shop floor

1. Shut off compressed air operated equipment (or conduct the test when no equipment is using compressed air).
2. Run the compressor to charge the system to set pressure of operation.
3. Note the subsequent time taken for "load" and "unload" 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:

$$\%\ \text{leakage} = T \times 100 / (T + t)$$

$$\text{(or) System leakage (m}^3\text{/minute)} = Q \times T / (T + t)$$

where

Q = Actual free air being supplied during trial, in cubic meters per minute (cmm)

T = Time on load in minutes

t = Time on unload in minutes

### 9.5.4 Importance of maintenance for power consumption

Table 9-2 Maintenance factors affecting power consumption

| S. No. | Maintenance Factor | Excess Power Consumption (%) |
|---|---|---|
| 1 | Worn-out pistons and gland packing | 3–5% |
| 2 | Worn-out valves | 5–6% |
| 3 | Misaligned bearings | 1–3% |
| 4 | Wrong grade oil | 1% |
| 5 | Choked filter | 3-5% |
| 6 | High cooling water temperature | 1% |
| 7 | Loose Belts | 4-6% |

## 9.6 ENERGY EFFICIENCY OPPORTUNITIES IN COMPRESSED AIR SYSTEMS

- Ensure that air intake to compressor is not warm and humid by locating compressors in a well-ventilated area or by drawing cold air from outside. Every 4°C rise in air inlet temperature will increase power consumption by 1%.
- Clean air-inlet filters regularly. Compressor efficiency will be reduced by 2% for every 250mm WC pressure drop increase across the filter. (A compressor is a breathing machine.)
- Keep compressor valves in good condition by removing and inspecting them once every six months. Worn-out valves can reduce compressor efficiency by as much as 50%.
- Install manometers across the filter and monitor the pressure drop as a guide to scheduled maintenance and replacement of elements.
- Minimize low-load compressor operation; if air demand is less than 50% of compressor capacity, consider changing to a smaller compressor or reducing compressor speed appropriately (by reducing motor pulley size), in case of belt-driven compressors.
- Consider the use of regenerative air dryers, which use the heat of compressed air to remove moisture.
- Fouled inter-coolers reduce compressor efficiency and cause more water condensation in air receivers and distribution lines, resulting in increased corrosion. Periodic cleaning of inter-coolers must be ensured.

- Compressor free air delivery test (FAD) must be done periodically to check the present operating capacity against its design capacity, and corrective steps must be taken if required.
- If more than one compressor is feeding to a common header, compressors must be operated in such a way that only one small compressor handles the load variations, while other compressors operate at full load.
- The possibility of heat recovery from hot compressed air to generate hot air or water for process application must be economically analyzed, in cases of large compressors.
- Consideration should be given to buying a two-stage or multi-stage compressor as it consumes less power for the same air output than a single-stage compressor.
- If pressure requirements for processes are widely different (e.g. 3 bar to 7 bar), it is advisable to have two separate compressed air systems.
- Reduce compressor delivery pressure, wherever possible, to save energy.
- Provide extra air receivers at points of high cyclic-air demand, which permits operation without extra compressor capacity.
- Retrofit with variable speed drives in big compressors (say over 100 kW) to eliminate the 'unloaded' running condition altogether.
- Maintain the minimum possible range between load and unload pressure settings.
- Automatic timer-controlled drain traps waste compressed air every time the valve opens. So frequency of drainage should be optimized.
- Trans-vector nozzles are to be used for low and intermediate pressure air requirements at user points. These nozzles draw a small quantity of motive air at higher pressure and mix it with ambient air, to produce compressed air at intermediate pressure, in an efficient manner, as against routine valve control method.
- Check air compressor logs regularly for abnormal readings, especially motor current cooling water flow and temperature, inter-stage and discharge pressures, and temperatures and compressor load-cycles.
- Compressed air leakage of 40%–50% is not uncommon. Carry out periodic leak tests to estimate the quantity of leakage.
- Install equipment interlocked solenoid cut-off valves in the air system so that air supply to a machine can be switched off when it is not in use.
- Present energy prices justify liberal designs of pipeline sizes to reduce pressure drops.
- Compressed air piping layout should be made preferably as a ring main to provide desired pressures for all users.
- A smaller dedicated compressor can be installed at load point, located far away from the central compressor house, instead of supplying air through lengthy pipelines.

- All pneumatic equipment should be properly lubricated, which will reduce friction and prevent wear of seals and other rubber parts, thus preventing energy wastage due to excessive air consumption or leakage.
- Misuse of compressed air, such as for body cleaning, agitation, general floor cleaning, and other similar applications, must be discouraged in order to save compressed air and energy.
- Pneumatic equipment should not be operated above the recommended operating pressure as this not only wastes energy but can also lead to excessive wear of equipment components which leads to further energy wastage.
- Pneumatic transport can be replaced by a mechanical system as the former consumes about 8 times more energy than the latter.
- Pneumatic tools such as drill and grinders consume about 20 times more energy than motor-driven tools. Hence, they have to be used efficiently. Wherever possible, they should be replaced with electrically operated tools.

- Where possible, welding is a good practice and should be preferred over threaded connections.
- On account of high pressure drop, ball or plug or gate valves are preferable to globe valves in compressed air lines.

## 9.7 GENERIC TIPS FOR EFFICIENT USE OF COMPRESSORS

- Install a control system to coordinate multiple air compressors.
- Study part–load characteristics and cycling costs to determine the most efficient mode for operating multiple air compressors.
- Avoid over-sizing: match the connected load.
- Avoid partial loading on modulation-controlled air compressors. (They use almost as much power at partial load as at full load.)
- Turn off the back-up air compressor until it is needed.
- Reduce air compressor discharge pressure to the lowest acceptable setting.

  *(Reduction of 1 kg/cm$^2$ air pressure (8 kg/cm$^2$ to 7 kg/cm$^2$) would result in 9% input power savings. This will also reduce compressed air leakage rates by 10%.)*
- Use the highest reasonable dryer dew point settings.
- Turn off refrigerated and heated air dryers when the air compressors are off.
- Use a control system to minimize heatless desiccant dryer purging.
- Minimize purges, leaks, excessive pressure drops, and condensation accumulation.

*(Compressed air leak from 1mm hole size at 7 kg/cm$^2$ pressure would mean power loss equivalent to 0.5 kW.)*

- Use drain controls instead of continuous air bleeds through the drains.
- Consider engine-driven or steam-driven air compression to reduce electrical demand charges.
- Replace standard V-belts with high-efficiency flat belts as the old V-belts wear out.
- Take air compressor intake air from the coolest (but not air-conditioned) location.

  *(Every 5°C reduction in intake air temperature will result in a 1% reduction in compressor power consumption.)*
- Use an air-cooled after-cooler to heat building makeup air in winter.
- Be sure that heat exchangers are not fouled (e.g. with oil).
- Be sure that air/oil separators are not fouled.
- Monitor pressure drops across suction and discharge filters, and clean or replace filters promptly upon increase in pressure drop.
- Use a properly sized compressed air storage receiver. Minimize disposal costs by using lubricant that is fully demulsible and an effective oil–water separator.
- Consider alternatives to compressed air such as blowers for cooling, hydraulic rather than air cylinders, electric rather than air actuators, and electronic rather than pneumatic controls.
- Use nozzles or Venturi-type devices rather than blowing with open compressed air lines.
- Check for leaking drain valves on compressed air filter/regulator sets. Certain rubber-type valves may leak continuously after they age and crack. Replacement is the best choice.
- In dusty environments, control packaging lines with high-intensity photocell units instead of standard units with continuous air purging of lenses and reflectors.
- Establish a compressed air efficiency-maintenance program. Start with an energy audit and follow-up, then make a compressed air efficiency-maintenance program a part of your continuous energy management program.

# 10. ENERGY EFFICIENCY IN REFRIGERATION SYSTEMS

## 10.1 INTRODUCTION

Refrigeration deals with the pumping out of heat, from a low-temperature heat source to a high-temperature heat sink, by using a low boiling temperature refrigerant. The cooling effect produced is quantified in tons of refrigeration.

**1 ton of refrigeration = 3024 kCal/hr heat rejected (pumped out)**

## 10.2 TYPES OF APPLICATIONS

Depending on applications, there are several options/combinations available for use, as listed below:

- Air conditioning (for human comfort/machines) using
  Split air conditioners
  Fan coil units in a larger system
  Air handling units in a larger system
- Small capacity modular units of direct expansion type similar to domestic refrigerators, small capacity refrigeration units.
- Centralized chilled water plants, with chilled water as a secondary coolant for temperature range over 5°C typically. They can also be used for ice bank formation.
- Brine plants, which use brines as low-temperature secondary coolant, for typically sub-zero temperature applications, which come as modular unit capacities as well as large centralized plant capacities.
- The plant capacities up to 50 TR are usually considered as small capacity, 50–250 TR as medium capacity and over 250 TR as large capacity units.
- A large industry may have a bank of such units, often with common chilled water pumps, condenser water pumps, cooling towers, as an off-site utility.
- A large industry may also have two or three levels of refrigeration & air conditioning such as:
  Comfort air conditioning (20°–25°C)
  Chilled water system (8°–10°C)
  Brine system (sub-zero applications)

## 10.3 TYPES OF REFRIGERATION PLANTS

### 10.3.1 Vapor compression type

Heat flows naturally from a hot to a colder body. In a refrigeration system, the opposite must occur: i.e., heat flows from a cold to a hotter body. This is achieved by using a refrigerant, which absorbs heat and hence boils or evaporates at a low pressure to form a gas. This gas is then compressed to a higher pressure, such that it transfers the heat it has gained to ambient air or water and turns it back (condenses it) into a liquid. In this way heat is absorbed, or removed, from a low temperature source and transferred to a higher temperature source.

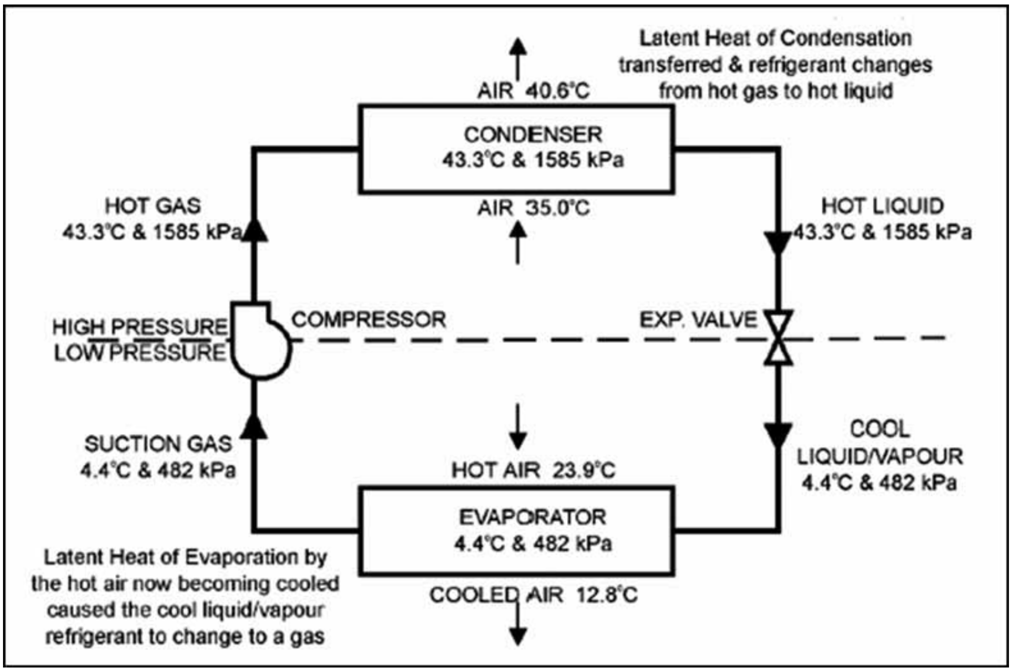

Figure 10-1 Vapor compression refrigeration

### 10.3.2 Vapor absorption type

The absorption chiller is a machine which produces chilled water by using heat such as steam, hot water, gas, oil, etc. Chilled water is produced by the principle that liquid (refrigerant), which evaporates at low temperature, absorbs heat from its surroundings when it evaporates. Pure water is used as refrigerant and lithium bromide solution is used as absorbent.

Heat for the vapor absorption refrigeration system can be provided by waste heat extracted from process, diesel generator sets, etc. Absorption systems require electricity only to run the pumps. Depending on the temperature required and the power cost, it may even be economical to generate heat or steam to operate the absorption system.

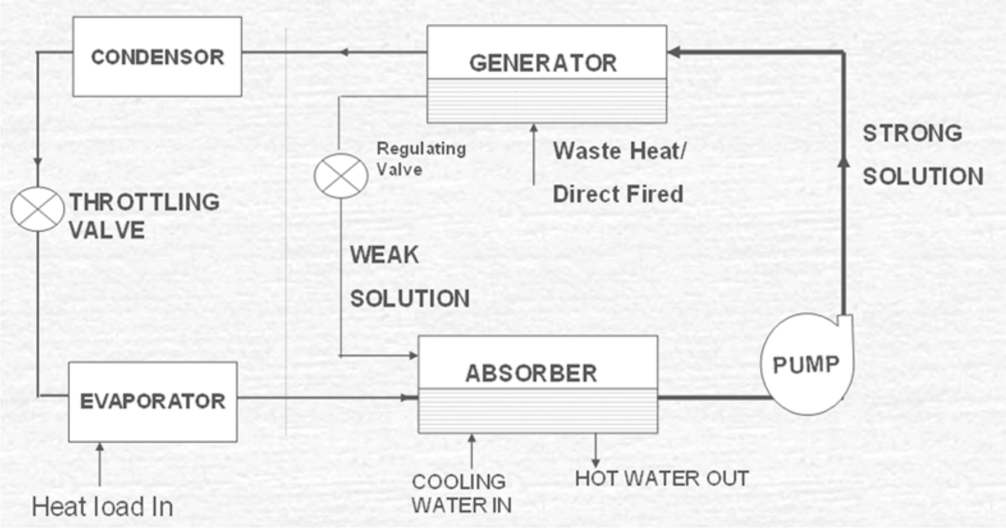

Figure 10-2 Vapor absorption refrigeration

## 10.4 PERFORMANCE ASSESSMENT

Specific power consumption, kW/TR, is a useful indicator of the performance of a refrigeration system. By measuring refrigeration duty performed in TR and the kW input, kW/TR is brought out as a performance indicator and used as a reference energy performance indicator.

The refrigeration TR is assessed as

$$TR = Q \times Cp \times (Ti - To) / 3024$$

where

TR is cooling TR effect produced

Q is mass flow rate of coolant in kg/hr

Cp is coolant specific heat in kCal/kg/°C

Ti is inlet temperature of coolant to evaporator (chiller) in °C

To is outlet temperature of coolant from evaporator (chiller) in °C

**Power consumption**

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

- Compressor kW
- Chilled water pump kW

- Condenser water pump kW
- Cooling tower fan kW
- kW/TR of refrigeration plant = sum of all above kW/TR

In field performance assessment, accurate instruments for inlet and outlet chilled water temperature and condenser water temperature measurement are required, preferably with a least count of 0.1°C. Flow measurements of chilled water can be made by an ultrasonic flow meter directly or inferred from pump duty parameters. Adequacy check of chilled water is often needed, and most units are designed for a typical 0.68 $m^3$/hr per TR (3 gpm/TR) chilled water flow. Condenser water flow measurement can also be made by a non-contact flow meter directly or inferred from pump duty parameters. Adequacy check of condenser water is also often needed, and most units are designed for a typical 0.91 $m^3$/hr per TR (4 gpm/TR) condenser water flow.

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

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

where Q is the air flow in $m^3$/h

p 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 psychometric charts can help to calculate $h_{in}$ and $h_{out}$ from dry bulb and wet bulb temperature values, which are measured during trials.

Power measurements at compressors, pumps, AHU fans, and cooling tower fans can be accomplished by a portable load analyzer.

Estimation of process air conditioning load is also possible, by calculating various heat loads (sensible and latent), based on inlet and outlet air parameters, air ingress factors, air flow, occupancy pattern, and type of materials stored.

An indicative TR load profile for comfort air conditioning is presented as follows:

| | |
|---|---|
| • Small office cabins | = 0.1 TR/$m^2$ |
| • Medium-size offices, i.e., 10–30 person occupancy with central A/C | = 0.06 TR/$m^2$ |
| • Large multistoried office complexes with central A/C | = 0.04 TR/ $m^2$ |

## 10.5 OPERATIONAL FACTORS AFFECTING PERFORMANCE AND ENERGY EFFICIENCY OF REFRIGERATION PLANTS

### 10.5.1 Design of process heat exchangers

There is a tendency with most of the process units to operate with high safety margins, which influences the compressor suction pressure/evaporator set point. For instance, a process cooling requirement of 15°C would need chilled water at a lower temperature, but the coolant temperature range can vary from 6°C to perhaps 10°C. At 10°C chilled water temperature, the refrigerant side temperature has to be lower, perhaps –5°C to +5°C. The refrigerant temperature again sets the corresponding suction pressure of the refrigerant, which determines the inlet duty conditions for work of compression of the refrigerant compressor. Having the optimum/minimum driving force (temperature difference) can, thus, help to achieve the highest possible suction pressure at the compressor, thereby leading to lower energy requirements. This requires proper sizing of heat transfer areas of process heat exchangers and evaporators as well as rationalizing the temperature requirement to highest possible value. A 1°C raise in evaporator temperature can help to save almost 3% on power consumption. The TR capacity of the same machine will also increase with the evaporator temperature, as given in Table 10-1.

Table 10-1 Effect of variation in evaporator temperature on compressor power consumption

| **Evaporator Temperature (°C)** | **Refrigeration Capacity* (tons)** | **Specific Power Consumption** | **Increase in kW/ton (%)** |
|---|---|---|---|
| 5.0 | 67.58 | 0.81 | - |
| 0.0 | 56.07 | 0.94 | 16.0 |
| -5.0 | 45.98 | 1.08 | 33.0 |
| -10.0 | 37.20 | 1.25 | 54.0 |
| -20.0 | 23.12 | 1.67 | 106.0 |

* Condenser temperature 40°C

In rationalizing the heat transfer areas, the heat transfer coefficient on the refrigerant side can be considered to range from 1400–2800 watts/m$^2$K. The refrigerant side heat transfer areas provided are of the order of 0.5 Sqm/TR and above in evaporators.

Condensers in a refrigeration plant are critical equipment that influences the TR capacity and power consumption demands. Given a refrigerant, the condensing temperature and corresponding condenser pressure depends upon the heat transfer area provided, thw effectiveness of heat exchange, and the type of cooling chosen. A lower condensing temperature and pressure, in the best of combinations, would mean that the compressor has to work between a lower pressure differential as the discharge pressure is fixed by the design and performance of the condenser. The choices of condensers in practice include air-cooled, air-cooled with water spray, and heat exchanger-cooled. Generously sized shell and tube heat exchangers as condensers, with good cooling tower operations, help to operate with low discharge pressure values, and the TR capacity of the refrigeration plant also improves. With the same refrigerant, R22, a condensing pressure of 15 kg/cm$^2$ is achieved with a water-cooled shell and tube condenser, and 20 kg/cm$^2$ is achieved with an air-cooled condenser, which indicates that almost 30% additional energy consumption is required by the plant if one selects the air-cooled version. One of the best options at the design stage would be to select generously sized (0.65 m$^2$/TR and above) shell and tube condensers with water-cooling as against cheaper alternatives like air-cooled condensers or water spray atmospheric condenser units.

The effect of condenser temperature on refrigeration plant energy requirements is given in Table 10-2.

Table 10-2 Effect of variation in condenser temperature on compressor power consumption

| **Condensing Temperature (°C)** | **Refrigeration Capacity (tons)** | **Specific Power Consumption (kW/TR)** | **Increase in kW/TR (%)** |
|---|---|---|---|
| 26.7 | 31.5 | 1.17 | - |
| 35.0 | 21.4 | 1.27 | 8.5 |
| 40.0 | 20.0 | 1.41 | 20.5 |

* Reciprocating compressor using R-22 refrigerant. Evaporator temperature.-10°C

### 10.5.2 Maintenance of heat exchanger surfaces

After ensuring procurement, effective maintenance holds the key to optimizing power consumption. Heat transfer can also be improved by ensuring proper separation of the lubricating oil and the refrigerant, timely defrosting of coils, and increasing the velocity of the secondary coolant (air, water, etc.). However, increased velocity results in larger pressure drops in the distribution system and higher power consumption in pumps and fans. Therefore, careful analysis is required to determine the most effective and efficient option.

Fouled condenser tubes force the compressor to work harder, to attain the desired capacity. For example, a 0.8mm scale build-up on condenser tubes can increase energy consumption by as much as 35%. Similarly, fouled evaporators (due to residual lubricating oil or infiltration of air) result in increased power consumption. Equally important is proper selection, sizing, and maintenance of cooling towers. A reduction of 0.55°C temperature in water returning from the cooling tower reduces compressor power consumption by 3.0 % (see Table 10-3).

Table 10-3 Effect of poor maintenance on compressor power consumption

| **Condition** | **Evap. Temp (°C)** | **Cond. Temp (°C)** | **Refrigeration Capacity* (tons)** | **Specific Power Consumption (kW/ton)** | **Increase in kW/Ton (%)** |
|---|---|---|---|---|---|
| Normal | 7.2 | 40.5 | 17.0 | 0.69 | - |
| Dirty condenser | 7.2 | 46.1 | 15.6 | 0.84 | 20.4 |
| Dirty evaporator | 1.7 | 40.5 | 13.8 | 0.82 | 18.3 |
| Dirty condenser and evaporator | 1.7 | 46.1 | 12.7 | 0.96 | 38.7 |

* 15-ton reciprocating compressor-based system. The power consumption is lower than that for systems typically available in India. However, the percentage change in power consumption is indicative of the effect of poor maintenance.

### 10.5.3 Multi-staging for efficiency

Efficient compressor operation requires that the compression ratio be kept low, to reduce discharge pressure and temperature. For low-temperature applications involving high compression ratios, and for wide temperature requirements, it is preferable (due to equipment design limitations) and often economical to employ multi-stage reciprocating machines or centrifugal/screw compressors.

Multi-staging systems are of two types, compound and cascade, and are applicable to all types of compressors. With reciprocating or rotary compressors, two-stage compressors are preferable for load temperatures from –20 to –58°C, and with centrifugal machines for temperatures around –43°C.

In multi-stage operation, a first-stage compressor, sized to meet the cooling load, feeds into the suction of a second-stage compressor after inter-cooling of the gas. A part of the high-pressure liquid from the condenser is flashed and used for liquid sub-cooling. The second compressor, therefore, has to meet the load of the evaporator and the flash gas. A single refrigerant is used in the system, and the work of compression is shared equally by the two compressors. Therefore, two compressors with low compression ratios can in combination provide a high compression ratio.

For temperatures in the range of −46°C to −101°C, cascaded systems are preferable. In this system, two separate systems using different refrigerants are connected such that one provides the means of heat rejection to the other. The chief advantage of this system is that a low-temperature refrigerant which has a high suction temperature and low specific volume can be selected for the low-stage to meet very low temperature requirements.

### 10.5.4 Matching capacity to system load

During partial-load operation, the evaporator temperature rises and the condenser temperature falls, effectively increasing the COP. But at the same time, deviation from the design operation point and the fact that mechanical losses form a greater proportion of the total power negate the effect of improved COP, resulting in lower partial-load efficiency.

Therefore, consideration of partial-load operation is important, because most refrigeration applications have varying loads. The load may vary due to variations in temperature and process cooling needs. Matching refrigeration capacity to the load is a difficult exercise, requiring knowledge of compressor performance and variations in ambient conditions, and detailed knowledge of the cooling load.

### 10.5.5 Capacity control and energy efficiency

The capacity of compressors is controlled in a number of ways. Capacity control of reciprocating compressors through cylinder unloading results in incremental (step-by-step) modulation as against continuous capacity modulation of centrifugal through vane control and screw compressors through sliding valves. 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 partial load is generally higher than either centrifugal compressors or reciprocating compressors, which may make them attractive in situations where partial-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.

### 10.5.6 Multi-level refrigeration for plant needs

The selection of refrigeration systems also depends on the range of temperatures required in the plant. For diverse applications requiring a wide range of temperatures, it is generally more economical to provide several packaged units (several units distributed throughout the plant) instead of one large central plant. Another advantage would be the flexibility and reliability accorded. The selection of packaged units could also be made depending on the distance at which cooling loads need to be met. Packaged units at load centers reduce distribution losses in the system. Despite the advantages of packaged units, central plants generally have lower power consumption since at reduced loads power consumption can be reduced significantly due to the large condenser and evaporator surfaces.

Many industries use a bank of compressors at a central location to meet the load. Usually the chillers feed into a common header from which branch lines are taken to different locations in the plant. In such situations, operation at partial-load requires extreme care. For efficient operation, the cooling load and the load on each chiller must be monitored closely. It is more efficient to operate a single chiller at full load than to operate two chillers at partial-load. The distribution system should be designed such that individual chillers can feed all branch lines. Isolation valves must be provided to ensure that chilled water (or other coolant) does not flow through chillers that are not in operation. Valves should also be provided on branch lines to isolate sections where cooling is not required. This reduces pressure drops in the system and reduces power consumption in the pumping system. Individual compressors should be loaded to their full capacity before operating a second compressor. In some cases it is economical to provide a separate smaller-capacity chiller, which can be operated on an on–off control to meet peak demands, with larger chillers meeting the base load.

Flow control is also commonly used to meet varying demands. In such cases the savings in pumping at reduced flow should be weighed against the reduced heat transfer in coils due to reduced velocity. In some cases, operation at normal flow rates, with subsequent longer periods of no-load (or shutoff) operation of the compressor, may result in larger savings.

### 10.5.7 Chilled water storage

Depending on the nature of the load, it is economical to provide a chilled water storage facility with very good cold insulation. Also, the storage facility can be fully filled to meet the process requirements so that chillers need not be operated continuously. This system is usually economical if small variations in temperature are acceptable. This system has the added advantage of allowing the chillers to be operated at periods of low electricity demand to reduce peak demand charges. Low tariffs offered by some electric utilities for operation at night can also be taken advantage of by using a storage facility. An added benefit is that lower ambient temperature at night lowers condenser temperature and thereby increases the COP.

If temperature variations cannot be tolerated, it may not be economical to provide a storage facility since the secondary coolant would have to be stored at a temperature much lower than required to provide for heat gain. The additional cost of cooling to a lower temperature may offset the benefits. The solutions are case-specific. For example, in some cases it may be possible to employ large heat exchangers, at a lower cost burden than low-temperature chiller operation, to take advantage of the storage facility even when temperature variations are not acceptable. Ice bank systems which store ice rather than water are often economical.

## 10.6 GOOD PRACTICES FOR ENERGY EFFICIENCY

In refrigeration plants and systems, adoption of the following good practices improves energy efficiency significantly:

### 10.6.1 Operation and maintenance-related measures

- Establish a chiller efficiency-maintenance program. Start with an energy audit and follow-up; then make a chiller efficiency-maintenance program a part of your continuous energy management program.
- Chillers often represent a plant’s single largest electric load. Fouled tubes, leaking refrigerant, changes in water temperature, and a myriad of other variables can increase operating costs by 8%–10%. Operating a chiller at its peak performance saves energy as well as maintenance costs.
- Chiller efficiencies have improved significantly during the past ten years, mostly as a result of new refrigerants and microprocessor controls, as well as improved compressor and motor design. However, high-tech chillers have narrower tolerances, and service and upkeep are more crucial than ever for keeping them operating at peak performance.
- Chiller performance varies significantly with operating conditions. Full-load performance is not a good indicator of overall performance, because chiller plants rarely operate at full load. Instead, partial-load performance is critical to good overall chiller plant performance. A good reference is ASHRAE Standard 90.1-2001, which lists minimum chiller efficiency requirements.
- The daily log is still the first step in maintaining an efficiently run chiller plant in terms of operating conditions, including temperature, pressure, fluid level, and flow rate. Although microprocessor controls are recording more of these statistics, there is no substitute for a written log detailing findings from daily inspection of controls in the chiller room.
- Heat transfer has the greatest single effect on chiller performance, and maintaining good heat transfer is fundamental to maintaining efficiency. Chiller efficiency declines rapidly when tubes become fouled. Contaminants,

such as minerals, scale, mud, algae and other impurities, increase thermal resistance and reduce overall performance. These contaminants accumulate on the water side of heat transfer surfaces in both closed- and open-loop systems. Fouling occurs gradually over time, depending on the quality and temperature of the water used.

- The compressor's approach temperature, the difference between the temperature of the fluid leaving the heat exchanger, and the saturation temperature of the refrigerant being cooled or heated are good indicators of heat transfer efficiency. An increasing approach is a prime indicator that heat transfer efficiency is decreasing. An accurate log sheet will reveal when temperatures start to vary from efficient levels.
- Condenser tubes should be brush-cleaned, rather than chemically cleaned, at least annually, with an automatic rotary-cleaning machine to keep them free of contaminants.
- Condenser water using open cooling sources, such as atmospheric cooling towers, require water treatment to prevent fouling. Erosive conditions—for example, sand flowing through the tubes at high velocity—may pit tubes, decreasing tube effectiveness. Untreated water can damage tubes, piping, and other materials.
- A cooling tower blowdown is the most effective way to remove solids and contaminants. When a sensor detects high water conductivity, an automatic valve dumps some water and its load of dissolved and suspended solids. A visual inspection also is a good (although less accurate) indicator of water quality. Inspect chilled water loops once a year for general water quality and evidence of corrosion.
- Lowering the temperature of the water entering the condenser can improve the chiller's efficiency.
- Flow rate must be regulated closely, because too low a flow rate reduces chiller efficiency, leading to laminar flow. The minimum velocity is typically around 3 ft/second. However, too high a flow rate leads to vibration, noise, and tube erosion. The maximum recommended flow rate is typically around 12 ft/second.
- The amount of cooling that any chiller can provide depends on how much refrigerant it moves through the compressor per unit time. It's important to maintain the proper level of refrigerant. Leaks, as well as air and moisture, decrease efficiency and system reliability. Low refrigerant charge, usually resulting from leaks, causes the compressor to work harder and achieve less cooling.
- Air and moisture are two non-condensables that can leak into low-pressure chillers. Non-condensables can reduce chiller efficiency by as much as 4% at 60% loads and 7% at 100% loads. Air insulates tubes, preventing exchange and elevating condensing temperatures, which also makes the compressor work harder. Moisture promotes acid formation, which can damage motor windings and bearings. Installing purge units on low-pressure chillers minimizes the effect of non-condensables. Positive

pressure chillers using HFC-134a, HFC-410a, and HCFC-22 do not require purge units because non-condensables cannot enter them.

- Once a year, test compressor lube oil for a spectrometric chemical analysis that will provide details about moisture content, metals, acids, and other contaminants that affect performance. Oil should be replaced only if necessary. High moisture levels can indicate a purge unit problem, which has a significant effect on efficiency. Test samples from low-pressure chillers more frequently, using a schedule based on purge run hours. Replace oil filters when they exhibit a high pressure drop and when the oil charge is replaced.
- For efficient starter and motor operation, check the safety and sensor calibrations on microprocessor controls. Consult the manufacturer’s guidelines. Check chiller electrical connections, wiring, and switch gear for hot spots and worn contacts. To prevent insulation faults, test motor windings for resistance to ground and winding-to-winding. Check the shaft seal on open drive motors for possible refrigerant leaks, and clean motor cooling air vents to maximize cooling.
- A chiller motor is typically the largest single electrical load in a building. Constant-speed compressors match capacity to load through inlet vanes, throttling the gas allowed into the compressor impellers. This is not the most efficient way to modulate chiller capacity. Under the right operating conditions, variable speed drives offer significant energy savings. Variable speed drives also act as “soft starters” to reduce the motor’s inrush current to almost that of the full-load running amps. This reduction is important for chillers operating on emergency power generators. Variable speed drives also reduce the mechanical shock of starting large-horsepower motors, increasing chiller reliability and life.

### 10.6.2 Other generic opportunities for energy efficiency

- The evolution of compressor technology has progressed from reciprocating to rotary, to twin rotary, to scroll, to screw, to centrifugal machines, in terms of efficiency. Need-based replacement for renovation and modernization for energy efficiency is a good opportunity.
- Select most efficient compressors with lowest I kW/TR (integrated kW/TR accounting for part load performance).
- Rooftop coating adoption, with reflective materials and under-deck insulation, will reduce U factor (heat transfer coefficient, which should be as low as possible) and heat ingress.
- Maintain optimum wall area (70%) to window area (30%) ratio for minimizing solar heat gain.
- Adopt energy-efficient low-wattage lighting systems to reduce cooling load.
- Optimize thermostat settings for energy economy.
- Adopt false ceilings in air-conditioned spaces to reduce the area to be conditioned.
- Adopt double-glazed glass panes in windows to reduce solar heat gains.

- Adopt sun film for heat solar gain reduction.
- Adopt good filter maintenance practices for better AHU performance.
- Regular cooling coil cleaning and ultraviolet light application will reduce bacterial effects.
- Adopt energy-efficient water-cooled condensers in place of air-cooled condensers.
- Adopt energy-efficient AHU fans.
- Adopt heat recovery wheels in AHUs.
- Adopt grooved copper tubes for better heat exchange.
- Adopt super slit fins for better heat exchange.
- Adopt heat recovery condensers.
- Adopt variable frequency drives for pumps and fans for power savings.
- Adopt cooling towers with 5°F approach, in place of conventional 7°F approach units, to optimize condenser performance.
- Use soft water for condensers to avoid condenser scaling effects.
- Use FRP blades in cooling tower fans, for power savings.
- Adopt two-way valves for AHUs, to achieve better operational control.
- Adopt intelligent building automation and controls.
- Adopt chilled water storage and ice bank storage, as applicable, for peak demand management and energy savings.
- Adopt automatic PF controllers for PF improvement.
- Adopt VAR systems, especially where waste heat steam is available at low cost, as an eco-friendly and cost-effective alternative.
- Adopt eco-friendly refrigerants.

# 11. GREEN BUILDING CONCEPTS AND GOOD BUILDING PRACTICES

## 11.1 INTRODUCTION

In current times of rapid infrastructure growth and a looming energy crisis, there is a strong need to address and incorporate good practices for efficient energy and resource use while planning for buildings, be it for residential purposes or for commercial applications.

Green buildings would squarely address ecological and environmental impacts in a holistic manner and at the same time offer tremendous economic benefits to the occupants. A Green building is one which incorporates several green features, such as energy-efficient and eco-friendly equipment, recycled and environment-friendly building materials, quality indoor air for human safety and comfort, use of renewable energy, effective controls and building management systems, efficient use of water, non-toxic and recycled materials, effective use of existing landscapes, and adoption of cost-effective and environment-friendly technologies.

## 11.2 TYPICAL FEATURES OF GREEN BUILDINGS

- Adoption of erosion control techniques like temporary seeding, permanent seeding, and mulching
- Occupants encouraged to use mass transportation like bus or rail; use of bicycles and use of cleaner fuels for automobiles
- Reduction of building footprints to minimize their impact on the environment
- Reduction of impervious areas to prevent storm water run-off
- Installation of high-efficiency irrigation methods and selection of vegetation which has low water consumption
- Use of low water plumbing installations
- Harvesting of site energy
- Use of CFC-free HVAC equipment
- Adoption of energy-efficient equipment for air-conditioning and lighting systems
- Use of on-site renewable energy
- Measurement and verification plan to ensure energy and water savings
- Adoption of controls and building management systems
- Segregation, collection, and disposal of waste streams at source
- Use of salvaged or refurbished materials from other sites
- Recycling of construction debris to other sites
- Use of building materials having a high recycled content

- Use of rapidly renewable materials (material which could be replenished within a life cycle of 10 years)
- Declaration of the site as a non-smoking area, or provision of designated areas for smoking
- Maintenance of indoor environmental quality, to avoid 'sick building' syndrome
- Use of low VOC (volatile organic compound) paints, sealants, and adhesives.

## 11.3 BENEFITS OF GREEN BUILDINGS

Green buildings have tremendous benefits, both tangible and intangible. The most tangible benefit is in reduction of operating energy and water costs right from day one, and during the entire life cycle of the building.

Green buildings offer a range of benefits, including the following:

- 30% to 40% reduction in operation cost
- Green corporate image
- Health and safety of building occupants
- Enhanced occupant comfort
- Improved productivity of occupants
- Incorporation of best operational practices from day one
- Incorporation of latest techniques and technologies.

## 11.4 GOOD PRACTICES IN THE BUILDING SECTOR

This section outlines some good practices criteria related to them, and technologies and strategies available for realizing them.

**Practice 1: Plan for minimum energy requirements**

Criteria:

Establish the minimum level of energy efficiency for the base building and systems.

**Practice 2:**

Design to meet building energy efficiency and performance as required by ASHRAE/IESNA 90.1-1999 or the local energy code, whichever is the more stringent.

Technologies and strategies:

- Design the building envelope and building systems to maximize energy performance.
- Use a computer simulation model to assess the energy performance and identify the most cost-effective energy efficiency measures.
- Quantify energy performance as compared to a baseline building.
- Have an energy audit performed for the facility regularly.

**Practice 3: Optimize energy performance**

Criteria:

Achieve increasing levels of energy performance above the prerequisite standard to reduce environmental impacts associated with excessive energy use.

**Practice 4:**

Reduce design energy cost compared to the energy cost budget, for regulated energy components, described in the requirements of ASHRAE/IESNA Standard 90.1-1999, as demonstrated by a whole building simulation using the Energy Cost Budget Method. Regulate energy components include HVAC systems, building envelope, service hot water systems, lighting and other regulated systems as defined by ASHRAE. It is often possible to reduce design energy cost by 10%–60%.

Technologies and strategies:

- Have an energy audit conducted for the building/facility. Design the building envelope and building systems to maximize energy performance.
- Use a computer simulation model to assess the energy performance and identify the most cost-effective energy efficiency measures. Quantify energy performance as compared to a baseline building.
- North light roofing, transparent roof sheets, ventilation design, chimney effect through tower design, aerated concrete blocks/hollow bricks, high ceiling, roof cooling salts.

**Practice 5: Plan for increasing levels of renewable technology use**

Criteria:

Encourage and recognize increasing levels of self-supply through renewable technologies to reduce environmental impacts associated with fossil fuel energy use.

**Practice 6:**

- Supply a net fraction of the building’s total energy use (as expressed as a fraction of annual energy cost) through the use of on-site renewable energy systems.
- Target the achievement of renewables share of total energy cost at between 5% and 20%.

Technologies and strategies:

- Assess the project for renewable energy potential including solar, wind, geothermal, biomass, hydro, and bio-gas strategies.
- When applying these strategies, take advantage of net information and Institutions local and international.
- Solar PV, CFL Solar hot water systems, solar cookers, bio-gas plants (rural segment), vermin composting.

**Practice 7: Plan for minimizing CFC Refrigerants in HVAC equipment**

Criteria:

Reduce ozone depletion.

**Practice 8:**

- Zero use of CFC-based refrigerants in new building HVAC base building systems.
- When reusing existing base building HVAC equipment, complete a comprehensive CFC phase out conversion.

Technologies and strategies:

- When reusing existing HVAC systems, conduct an inventory to identify equipment that uses CFC refrigerants and adopt a replacement schedule for these refrigerants.
- For new buildings, specify new HVAC equipment that uses no CFC refrigerants, e.g. VAR or R134A in vapor compression systems.
- Eco-friendly refrigeration systems, VAR (Central A/c) chillers.

**Practice 9: Plan for minimizing ozone depletion**

Criteria:

Reduce ozone depletion and support early compliance with the Montreal Protocol.

**Practice 10:**

Install base building level HVAC and refrigeration equipment and fire suppression systems that do not contain HCFCs or Halons.

Technologies and strategies for adoption:

- When reusing buildings, replace inventory of refrigerants and fire suppression chemicals in existing building systems with those that contain HCFCs or halons.
- For new buildings, specify refrigeration and fire suppression systems that use no HCFCs or halons.

**Practice 11: Plan for easy accounting of energy and water consumption**

Criteria:

Provide for the ongoing accountability and optimization of building energy and water consumption performance over time.

**Practice 12:**

Plan with long-term continuous measurement of performance:

- Lighting systems and controls
- Constant and variable motor loads
- Variable frequency drive (VFD) operation
- Chiller efficiency at variable loads (kW/ton)
- Cooling load
- Air and water economizer and heat recovery cycles
- Air distribution static pressures and ventilation air volumes
- Boiler efficiencies
- Building-specific process energy efficiency systems and equipment
- Indoor water risers and outdoor irrigation systems

Technologies and strategies:

- Through building energy audit, model the energy and water systems to predict savings.
- Design the building with equipment to measure energy and water performance.
- Draft a Measurement and Verification Plan to apply during building operation that compares predicted savings to those actually achieved in the field.

**Practice 13: Plan for water-efficient landscaping**

Criteria:

Limit or eliminate the use of potable water for landscape irrigation.

**Practice 14:**

- Use high efficiency irrigation technology, or
- Use captured rain or recycled site water, to reduce potable water consumption for irrigation over conventional means.

Technologies and strategies:

- Perform a soil/climate analysis to determine appropriate landscape types.
- Design the landscape with indigenous plants to reduce or eliminate irrigation requirements.
- Use high-efficiency irrigation systems and consider reuse of storm water for irrigation.
- Adopt ISO:14000 certification for large facilities.
- Use pervious paver blocks, roof cover with gardens, rainwater harvesting.

**Practice 15: Plan for maximum wastewater reuse and less dependence on municipal water source**

Criteria:

Reduce the generation of wastewater and potable water demand, while increasing the local aquifer recharge.

**Practice 16:**

- Reduce the use of municipally provided potable water for building sewage conveyance, or
- Treat all wastewater on-site for re-use application.

Technologies and strategies:

- Estimate the wastewater volume generated in the building and specify high-efficiency fixtures and dry fixtures such as composting toilets and waterless urinals to reduce these volumes.
- Consider reusing storm water for sewage conveyance or on-site wastewater treatment systems (mechanical or natural).
- Biological root zone treatment.
- Recycled water for gardening.
- Sewage water for mechanical (filter press drum) type cleaning systems, etc.

**Practice 17: Plan for maximizing water use efficiency**

Criteria:

Maximize water efficiency within buildings to reduce the burden on municipal water supply and wastewater systems.

**Practice 18:**

- Employ strategies that in the aggregate use less water than the water-use baseline calculated for the building (not including irrigation).
- Reduce potable water use by at least 10%.

Technologies and strategies:

- Estimate the potable and non-potable water needs for the building.
- Use high-efficiency fixtures, dry fixtures such as composting toilets and waterless urinals, and occupant sensors to reduce the potable water demand.
- Consider reuse of storm water for non-potable applications such as toilet and urinal flushing, mechanical systems, and custodial uses.

**Practice 19: Plan for storage and collection of recyclables while building**

Criteria:

Facilitate the reduction of waste generated by building occupants that is hauled to and disposed of in landfills.

**Practice 20:**

Provide an easily accessible area that serves the entire building and is dedicated to the separation, collection, and storage of materials for recycling including (at a minimum) paper, glass, plastics, and metals.

Technologies and strategies:

- Designate an area for recyclable collection and storage that is appropriately sized and located in a convenient area.
- Identify local waste handlers and buyers for glass, plastic, office paper, newspaper, cardboard, and organic wastes.
- Instruct occupants on building recycling procedures.
- Consider employing cardboard balers, aluminum can crushers, recycling chutes, and other waste management technologies to further enhance the recycling program.
- Recycle wood, glass, aluminum and ceramic tiles, furniture made of bagasse-based completed wood, etc.

**Practice 21: Plan for building life extension and re-use**

Criteria:

- Extend the life cycle of existing building stock.
- Conserve resources.
- Retain cultural resources.
- Reduce waste.

- Reduce environmental impacts of new buildings as they relate to materials manufacturing and transport.

**Practice 22:**

- Reuse large portions of existing structures during renovation or redevelopment projects.
- Identify opportunities to incorporate salvage materials such as beams and posts, flooring, paneling doors, frames, cabinets, furniture, bricks and decorative items.

Technologies and strategies:

- Consider reuse of existing buildings, including structure, shell, and non-shell elements.
- Remove elements that pose contamination risk to building occupants and upgrade outdated components such as windows, mechanical systems, and plumbing fixtures.

**Practice 23: Plan for increasing ventilation effectiveness**

Criteria:

Provide for the effective delivery and mixing of fresh air to support the health, safety, and comfort of building occupants.

**Practice 24:**

- For mechanically ventilated buildings, design ventilation systems that result in an air change effectiveness (E) greater than or equal to 0.9 as determined by ASHRAE 129-1997.
- For naturally ventilated spaces, demonstrate a distribution and laminar flow pattern that involves not less than 90% of the room or zone area in the direction of air flow.

Technologies and strategies:

- Design the HVAC system and building envelope to optimize air change effectiveness.
- Air change effectiveness can be optimized using a variety of ventilation strategies including displacement ventilation, low-velocity ventilation, and operable windows.
- The air change effectiveness of the building after construction should be regularly tested.
- CO2 monitoring; chimney type ducting for intake/exhaust.

**Practice 25: Plan for minimum indoor air quality requirement**

Criteria:

Establish minimum indoor air quality (IAQ) performance to prevent the development of indoor air quality problems in buildings, maintaining the health and wellbeing of the occupants.

**Practice 26:**

Meet the minimum requirements of voluntary consensus standard ASHRAE 62-1999, Ventilation for Acceptable Indoor Air Quality and Approved Addenda.

Technologies and strategies

- Design the HVAC system to meet the ventilation requirements of the reference standard.
- Identify potential IAQ problems on the site and locate air intakes away from contaminant sources like low volatile organic matter paints, carpets, adhesives, and sealants.

**Practice 27: Plan for increased use of local/regional materials**

Criteria:

Increase demand for building products that are manufactured locally, thereby reducing the environmental impacts resulting from their transportation and supporting the local economy.

**Practice 28:**

Specify at least 20%–50% of building materials that are manufactured in the local economy.

Technologies and strategies:

- Establish a project goal for locally sourced materials and identify materials and material suppliers who can achieve this goal.
- During construction, ensure that the specified local materials are installed and quantify the total percentage of local materials installed.
- Use compressed earth blocks, wood/straw boards, fly ash cement, hollow bricks.

**Practice 29: Plan for efficient and safe wiring practices**

Criteria:

Quality assurance of electrical wiring material, wiring accessories, grounding, leakage protection, overload protection devices and metering to ensure a safe and energy-efficient distribution infrastructure.

**Practice 30:**

Adopt well-established standard material and engineering practices.

Technologies and strategies:

MCCBs/MCBs, CVTs, UPS, electronicb, CFLs, remote controls for lights and fans, electronic regulators, earth leakage protection relays, and occupancy sensors are some of the devices and technologies applicable in this context.

## 11.5 SOME OTHER GENERIC PRACTICES THAT CAN BE ADOPTED

- Use of fly-ash-based cement
- Use of fly-ash-based Aerocon blocks
- Declaration of building as “non-smoking”
- CO2 censor installation
- Regular checks on AHU filters
- Use of composite wood in preference to hardwoods like teak

- Daylight view for 90% of occupied areas
- Minimum 25% open space set apart from built-up area
- Site location selected close to bus and rail lines
- Better access to community transport rather than individual transportation
- Extensive roof garden coverage
- Rain water harvesting adoption
- Drip irrigation adoption
- Adoption of fast-growing plantations
- Use of low-U-value glazed glass
- Adoption of daylight dimmer controls.

# 12. CLEAN DEVELOPMENT MECHANISM

## 12.1 INTRODUCTION

The Clean Development Mechanism (CDM) was instituted in 2001, under the Kyoto Protocol, to enable developed countries to meet their greenhouse gas (GHG) reduction targets at lower cost through projects in developing countries.

A CDM project is a development project, driven by market forces, that reduces GHGs. In a CDM project, an investor from an industrialized country supplies capital or technology, based on the future values of certified emission reduction units (CERs), also known as carbon credits, which measure the reduction of GHGs in the developing country. The procedure starts with the industrialized country keeping a regularly updated inventory of its emissions. The country may choose to allocate its national target (set by the Kyoto Protocol) across a number of domestic emitters, in much the same way that resources such as fishing rights or logging rights are allocated. A domestic emitter can meet its allocated target through mitigation activities within the country, or it can make use of the two Kyoto Protocol project-based flexibility mechanisms. The CDM allows the emitter to invest in a project in a developing country or buy CERs from someone who has invested in a project. Under the CDM, all parties benefit: the host country is assisted in achieving sustainable development; the owner of the project receives financial and technological assistance; and the emitter in the industrialized country receives carbon credits.

## 12.2 OBJECTIVES OF CDM

The CDM has three stated objectives:

- To assist parties not included in Annex I (i.e., developing countries) in achieving sustainable development.
- To contribute to the ultimate objective of the convention (i.e., stabilize GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system).
- To assist parties included in Annex I (developed countries) in achieving compliance with their quantified emission limitation and reduction commitments under article 3 of the Kyoto Protocol.

## 12.3 CDM AS A SUSTAINABLE DEVELOPMENT STRATEGY

The Clean Development Mechanism is designed as an element of the sustainable development strategy allowing industrialized countries investing in “clean” projects in developing countries also to gain emission credits. These credits are given in the form of Certified Emission Reductions (CERs), which, like all the other Kyoto accounting units, are expressed in tons of carbon dioxide equivalent. The financing country can use these units to offset its own emission of greenhouse gases during a given period, or sell them to a country. It can also bank them for use during a subsequent period. Since these investments are viewed in a positive light, they also add to the reputation of project developers and investors. At the same time, the recipient country gains from an increase in investment (which may be from private or public sources) in sustainable development.

## 12.4 METHODOLOGIES

The Marrakech Accords stipulate that an emission reduction project activity under the CDM must, among other things:

- use an approved methodology to define the baseline emissions (i.e., the emission that would have occurred in the absence of the project), from which reductions are calculated;
- use an approved monitoring methodology to monitor actual emissions and collect other information needed to calculate the emission reductions achieved; and
- be reviewed by an accredited "designated operational entity" which confirms that the proposed baseline and monitoring methodologies are appropriate and that other eligibility requirements are met.

## 12.5 STAKEHOLDERS AND ROLES

The implementation of CDM projects involves a number of stakeholder participants and organizations:

- Host Government DNA
- Annex I DNA
- Local Stakeholders
- Project Participants
- Designated Operating Entity
- Executive Board (and Panels)
- Meeting of parties to the Kyoto Protocol
- Accredited NGOs

**Conference of parties serving as meeting of parties (CoP/MoP):**

The Conference of Parties Serving as Meeting of Parties (CoP/MoP) to the Kyoto Protocol is the authority and provides guidance to CDM. The CoP/MoP takes decision on recommendations by the Executive Board (EB) and designates Operating Entities (OE). The CoP/MoP also reviews the EB reports as well as the distribution of Operating Entities and CDM project activities.

**Executive board:**

The Executive Board supervises the CDM under authority of the MoP of the Kyoto Protocol. The EB develops the modalities and procedures for the CDM, as well as the rules and procedures; approves new methodologies; simplifies modalities and procedures for small-scale CDM projects; accredits and designates OEs; develops and maintains a CDM registry; makes information relating to CDM projects publicly available; and reports to the MoP.

**Operational entities (OEs):**

OEs are accredited and designated by the Executive Board based on the accreditation standards. The OE validates proposed CDM project activities or verifies and certifies emission reductions.

**Designated National Authority (DNA):**

A Designated National Authority (DNA) for CDM should be specified by all the parties to Kyoto Protocol who participate in CDM project activities. While the purpose of the DNAs in Annex I countries is to ensure meeting their commitments specified in Annex B to the Kyoto Protocol and provide written approval of voluntary participation in each CDM project activity, the DNAs in Non-Annex I countries which are host parties have the additional responsibility of providing host country approval and confirming that the project activity assists the party in achieving sustainable development.

**Project participants:**

Project participants can either be a party participating in a CDM or public or private entities authorized by a party to participate in CDM project activities. Project participants usually initiate and complete measures, operations, or actions that aim at reducing GHGs and decide on allocation of CERs.

**Other stakeholders, parties, and accredited NGOs:**

Stakeholders are the public, including individuals, groups, or communities who are affected or likely to be affected by the proposed CDM activity or actions. In the context of CDM, parties will be parties to the Kyoto Protocol. NGOs that have been accredited by UNFCCC can also make stakeholder comments on a CDM project activity.

## 12.6 CDM APPLICATIONS IN INDUSTRIAL ENERGY SYSTEMS

**Renewable energy**

- Wind power
- Solar
- Biomass power
- Hydro power

**Energy efficiency measures**

- Boiler and steam efficiency
- Pumps and pumping system
- Efficient cooling systems

- Back pressure turbines

**Co-generation in industries having both steam and power requirements**

**Power sector**

- Induction of new technologies which are efficient (e.g. thermal)
- Reduction in technical T&D losses

**Fuel switching**

- From fossil fuel to green fuels like biomass

**Waste management**

- Capturing of landfill methane emissions to generate power
- Utilization of waste and waste water emissions for generation of energy

# Annex

## SME energy efficiency opportunities assessment checklist

| S. No. | Enconomic Opportunity | Applicability | Estimated Energy Consumption /hr (or any relevant energy indicator) by Existing Equipment | Hours of Operation /Day | Nos. | Estimated Potential for Savings *(Order of magnitude of savings margin indicated in brackets)* |
|---|---|---|---|---|---|---|
| 1. | Soft Starters Energy Savers | Applicable/ Not Applicable | | | | *(3% of operating kW)* |
| 2. | Variable Speed Drives (Hydraulic/eddy current type) | Applicable/ Not Applicable | | | | *(3–5 % of operating kW* |
| 3. | Maximum Demand controller | Applicable/ Not Applicable | | | | *(Reduction of demand charges)* |
| 4. | Capacitor and auto PF controls: | Applicable/ Not Applicable | | | | *(1% on energy consumption in terms of distribution loss reduction)* |
| 5. | Electronic timers for machineries and lighting | Applicable/ Not Applicable | | | | *(Direct savings -depends on the excess hours of operation above prescribed time of operation)* |
| 6. | Variable frequency drive (Electronic) | Applicable/ Not Applicable | | | | *(5–15% of operating kW* |
| 7. | Permanent magnet motor for variable speed applications | Applicable/ Not Applicable | | | | *(10–15% on average operating kW)* |

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|---|---|---|---|---|---|---|
| 8. | Lighting energy savers (voltage controller) | Applicable/ Not Applicable | | | | *(15–20% on operating lighting kW)* |
| 9. | Efficient lamps (T5, CFL, métal halide, HPSV) | Applicable/ Not Applicable | | | | *(30–50% of existing lighting kW)* |
| 10. | Transparent roofing sheets to reduce lighting load | Applicable/ Not Applicable | | | | *(Avoids at least 25% of existing Shop Floor Day Lighting)* |
| 11. | Energy-efficient water pumps | Applicable/ Not Applicable | | | | *(Improvement in existing efficiency up to 75%)* |
| 12. | FRP blades for cooling tower fans | Applicable/ Not Applicable | | | | *(Being small fans reduction of 5-7% on existing fan kW drawl)* |
| 13. | Efficient spray nozzles in cooling towers | Applicable/ Not Applicable | | | | *(Improves spray in mist form and completely eliminates need for CT-ID fan)* |
| 14. | Compressed air ON/OFF controller | Applicable/ Not Applicable | | | | *(3–5% Savings in overall existing kWh consumption)* |
| 15. | Compressed air generation pressure reduction | Applicable/ Not Applicable | | | | *(8% reduction in motor input kW for every 1 kg/ cm2 reduction in discharge pressure)* |
| 16. | Compressed air leakage reduction | Applicable/ Not Applicable | | | | *(Direct saving- Leakage based on Trial (or estimated) varies between 10–40%)* |

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|---|---|---|---|---|---|---|
| 17. | Trans-vector nozzles for end use compressed air cleaning applications | Applicable/ Not Applicable | | | | *(15% reduction in compressed air end use for a particular cleaning application)* |
| 18. | Compressor speed reduction based on load and unload cycles | Applicable/ Not Applicable | | | | *(Depending on ON/OFF cycles compressor capacity can be optimized by speed reduction– by pulley modification or VFD)* |
| 19. | Vapor absorption chiller | Applicable/ Not Applicable | | | | *(Normal existing kW/TR (anywhere between 1–2) will reduce to a meager 0.1 kW/ TR. Feasible only if waste heat is used for VAR* |
| 20. | Steam traps | Applicable/ Not Applicable | | | | *Identification of faulty, leaking traps can save direct steam loss through them (10–40% on case to case basis)* |
| 21. | Condensate recovery | Applicable/ Not Applicable | | | | *(Up to 70% recovery is possible–this is direct savings as heat input to the boiler OR Hot Water requirement for the process)* |

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|---|---|---|---|---|---|---|
| 22. | Air pre-heaters for waste heat recovery in Bbiler exhaust gas | Applicable/<br>Not Applicable | | | | *(Flue gas temperature can be reduced from existing value to 170℃ in case of oil fired and 130℃ in case of Coal fired. Minimum ΔT of flue gas should be 40–50℃)* |
| 23. | Air pre-heaters for waste heat recovery in furnace exhaust gas | Applicable/<br>Not Applicable | | | | *(Flue gas temperature can be reduced from existing value to 170℃ in case of oil fired and 130℃ in case of Coal fired. Here ΔT of flue gas will be huge and WHR potential also huge)* |
| 24. | Ceramic insulation for heat loss reduction from furnace surfaces | Applicable/<br>Not Applicable | | | | *(5–7% of existing surface heat loss for temperatures below 200℃ and up to 10% for temperatures between 300–500℃)* |