



MOHAMED SATHAK A.J. COLLEGE OF ENGINEERING

(Approved by AICTE, New Delhi and Affiliated to Anna University, Chennai)



OME551 - Energy Conservation & Management

Five Unit Notes

Prepared by

**Mr. Vigneshwaran V,
Assistant Professor,
Department of Mechanical Engineering
&**

**Mr. S R Mohan,
Assistant Professor,
Department of Mechanical Engineering**

UNIT I - INTRODUCTION

1. Introduction

Energy is one of the major inputs for the economic development of any country. In the case of the developing countries, the energy sector assumes a critical importance in view of the ever increasing energy needs requiring huge investments to meet them.

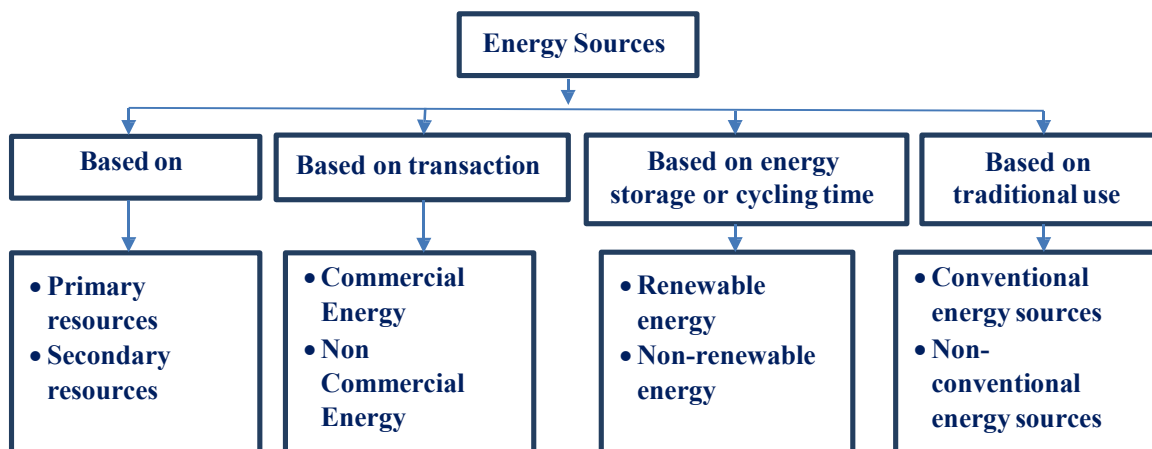
Energy is the ability to do work and work is the transfer of energy from one form to another. In practical terms, energy is what we use to manipulate the world around us, whether by exciting our muscles, by using electricity, or by using mechanical devices such as automobiles. Energy comes in different forms - heat (thermal), light (radiant), mechanical, electrical, chemical, and nuclear energy.

Energy can be classified into several types based on the following criteria:

- Primary and Secondary energy
- Commercial and Non-commercial energy
- Renewable and Non-Renewable energy

1.1.1 Primary and Secondary Energy

Primary energy sources are those that are either found or stored in nature. Common primary energy sources are coal, oil, natural gas, and biomass (such as wood). Other primary energy sources available include nuclear energy from radioactive substances, thermal energy stored in earth's interior, and potential energy due to earth's gravity. The major primary and secondary energy sources are shown in Figure 1.1



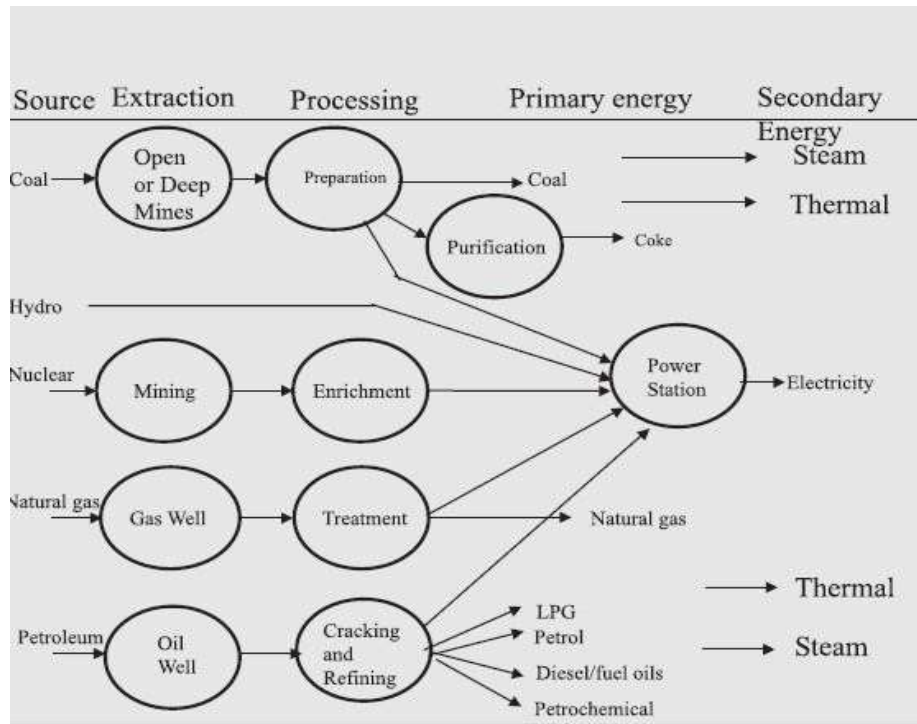


Figure 1.1 Major Primary and Secondary Sources

Primary energy sources are mostly converted in industrial utilities into secondary energy sources; for example coal, oil or gas converted into steam and electricity. Primary energy can also be used directly. Some energy sources have non-energy uses, for example coal or natural gas can be used as a feedstock in fertilizer plants.

1.1.2 Commercial Energy and Non Commercial Energy

Commercial Energy

The energy sources that are available in the market for a definite price are known as commercial energy. By far the most important forms of commercial energy are electricity, coal and refined petroleum products. Commercial energy forms the basis of industrial, agricultural, transport and commercial development in the modern world. In the industrialized countries, commercialized fuels are predominant source not only for economic production, but also for many household tasks of general population.

Examples: Electricity, lignite, coal, oil, natural gas etc.

Non-Commercial Energy

The energy sources that are not available in the commercial market for a price are classified as non-commercial energy. Non-commercial energy sources include fuels such as firewood, cattle dung and agricultural wastes, which are traditionally gathered, and not bought at a price used especially in rural households. These are also called traditional fuels. Non-commercial energy is often ignored in energy accounting.

Example: Firewood, agro waste in rural areas; solar energy for water heating, electricity generation, for drying grain, fish and fruits; animal power for transport, threshing, lifting water for irrigation, crushing sugarcane; wind energy for lifting water and electricity generation.

1.1.3 Renewable and Non-Renewable Energy

Renewable energy is energy obtained from sources that are essentially inexhaustible. Examples of renewable resources include wind power, solar power, geothermal energy, tidal power and hydroelectric power (See Figure 1.2). The most important feature of renewable energy is that it can be harnessed without the release of harmful pollutants.

Non-renewable energy is the conventional fossil fuels such as coal, oil and gas, which are likely to deplete with time.

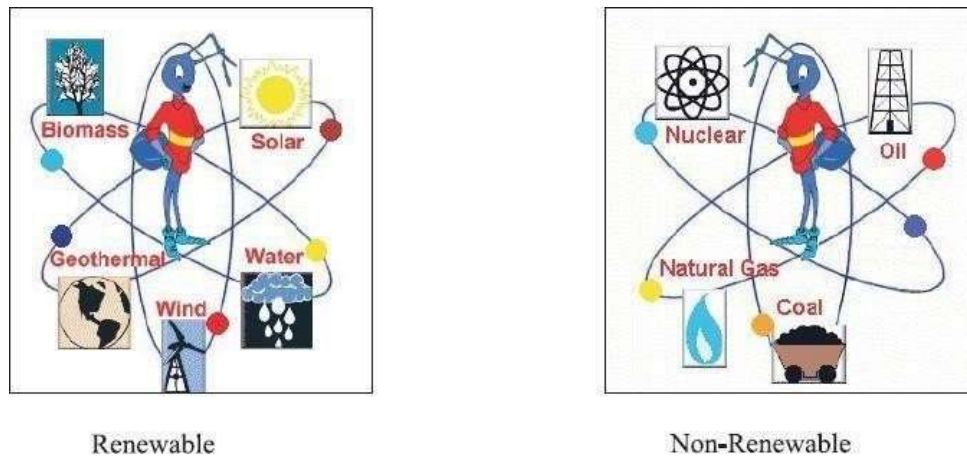


Figure 1.2 Renewable and Non-Renewable Energy

1.2 Energy and Power

1.2.1 Energy

Energy is the ability to do a work. Its unit is Joule (J)

$$\text{Energy} = \text{force} * \text{Distance}$$

1.2.2 Power

Power is defined as the rate of doing work. Its unit is watt (W)

1.2.3 Relation between Energy and Power

$$\text{Energy} = \text{Power} * \text{Time}$$

Example 1.1

A portable machine requires a force of 200N to move it. How much work is done if the machine is moved 20m and what average power is utilized if the movement takes 25s?

Solution

$$\text{Work done} = \text{force} * \text{distance}$$

$$= 200\text{N} * 20\text{m}$$

$$= 4000 \text{ Nm or 4 kJ}$$

$$\text{Power} = \text{work done} / \text{time taken} = 4000 \text{ J} / 25 \text{ s} = 160 \text{ J/s} = 160 \text{ W}$$

1.3 Present and Past Scenario of Primary Energy Resources in the World

1.3.1 Coal

Coal is the most abundant fossil fuel in the world. Coal reserves are available in almost every country in the world. The largest coal reserves are available in the USA followed by Russia, China, Australia and India. The global coal reserve was estimated to be **891.531 billion tones by the end of 2013**. But by the end of **2003, it was estimated to be 984.453 billion tones**.

2. Crude Oil

The global proven crude oil reserve was estimated to be **1687 billion barrels by the end of 2013**. But by the end of **2003, it was estimated to be 1147 billion barrels**. Almost 48% of proven oil reserves are in the Middle East countries. Saudi Arabia has the largest share of the reserve with 15.8% followed by Russia and USA.

3. Natural Gas

Natural gas is a gaseous fossil fuel consisting primarily of methane but also includes small quantities of ethane, propane, butane and pentane. Before natural gas can be used as a fuel, it undergoes extensive processing for removing almost all constituents except methane. Natural gas resources are large but they are highly concentrated in few countries. Iran has largest share (18.2%) followed by Russia (16.8%) and Qatar (13.3%). India has only about 0.7% of global natural reserves. The global proven natural gas reserve was estimated to be **176 trillion cubic meters by the end of 2003**. But by the end of 2013, it was estimated to be **186 trillion cubic meters**.

4. National Energy Consumption Data

The primary energy consumption of some of the countries are given in table. It is seen that India's primary energy consumption is only 4.7% of the world (USA-18%, China-22%).

Table 2.4. Conversion Factors for Joule (J) to Other Units of Energy

1 <i>Equal to One</i>	2 <i>J</i>	3 <i>kWh</i>	4 <i>eV</i>	5 <i>erg</i>	6 <i>cal</i>	7 <i>kgm</i>	8 <i>BTU</i>	9 <i>tce</i>	10 <i>MWd</i>	11 <i>g.mass</i>
J		2.78×10^{-7}	6.24×10^{18}	1×10^7	2.39×10^{-1}	1.02×10^{-1}	9.48×10^{-4}	3.41×10^{-11}	1.16×10^{-11}	1.11×10^{-14}
kWh	3.6×10^6		2.25×10^{25}	3.60×10^{13}	8.601×10^5	3.67×10^5	3.41×10^3	1.23×10^{-4}	4.17×10^{-5}	4.01×10^{-8}
eV	1.60×10^{-19}	4.45×10^{-26}		1.60×10^{-12}	3.83×10^{-20}	1.63×10^{-20}	1.52×10^{-22}	5.46×10^{-30}	1.85×10^{-30}	1.78×10^{-33}
erg	1.00×10^{-7}	2.78×10^{-14}	6.24×10^{11}		2.39×10^{-8}	1.02×10^{-8}	9.48×10^{-11}	3.41×10^{-18}	1.16×10^{-18}	1.11×10^{-21}
cal	4.186×10^0	1.16×10^{-6}	2.61×10^{19}	4.19×10^7		7×10^{-1}	3.97×10^{-3}	1.43×10^{-10}	4.84×10^{-11}	4.66×10^{-14}
kgm	9.807×10^0	2.72×10^{-6}	6.12×10^{19}	9.81×10^7	2.34×10^0		9.29×10^{-3}	3.35×10^{-10}	1.14×10^{-10}	1.09×10^{-13}
BTU	1.055×10^3	2.93×10^{-4}	6.57×10^{21}	1.05×10^{10}	2.52×10^2	1.07×10^2		3.60×10^{-8}	1.22×10^{-8}	1.17×10^{-11}
tce	2.93×10^{10}	8.14×10^3	1.83×10^{29}	2.93×10^{17}	7.000×10^9	2.99×10^9	2.78×10^7		3.93×10^{-1}	3.26×10^{-4}
MWd	8.64×10^{10}	2.400×10^4	5.93×10^{29}	8.64×10^{17}	2.06×10^{10}	8.81×10^9	8.19×10^7	2.95×10^0		9.61×10^{-4}
g.mass	8.99×10^{13}	2.50×10^7	5.61×10^{32}	8.99×10^{20}	2.15×10^{13}	9.17×10^{12}	8.51×10^{10}	3.07×10^3	1.04×10^3	

Meaning : BTU = British Thermal Unit ; $3.6 \times 10^6 = 3.6 \times 10^6$
tce = tonne coal equivalent ; Comma = Decimal point
tpe = tonne petroleum equivalent ;
MWd = megawatt.day
kWh = kilo Watt.hour
hp.h = horse-power.hour
amu = atomic mass unit
th = thermic (Mcal)

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Table-1.7 Primary Energy consumption at the end of 2013								
	Million tonnes of oil equivalent (Mtoe)							
Country	Oil	Natural gas	Coal	Nuclear Energy	Hydro-Power	Renewable Energy	Total	% of Share
China	507.4	145.5	1925.3	25	206.3	42.9	2852.4	22.4
US	831.0	671.0	455.7	187.9	61.5	58.6	2265.8	17.8
Russia	153.1	372.1	93.5	39.1	41	0.1	699	5.5
India	175.2	46.3	324.3	7.5	29.8	11.7	595.0	4.7
Japan	208.9	105.2	128.6	3.3	18.6	9.4	474.0	3.7
Germany	112.1	75.3	81.3	22.0	4.6	29.7	325.0	2.6
Others	2197.4	1198.3	818	278.4	494	126.9	5519.2	43.3
World	4185.1	3030.4	3826.7	563.2	855.8	279.3	12730.4	100

Source: BP Statistical Review of World Energy, June 2014

	4.18%	1.52%	8.47%	1.33%	3.48%	4.18%	4.7%
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1.5 Environmental Aspects Associated with energy utilization

The usage of energy resources in industry leads to environmental damages by polluting the atmosphere. Few of examples of air pollution are sulphur dioxide (SO₂), nitrous oxide (NO_x) and carbon monoxide (CO) emissions from boilers and furnaces, chloro-fluoro carbons (CFC) emissions from refrigerants use, etc. In chemical and fertilizers industries, toxic gases are released. Cement plants and power plants spew out particulate matter.

1.5.1 Air Pollution

In both developed and rapidly industrializing countries, the major historic air pollution problem has typically been high levels of smoke and SO₂ arising from the combustion of sulphur-containing fossil fuels such as coal for domestic and industrial purposes.

In both developed and developing countries, the major threat to clean air is now posed by traffic emissions. Petrol- and diesel-engined motor vehicles emit a wide variety of pollutants, principally carbon monoxide (CO), oxides of nitrogen (NO_x), volatile organic compounds (VOCs) and

particulates, which have an increasing impact on urban air quality.

In addition, photochemical reactions resulting from the action of sunlight on NO₂ and VOCs from vehicles leads to the formation of ozone, a secondary long-range pollutant, which impacts in rural areas often far from the original emission site. Acid rain is another long-range pollutant influenced by vehicle NO_x emissions.

The principle pollutants produced by industrial, domestic and traffic sources are Sulphur dioxide, nitrogen oxides, particulate matter, carbon monoxide, ozone, hydrocarbons, benzene, 1,3-butadiene, toxic organic micro pollutants, lead and heavy metals

2. Climate Change

Human activities, particularly the combustion of fossil fuels, have made the blanket of greenhouse gases (water vapour, carbon dioxide, methane, ozone etc.) around the earth thicker. The resulting increase in global temperature is altering the complex web of systems that allow life to thrive on earth such as rainfall, wind patterns, ocean currents and distribution of plant and animal species.

3. Greenhouse Effect and Carbon Cycle

Life on earth is made possible by energy from the sun, which arrives mainly in the form of visible light. About 30 percent of the sunlight is scattered back into space by outer atmosphere and the balance 70 percent reaches the earth's surface, which reflects it in form of infrared radiation. The escape of slow moving infrared radiation is delayed by the greenhouse gases. A thicker blanket of greenhouse gases traps more infrared radiation and increase the earth's temperature

Carbon dioxide is responsible for 60 percent of the "enhanced greenhouse effect". Humans are burning coal, oil and natural gas at a rate that is much faster than the rate at which these fossil fuels were created. This is releasing the carbon stored in the fuels into the atmosphere and upsetting the carbon cycle (a precise balanced system by which carbon is exchanged between the air, the oceans and land vegetation taking place over millions of years). Currently, carbon dioxide levels in the atmospheric are rising by over 10 percent every 20 years.

The effects of increase in the earth's temperature are as follows:

- **Severe Storms and Flooding**
- **Food Shortages**
- **Reduced Freshwater supply**
- **Loss of Biodiversity**
- **Increased Diseases**

1.5.4 Acid Rain

Acid rain is caused by release of SOX and NOX from combustion of fossil fuels, which then mix with water vapour in atmosphere to form sulphuric and nitric acids respectively.

The effects of acid rain are as follows:

- Acidification of lakes, streams, and soils
- Direct and indirect effects (release of metals, For example: Aluminum which washes away plant nutrients)
- Killing of wildlife (trees, crops, aquatic plants, and animals)
- Decay of building materials and paints, statues, and sculptures
- Health problems (respiratory, burning- skin and eyes)

1.6 Energy Auditing

As per the Energy Conservation Act, 2001, Energy Audit is defined as "*the verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption*".

The objective of Energy Management is to achieve and maintain optimum energy procurement and utilization, throughout the organization and:

To minimize energy costs / waste without affecting production & quality
To minimize environmental effects.

1.7 Energy Audit: Needs

In any industry, the three top operating expenses are often found to be energy (both electrical and thermal), labour and materials. If one were to relate to the manageability of the cost or potential cost savings in each of the above components, energy would invariably emerge as a top ranker, and thus energy management function constitutes a strategic area for cost reduction. Energy Audit will help to understand more about the ways energy and fuel are used in any industry, and help in identifying the areas where waste can occur and where scope for improvement exists.

The Energy Audit would give a positive orientation to the energy cost reduction, preventive maintenance and quality control programmes which are vital for production and utility activities. Such an audit programme will help to keep focus on variations which occur in the energy costs, availability and reliability of supply of energy, decide on appropriate energy mix, identify energy conservation technologies, retrofit for energy conservation equipment etc.

In general, Energy Audit is the translation of conservation ideas into realities, by lending technically feasible solutions with economic and other organizational considerations within a specified time frame.

The primary objective of Energy Audit is to determine ways to reduce energy consumption per unit of product output or to lower operating costs. Energy Audit provides a "bench-mark" (Reference point) for managing energy in the organization and also provides the basis for planning a more effective use of energy throughout the organization.

8. Energy Audit: Types

Type of Energy Audit

The type of Energy Audit to be performed depends on:

- Function and type of industry
- Depth to which final audit is needed, and
- Potential and magnitude of cost reduction desired

Thus Energy Audit can be classified into the following two types.

- Preliminary Audit
- Detailed Audit

Preliminary Energy Audit Methodology

Preliminary energy audit is a relatively quick exercise to:

- Establish energy consumption in the organization
- Estimate the scope for saving
- Identify the most likely (and the easiest areas for attention
- Identify immediate (especially no-/low-cost) improvements/ savings
- Set a 'reference point'
- Identify areas for more detailed study/measurement
- Preliminary energy audit uses existing, or easily obtained data

Detailed Energy Audit Methodology

A comprehensive audit provides a detailed energy project implementation plan for a facility, since it evaluates all major energy using systems.

This type of audit offers the most accurate estimate of energy savings and cost. It considers the interactive effects of all projects, accounts for the energy use of all major equipment, and includes detailed energy cost saving calculations and project cost.

In a comprehensive audit, one of the key elements is the energy balance. This is based on an inventory of energy using systems, assumptions of current operating conditions and calculations of energy use. This estimated use is then compared to utility bill charges.

Detailed energy auditing is carried out in three phases: Phase I, II and III.

Phase I - Pre Audit Phase

Phase II - Audit Phase

Phase III - Post Audit Phase

Phase I -Pre Audit Phase Activities

A structured methodology to carry out an energy audit is necessary for efficient working. An initial study of the site should always be carried out, as the planning of the procedures necessary for an audit is most important.

Initial Site Visit and Preparation Required for Detailed Auditing

An initial site visit may take one day and gives the Energy Auditor/Engineer an opportunity to meet the personnel concerned, to familiarize him with the site and to assess the procedures necessary to carry out the energy audit.

During the initial site visit the Energy Auditor/Engineer should carry out the following actions: -

- Discuss with the site's senior management the aims of the energy audit.
- Discuss economic guidelines associated with the recommendations of the audit.
- Analyze the major energy consumption data with the relevant personnel.
- Obtain site drawings where available - building layout, steam distribution, compressed air distribution, electricity distribution etc.
- Tour the site accompanied by engineering/production

The main aims of this visit are: -

- To finalize Energy Audit team
- To identify the main energy consuming areas/plant items to be surveyed during the audit.
- To identify any existing instrumentation/ additional metering required.
- To decide whether any meters will have to be installed prior to the audit eg. kWh, steam, oil or gas meters.

- To identify the instrumentation required for carrying out the audit.
- To plan with time frame
- To collect macro data on plant energy resources, major energy consuming centers
- To create awareness through meetings/ programme

Phase II- Detailed Energy Audit Activities

Depending on the nature and complexity of the site, a comprehensive audit can take from several weeks to several months to complete. Detailed studies to establish, and investigate, energy and material balances for specific plant departments or items of process equipment are carried out. Whenever possible, checks of plant operations are carried out over extended periods of time, at nights and at weekends as well as during normal daytime working hours, to ensure that nothing is overlooked.

The audit report will include a description of energy inputs and product outputs by major department or by major processing function, and will evaluate the efficiency of each step of the manufacturing process. Means of improving these efficiencies will be listed, and at least a preliminary assessment of the cost of the improvements will be made to indicate the expected pay- back on any capital investment needed. The audit report should conclude with specific recommendations for detailed engineering studies and feasibility analyses, which must then be performed to justify the implementation of those conservation measures that require investments.

The information to be collected during the detailed audit includes: -

1. Energy consumption by type of energy, by department, by major items of process equipment, by end-use
2. Material balance data (raw materials, intermediate and final products, recycled materials, use of scrap or waste products, production of by-products for re-use in other industries, etc.)
3. Energy cost and tariff data
4. Process and material flow diagrams

5. Generation and distribution of site services (eg. compressed air, steam).
6. Sources of energy supply (e.g. electricity from the grid or self-generation)
7. Potential for fuel substitution, process modifications, and the use of co-generation systems (combined heat and power generation).
8. Energy Management procedures and energy awareness training programs within the establishment

1.9 Energy Audit -Methodology

A comprehensive ten-step methodology for conduct of Energy Audit at field level is presented below. Energy Manager and Energy Auditor may follow these steps to start with and add/change as per their needs and industry types.

Ten Steps Methodology for Detailed Energy Audit

Step No	PLAN OF ACTION	PURPOSE / RESULTS
	<u>Phase I –Pre Audit Phase</u>	
Step 1	<ul style="list-style-type: none"> Plan and organise Walk through Audit Informal Interview with Energy Manager, Production / Plant Manager 	<ul style="list-style-type: none"> Resource planning, Establish/organize a Energy audit team Organize Instruments & time frame Macro Data collection (suitable to type of industry.) Familiarization of process/plant activities First hand observation & Assessment of current level operation and practices
Step 2	<ul style="list-style-type: none"> Conduct of brief meeting / awareness programme with all divisional heads and persons concerned (2-3 hrs.) 	<ul style="list-style-type: none"> Building up cooperation Issue questionnaire for each department Orientation, awareness creation
	<u>Phase II –Audit Phase</u>	
Step 3	<ul style="list-style-type: none"> Primary data gathering, Process Flow Diagram, & Energy Utility Diagram 	<ul style="list-style-type: none"> Historic data analysis, Baseline data collection Prepare process flow charts All service utilities system diagram (Example: Single line power distribution diagram, water, compressed air & steam distribution. Design, operating data and schedule of operation Annual Energy Bill and energy consumption pattern (Refer manual, log sheet, name plate, interview)
Step 4	<ul style="list-style-type: none"> Conduct survey and monitoring 	<ul style="list-style-type: none"> Measurements : Motor survey, Insulation, and Lighting survey with portable instruments for collection of more and accurate data. Confirm and compare operating data with design data.
Step 5	<ul style="list-style-type: none"> Conduct of detailed trials /experiments for selected energy guzzlers 	<ul style="list-style-type: none"> Trials/Experiments: <ul style="list-style-type: none"> 24 hours power monitoring (MD, PF, kWh etc.). Load variations trends in pumps, fan compressors etc.

		<ul style="list-style-type: none"> - Boiler/Efficiency trials for (4 – 8 hours) - Furnace Efficiency trials Equipments Performance experiments etc
Step6	<ul style="list-style-type: none"> • Analysis of energy use 	<ul style="list-style-type: none"> • Energy and Material balance & energy loss/waste analysis
Step 7	<ul style="list-style-type: none"> • Identification and development of Energy Conservation (ENCON) opportunities 	<ul style="list-style-type: none"> • Identification & Consolidation ENCON measures • Conceive, develop, and refine ideas • Review the previous ideas suggested by unit personal • Review the previous ideas suggested by energy audit if any • Use brainstorming and value analysis techniques • Contact vendors for new/efficient technology
Step 8	<ul style="list-style-type: none"> • Cost benefit analysis 	<ul style="list-style-type: none"> • Assess technical feasibility, economic viability and prioritization of ENCON options for implementation • Select the most promising projects • Prioritise by low, medium, long term measures
Step9	<ul style="list-style-type: none"> • Reporting & Presentation to the Top Management 	<ul style="list-style-type: none"> • Documentation, Report Presentation to the top Management.
Step10	<p><u>Phase III –Post Audit phase</u></p> <ul style="list-style-type: none"> • Implementation and Follow-up 	<p>Assist and Implement ENCON recommendation measures and Monitor the performance</p> <ul style="list-style-type: none"> • Action plan, Schedule for implementation • Follow-up and periodic review

10. Barriers to Energy Conservation

Traditional energy prices are understated because they do not include the health, social, and environmental costs of using fuels. For example, gasoline prices do not take into account the costs associated with military requirements to protect access to oil sources, global warming, acid rain, and adverse health effects. This is an institutional barrier to increasing energy efficiency. Some of the key barriers to achieving increased efficiency are listed below.

1. Lack of Objective Consumer Information

Efficiency claims in the market place are often made by competing manufacturers, without an objective third party to evaluate the actual efficiency claims.

2. Failure of Consumers to Make Optimal Energy-Efficiency Decisions

Consumers often choose the least expensive appliance, rather than the appliance that will save them money over the long term; consumers are also often confused about efficiency ratings and efficiency improvements.

3. Replacement Market Decisions Based on Availability Rather Than Efficiency

Decisions concerning replacement of worn out or broken equipment are made without energy efficiency as a high priority. Usually, the primary concern for the consumer is restoring service as quickly as possible. This requires buying whatever equipment the plumbing or heating contractor may have on hand.

4. Energy Prices do not take into Account the Full Environmental or Societal Costs

External costs associated with public health, energy production, global warming, acid rain, air pollution, energy security, or reliability of supply are usually ignored.

5. Competition for Capital to Make Energy-Efficiency Investments

Energy-efficiency investments in the commercial and industrial sectors often must compete with other business investments; therefore, efficiency investments with a payback of more than 3 years are avoided.

6. The Separation of Building Ownership from Utility Bill Responsibility

Renters will rarely make energy-efficiency investments in buildings that they do not own, especially when the utilities are included in the rent.

7. Commercial Buildings and Retail Space are Usually Built on Speculation with Low First-Cost a Priority

The building's long-term operation cost, which is usually paid by the tenant(s) rather than the owner, is not important to the speculator/builder.

1.11 Role of Energy Managers

“The tasks of energy manger are setting goals, tracking progress, and promoting the energy management program. An Energy Manager helps an organization achieve its goals by establishing energy performance as a core value.”

The Energy Manager is not always an expert in energy and technical systems. Successful Energy Manager understands how energy management helps the organization achieve its financial and environmental goals and objectives. Depending on the size of the organization, the Energy Manager role can be a full-time position or an addition to other responsibilities.

Energy Manager: Responsibilities and Duties to be assigned under the Energy Conservation Act, 2001.

Responsibilities






- Prepare an annual activity plan and present to management concerning financially attractive investments to reduce energy costs
- Establish an energy conservation cell within the firm with management's consent about the mandate and task of the cell.
- Initiate activities to improve monitoring and process control to reduce energy costs.
- Analyze equipment performance with respect to energy efficiency
- Ensure proper functioning and calibration of instrumentation required to assess level of energy consumption directly or indirectly.
- Prepare information material and conduct internal workshops about the topic for other staff.
- Improve disaggregating of energy consumption data down to shop level or profit center of a firm.
- Establish a methodology how to accurately calculate the specific energy consumption of various products/services or activity of the firm.
- Develop and manage training programme for energy efficiency at operating levels.
- Co-ordinate nomination of management personnel to external programs.

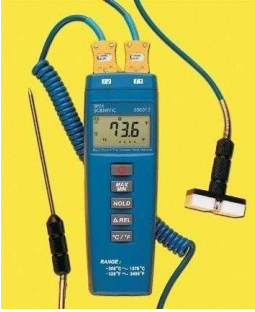



- Create knowledge bank on sectoral, national and inter-national development on energy efficiency technology and management system and information denomination
- Develop integrated system of energy efficiency and environmental up gradation.
- Co-ordinate implementation of energy audit/efficiency improvement projects through external agencies.
- Establish and/or participate in information exchange with other energy managers of the same sector through association

Duties

- Report to BEE and State level Designated Agency once a year the information with regard to the energy consumed and action taken on the recommendation of the accredited energy auditor, as per BEE Format.
- Establish an improved data recording, collection and analysis system to keep track of energy consumption.
- Provide support to Accredited Energy Audit Firm retained by the company for the conduct of energy audit
- Provide information to BEE as demanded in the Act, and with respect to the tasks given by a mandate, and the job description.
- Prepare a scheme for efficient use of energy and its conservation and implement such scheme keeping in view of the economic stability of the investment in such form and manner as may be provided in the regulations of the Energy Conservation Act.

1.12 Energy Audit Instruments

 	<p>Electrical Measuring Instruments:</p> <p>These are instruments for measuring major electrical parameters such as kVA, kW, PF, Hertz, kVAr, Amps and Volts. In addition some of these instruments also measure harmonics.</p> <p>These instruments are applied on-line i.e on running motors without any need to stop the motor. Instant measurements can be taken with hand-held meters, while more advanced ones facilitates cumulative readings with print outs at specified intervals.</p>
	<p>Combustion analyzer:</p> <p>This instrument has in-built chemical cells which measure various gases such as O₂, CO, NO_x and SO_x.</p>
	<p>Fuel Efficiency Monitor:</p> <p>This measures oxygen and temperature of the flue gas. Calorific values of common fuels are fed into the microprocessor which calculates the combustion efficiency.</p>
	<p>Fyrite:</p> <p>A hand bellow pump draws the flue gas sample into the solution inside the fyrite. A chemical reaction changes the liquid volume revealing the amount of gas. A separate fyrite can be used for O₂ and CO₂ measurement.</p>

	<p>Contact thermometer:</p> <p>These are thermocouples which measures for example flue gas, hot air, hot water temperatures by insertion of probe into the stream.</p> <p>For surface temperature, a leaf type probe is used with the same instrument.</p>
	<p>Infrared Thermometer:</p> <p>This is a non-contact type measurement which when directed at a heat source directly gives the temperature read out. This instrument is useful for measuring hot spots in furnaces, surface temperatures etc.</p>
	<p>Pitot Tube and manometer:</p> <p>Air velocity in ducts can be measured using a pitot tube and inclined manometer for further calculation of flows.</p>
	<p>Water flow meter:</p> <p>This non-contact flow measuring device using Doppler effect / Ultra sonic principle. There is a transmitter and receiver which are positioned on opposite sides of the pipe. The meter directly gives the flow. Water and other fluid flows can be easily measured with this meter.</p>

		<p>Speed Measurements:</p> <p>In any audit exercise speed measurements are critical as they may change with frequency, belt slip and loading.</p> <p>A simple tachometer is a contact type instrument which can be used where direct access is possible.</p> <p>More sophisticated and safer ones are non contact instruments such as stroboscopes.</p>
		<p>Leak Detectors:</p> <p>Ultrasonic instruments are available which can be used to detect leaks of compressed air and other gases which are normally not possible to detect with human abilities.</p>
		<p>Lux meters:</p> <p>Illumination levels are measured with a lux meter. It consists of a photo cell which senses the light output, converts to electrical impulses which are calibrated as lux.</p>

TEN STEPS METHODOLOGY FOR DETAILED ENERGY AUDIT

Basically Energy audit is divided in to three phases. They are

A. Phase: I covers steps 1 & 2

B. Phase: II covers steps 3 to 9

C. Phase III covers step 10.

STEP NO	ACTION PLAN
	PHASE:1
1	a. Plan & organise visit b. Walk through audit of the set up c. Informal interview with production or plant manager or incharge.
2	Conduct brief meeting / awareness program on energy audit with all divisional heads and persons concerned.
	PHASE:II
3	Primary data collection, process flow diagram, energy utility diagram and collection of any other relevant datas.
4	Conduct survey and monitoring
5	Conduct detailed trials / experiments for the selected energy guzzlers
6	Analysis of energy use
7	Identification and development of energy conservation opportunities
8	Cost benefit analysis
9	Reporting & presentation to top management on findings
	PHASE:III
10	Implementation, commissioning and follow up

No.	Name of the Instrument	Intended Use
1.	Flue Gas Analysers	Used for optimizing the combustion efficiency by measuring/monitoring the oxygen and CO levels in flue gas of boilers, furnaces etc. and calculation of CO2 percentage in excess air level and efficiency.
2.	Temperature Indicators	Used for measuring temperatures of gases/air, liquids, slurries, semi solids, powders etc. Using different types of probes.
3.	Infrared Thermometers	Used for measuring temperatures from a distance using infrared technology.
4.	Thermal Insulation scanner	Used for measuring loss of energy in Kcal per unit area from hot/cold insulated surfaces. The total loss can be obtained by multiplying the total surface under study.
5.	Steam Trap Monitor	Used for performance evaluation of steam Traps.

6.	Conductivity Meter	Used for on the spot water analysis of the amount of dissolved solids in water.
7.	pH meter	Used for on the spot analysis of effective acidity or alkalinity of a solution/water. Acidity /alkalinity water.
8.	Thermo-hygrometer	Used for measurement of air velocity & humidification, ventilation, Air-conditioning and refrigeration systems etc.
9.	Thermo-hygrometer	Used for measurement of humidity and temperature and the calculation of dew point to find out the heat being carried away by out going gases in industries. Where product drying requires hot air.
10.	Ultrasonic Flow Meter	Used for measurement of flow of liquids through pipelines of various sizes through ultrasonic sensors mounted on the pipelines.

11.	U-Tube Manometer	Used for measurement of differential pressure.
12.	Digital Manometer	Used for measurement of differential pressure.
13.	Visguage	Used for measurement of differential viscosity.
14.	Used Lube Oil Test Kit	Used for testing lube oil.
15.	Non-Contact Tachometer	Used for measurement of speed of rotation equipment.

16.	Demand Analyser	Used for measurement and analysis of electrical load and demand control.
17.	Power Analyser	Used for measurement and analysis of electrical Power.
18.	Harmonic Analyser	Used for analysis of harmonics in power System.
19.	Luxmeter	Used for measurement of illumination level.
20.	Clip on Dig. Watt Meter	Used for measurement of power without interrupting the connections.

21.	Clip on Dig. PF Meter	Used for measurement of power factor without interrupting the connection.
22.	Clamp on amp. Meter	Used for measurement of current without Interrupting the connections.
23.	Digital Multimeter	Used for measurement of voltage. Current and resistance.
24.	Frequency Meter	Used for measurement of power supply frequency.

<https://youtu.be/lkNIuFkzxBk>

Energy Crisis:

- The energy crisis is the concern that the world's demands on the limited natural resources that are used to power industrial society are diminishing as the demand rises.
- These natural resources are in limited supply. While they do occur naturally, it can take hundreds of thousands of years to replenish the stores.
- Governments and concerned individuals are working together to make the use of renewable resources a priority and to lessen the irresponsible use of natural supplies through increased conservation.
- "An energy crisis is any significant bottleneck in the supply of energy resources to an economy. In literature, it often refers to one of the energy sources used at a certain time and place, in particular those that supply national electricity grids or those used as fuel in Industrial development and population growth have led to a surge in the global demand for energy in recent years."

Various Causes of the Global Energy Crisis:

The energy crisis is the concern that the world's demands on the limited natural resources that are used to power industrial society are diminishing as the demand rises.

1. Overconsumption
2. Overpopulation
3. Poor Infrastructure
4. Unexplored Renewable Energy Options
5. Delay in Commissioning of Power Plants
6. Wastage of Energy
7. Poor Distribution System
8. Major Accidents and Natural Calamities
9. Wars and Attacks
10. Miscellaneous Factors

1. Overconsumption:

- The energy crisis is a result of many different strains on our natural resources, not just one.
- There is a strain on fossil fuels such as oil, gas, and coal due to overconsumption – which then, in turn, can put a strain on our water and oxygen resources by causing pollution.

2. Overpopulation:

- A steady increase in the world's population and its demands for fuel and products.
- No matter what type of food or products you choose to use – from fair trade and organic to those made from petroleum products in a sweatshop – not one of them is made or transported without a significant drain on our energy resources.

3. Poor Infrastructure:

- Aging infrastructure of power generating equipment is yet another reason for energy shortage.
- Most of the energy-producing firms keep on using outdated equipment that restricts the production of energy.
- It is the responsibility of utilities to keep on upgrading the infrastructure and set a high standard of performance.

4. Unexplored Renewable Energy Options:

- Renewable energy still remains unused in most of the countries.
 - Most of the energy comes from non-renewable sources like coal. It, therefore, remains the top choice to produce energy.
 - Unless we give renewable energy a serious thought, the problem of energy crisis cannot be solved.
 - Renewable energy sources can reduce our dependence on fossil fuels and also helps to reduce greenhouse gas emissions.
-

5. Delay in Commissioning of Power Plants:

- In a few countries, there is a significant delay in the commissioning of new power plants that can fill the gap between demand and supply of energy.
- The result is that old plants come under huge stress to meet the daily demand for power.
- When supply doesn't match demand, it results in load-shedding and breakdown.

6. Wastage of Energy :

- In most parts of the world, people do not realize the importance of conserving energy.
- It is only limited to books, the internet, newspaper ads, lip service, and seminars. Unless we give it a serious thought, things are not going to change anytime sooner.
- Simple things like switching off fans and lights when not in use, using maximum daylight, walking instead of driving for short distances, using CFL instead of traditional bulbs, proper insulation for leakage of energy can go a long way in saving energy.

7. Poor Distribution System:

- Frequent tripping and breakdown are a result of a poor distribution system.

8. Major Accidents and Natural Calamities:

- In Major accidents like pipeline burst and natural calamities like the eruption of volcanoes, floods, earthquakes can also cause interruptions to energy supplies.
- The huge gap between supply and demand for energy can raise the price of essential items, which can give rise to inflation.

9. Wars and Attacks:

- Wars between countries can also hamper the supply of energy, especially if it happens in Middle East countries like Saudi Arabia, Iraq, Iran, Kuwait, UAE, or Qatar.
- That is what happened during the 1990 Gulf war when the price of oil reached its peak causing global shortages and created major problems for energy consumers.

10. Miscellaneous Factors:

- Tax hikes, strikes, military coup, political events, severe hot summers or cold winters can cause a sudden increase in demand for energy and can choke supply.
- A strike by trade unions in an oil-producing firm can cause an energy crisis.

Various Effects of the Global Energy Crisis:

The growth of human civilization has led to an increase in the consumption of traditional sources of energy. The very basic source of energy is precious fossil fuels. The usage of all these sources is bound to produce certain effects. Some important effects of the global energy crisis are as follows:

1. Environmental Effects
2. Increasing Prices of the Fuel Resources
3. Political Disturbances
4. The Effect on the Tourism Industry

1. Environmental Effects:

- Energy is produced by the burning of non-renewable fossil fuels.
- This does not only affect the global resources of fossil fuels, but it also affects the environment.
- The burning of fossil fuels releases greenhouse gases like carbon dioxide and others.
- These gases create a blanket on the earth's surface, which prevents the release of the short rays of the sun by night.
- Thus, the energy crisis facilitates making the earth a warmer place by promoting global warming.

2. Increasing Prices of the Fuel Resources :

- As the use of fossil fuels increases, the cost of these resources increases too.
- We must remember that the quantity in which these fossil fuels are available is limited. As we keep on using these resources, the amount of these fossil fuels further decreases.

-
- With every passing day, the demand for these fuels increases daily while their available quantity decreases every day.
 - This leads to an immense increase in the price of fossil fuels, causing the price to increase day in and day out. This creates a huge economic disturbance across the globe.

3. Political Disturbances:

- The fact that the energy crisis creates some socio-economic disturbances, also tells us that this global energy crisis also creates a lot of political disturbances across the globe.
- The quest for fossil fuels is one of the major causes of the same.
- Besides, with the failure of the energy markets, we see a crash in not only the global economy but also a crash of the energy available.
- All these are enough to give rise to the various socio-political disturbances.

4. The Effect on the Tourism Industry:

- The tourism industry is largely dependent on the rise and fall of fuel prices.
- The tremendous rise of the fuel prices that comes as a result of the energy crisis affects the tourism industry pretty adversely.
- With the increase in fuel prices, there is an increase in the costs of tourism as well.
- As a result of this, there are many who cannot afford the same.
- And as a result of all this, it is the tourism industry that suffers.

Possible Solutions to the Problem of Global Energy Crisis:

Some important Solutions to the global energy crisis are as follows:

1. Move Towards Renewable Resources
2. Buy Energy-Efficient Products
3. Lighting Controls
4. Easier Grid Access
5. Energy Simulation
6. Perform Energy Audit
7. Common Stand on Climate Change

1. Move Towards Renewable Resources:

- The best possible solution is to reduce the world's dependence on non-renewable resources and to improve overall conservation efforts.
- Much of the industrial age was created using fossil fuels, but there is also known technology that uses other types of renewable energies – such as steam, solar, and wind.
- The major concern isn't so much that we will run out of gas or oil, but that the use of coal is going to continue to pollute the atmosphere and destroy other natural resources in the process of mining the coal that it has to be replaced as an energy source.
- This isn't easy as many of the leading industries use coal, not gas or oil, as their primary source of power for manufacturing.

1. Buy Energy-Efficient Products:

- The Replace traditional bulbs with CFLs and LEDs. They use fewer watts of electricity and last longer.
- If millions of people across the globe use LEDs and CFLs for residential and commercial purposes, the demand for energy can go down, and an energy crisis can be averted.

2. Lighting Controls:

- There are a number of new technologies out there that make lighting controls that much more interesting, and they help to save a lot of energy and cash in the long run.

3. Easier Grid Access:

- People who use different options to generate power must be given permission to plug into the grid and getting credit for the power you feed into it.
 - The hassles of getting credit for supplying surplus power back into the grid should be removed.
-

- Apart from that, subsidy on solar panels should be given to encourage more people to explore renewable options.

5. Energy Simulation:

- Energy simulation software can be used by big corporates and corporations to redesign the building unit and reduce running business energy costs.
- Engineers, architects, and designers could use this design to come with most energy-efficient buildings and reduce carbon footprint.

6. Perform Energy Audit:

- The energy audit is a process that helps you to identify the areas where your home or office is losing energy and what steps you can take to improve energy efficiency.
- Energy audit, when done by a professional, can help you to reduce your carbon footprint, save energy and money, and avoid energy crisis.

7. Common Stand on Climate Change:

- Both developed and developing countries should adopt a common stand on climate change. They should focus on reducing greenhouse gas emissions through an effective cross border mechanism.
- With current population growth and overconsumption of resources, the consequences of global warming and climate change cannot be ruled out.
- Both developed and developing countries must focus on emission cuts to halve their emissions from current levels by 2050.

UNIT II - ELECTRICAL SYSTEMS

1. Electricity Billing - HT Supply

The electricity billing by utilities for medium & large enterprises, in High Tension (HT) category, is often done on two-part tariff structure, i.e. one part for capacity (or demand) drawn and the second part for actual energy drawn during the billing cycle. Capacity or demand is in kVA (apparent power) or kW terms. The reactive energy (i.e.) kVArh drawn by the service is also recorded and billed for in some utilities, because this would affect the load on the utility.

Accordingly, utility charges for maximum demand, active energy and reactive power drawn (as reflected by the power factor) in its billing structure. In addition, other fixed and variable expenses are also levied.

2. The Tariff Structure of HT Electricity Billing

The tariff structure of HT supply generally includes the following components:

a) Maximum demand Charges

These charges relate to maximum demand registered during month/billing period and corresponding rate of utility.

b) Energy Charges

These charges relate to energy (kilowatt hours) consumed during month / billing period and corresponding rates, often levied in slabs of use rates. Some utilities now charge on the basis of apparent energy (kVAh), which is a vector sum of kWh and kVArh.

c) Power factor

Power factor penalty or bonus rates, as levied by most utilities, are to contain reactive power drawn from grid.

d) Fuel cost

Fuel cost adjustment charges as levied by some utilities are to adjust the increasing fuel expenses over a base reference value.

e) **Electricity duty charges**

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

f) **Meter rentals**

g) **Lighting and fan power consumption**

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

h) **Time Of Day (TOD)**

Time Of Day (TOD) rates like peak and non-peak hours are also prevalent in tariff structure provisions of some utilities.

i) **Penalty for exceeding contract demand**

2.3 Electricity Billing - LT Supply

The electricity billing by utilities for LT category, is often done on one-part tariff structure, i.e. billing is done for actual energy drawn during the billing cycle.

2.4 The Tariff Structure of LT Electricity Billing

The tariff structure of LT supply generally includes the following components:

a) **Energy Charges**

These charges relate to energy (kilowatt hours) consumed during month / billing period and corresponding rates, often levied in slabs of use rates. Some utilities now charge on the basis of apparent energy (kVAh), which is a vector sum of kWh and kVAh.

b) **Meter rentals**

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

2.5 Transformers

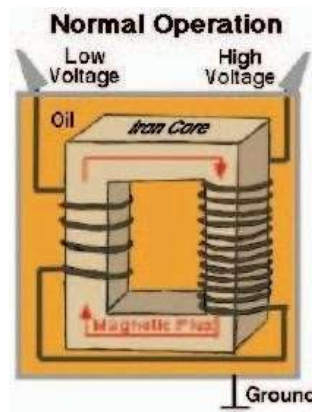
A transformer can accept energy at one voltage and deliver it at another voltage. This permits electrical energy to be generated at relatively low voltages and transmitted at high voltages and low currents, thus reducing line losses and voltage drop (see Figure 2.1).

Figure 2.1 View of a Transformer



Transformers consist of two or more coils that are electrically insulated, but magnetically linked. The primary coil is connected to the power source and the secondary coil connects to the load. The turn's ratio is the ratio between the number of turns on the secondary to the turns on the primary (See Figure 2.2).

Figure 2.2 Transformer Coil



The secondary voltage is equal to the primary voltage times the turn's ratio. Ampere-turns are calculated by multiplying the current in the coil times the number of turns. Primary ampere-turns are equal to secondary ampere-turns. Voltage regulation of a transformer is the percent increase in voltage from full load to no load.

1. **Types of Transformers**

Transformers are classified as two categories: power transformers and distribution transformers.

Power transformers are used in transmission network of higher voltages, deployed for step-up and step down transformer application (400 kV, 200 kV, 110 kV, 66 kV, 33kV)

Distribution transformers are used for lower voltage distribution networks as a means to end user connectivity. (11kV, 6.6 kV, 3.3 kV, 440V, 230V)

2. **Rating of Transformer**

Rating of the transformer is calculated based on the connected load and applying the diversity factor on the connected load, applicable to the particular industry and arrive at the kVA rating of the Transformer. Diversity factor is defined as the ratio of overall maximum demand of the plant to the sum of individual maximum demand of various equipments. Diversity factor varies from industry to industry and depends on various factors such as individual loads, load factor and future expansion needs of the plant. Diversity factor will always be less than one.

3. **Location of Transformer**

Location of the transformer is very important as far as distribution loss is concerned. Transformer receives HT voltage from the grid and steps it down to the required voltage. Transformers should be placed close to the load centre, considering other features like optimization needs for centralized control, operational flexibility etc. This will bring down the distribution loss in cables.

4. **Transformer Losses and Efficiency**

The efficiency varies anywhere between 96 to 99 percent. The efficiency of the transformers not only depends on the design, but also, on the effective operating load.

Transformer losses consist of two parts: No-load loss and Load loss

1. No-load loss (also called core loss) is the power consumed to sustain the magnetic field in the transformer's steel core. Core loss occurs whenever the transformer is energized; core loss does not vary with load. Core losses are caused by two factors: hysteresis and eddy current losses. Hysteresis loss is that energy lost by reversing the magnetic field in

the core as the magnetizing AC rises and falls and reverses direction. Eddy current loss is a result of induced currents circulating in the core.

2. Load loss (also called copper loss) is associated with full-load current flow in the transformer windings. Copper loss is power lost in the primary and secondary windings of a transformer due to the ohmic resistance of the windings. Copper loss varies with the square of the load current. ($P = I^2R$).

2.6 Power Factor Improvement and Benefits

2.6.1 Power factor Basics

In all industrial electrical distribution systems, the major loads are resistive and inductive. Resistive loads are incandescent lighting and resistance heating. In case of pure resistive loads, the voltage (V), current (I), resistance (R) relations are linearly related, i.e.

$$V = I \times R \quad \text{and} \quad \text{Power (kW)} = V \times I$$

Typical inductive loads are A.C. Motors, induction furnaces, transformers and ballast- type lighting. Inductive loads require two kinds of power: a) active (or working) power to perform the work and b) reactive power to create and maintain electro-magnetic fields.

Active power is measured in kW (Kilo Watts). Reactive power is measured in kVAr (Kilo Volt-Amperes Reactive).

The vector sum of the active power and reactive power make up the total (or apparent) power used. This is the power generated by the SEBs for the user to perform a given amount of work. Total Power is measured in kVA (Kilo Volts-Amperes) (See Figure 2.3).

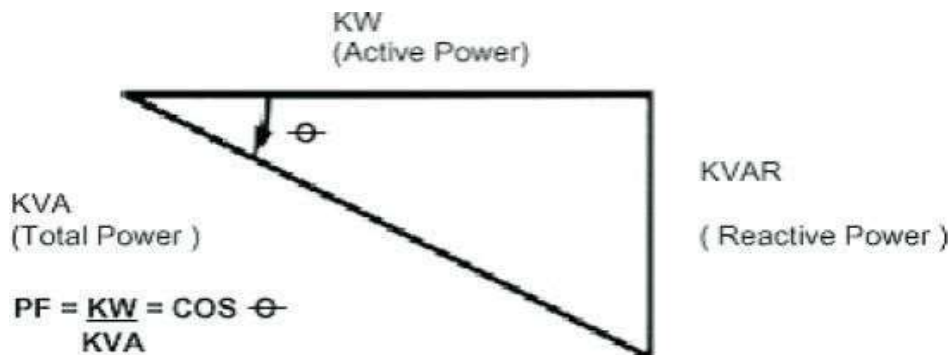


Fig 2.3 Power Triangle

The active power (shaft power required or true power required) in kW and the reactive power required (kVAr) are 90° apart vectorically in a pure inductive circuit i.e., reactive power kVAr lagging the active kW. The vector sum of the two is called the apparent power or kVA, as illustrated above and the kVA reflects the actual electrical load on distribution system.

The ratio of kW to kVA is called the power factor, which is always less than or equal to unity. Theoretically, when electric utilities supply power, if all loads have unity power factor, maximum power can be transferred for the same distribution system capacity. However, as the loads are inductive in nature, with the power factor ranging from 0.2 to 0.9, the electrical distribution network is stressed for capacity at low power factors.

2. Improving Power Factor

The solution to improve the power factor is to add power factor correction capacitors to the plant power distribution system. They act as reactive power generators, and provide the needed reactive power to accomplish kW of work. This reduces the amount of reactive power, and thus total power, generated by the utilities.

3. The advantages of PF improvement by capacitor addition

- Reactive component of the network is reduced and so also the total current in the system from the source end.
- I²R power losses are reduced in the system because of reduction in current.
- Voltage level at the load end is increased.
- kVA loading on the source generators as also on the transformers and lines up to the capacitors reduces giving capacity relief. A high power factor can help in utilizing the full capacity of your electrical system.

2.6.4 Cost benefits of PF improvement

While costs of PF improvement are in terms of investment needs for capacitor addition the benefits to be quantified for feasibility analysis are:

- Reduced kVA (Maximum demand) charges in utility bill
- Reduced distribution losses (KWH) within the plant network
- Better voltage at motor terminals and improved performance of motors

- A high power factor eliminates penalty charges imposed when operating with a low power factor
- Investment on system facilities such as transformers, cables, switchgears etc for delivering load is reduced.

2.6.5 Direct relation for capacitor sizing

$$\text{kVAR Rating} = \text{kW} [\tan \Phi_1 - \tan \Phi_2]$$

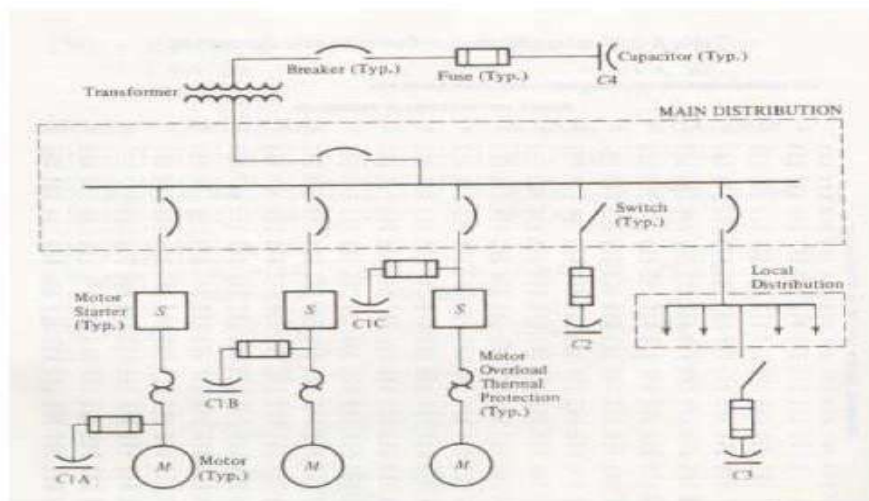
Where kVAR rating is the size of the capacitor needed, kW is the average power drawn, $\tan \phi_1$ is the trigonometric ratio for the present power factor, and $\tan \phi_2$ is the trigonometric ratio for the desired PF.

$\Phi_1 = \text{Existing (Cos-1 PF}_1\text{)}$ and $\Phi_2 = \text{Improved (Cos-1 PF}_2\text{)}$

2.6.6 Location of Capacitors

The primary purpose of capacitors is to reduce the maximum demand. Additional benefits are derived by capacitor location. The Figure 2.3 indicates typical capacitor locations. Maximum benefit of capacitors is derived by locating them as close as possible to the load. At this location, its kVAR are confined to the smallest possible segment, decreasing the load current. This, in turn, will reduce power losses of the system substantially. Power losses are proportional to the square of the current. When power losses are reduced, voltage at the motor increases; thus, motor performance also increases.

Fig 2.4 Power Distribution Diagram Illustrating Capacitor Locations



Locations C1A, C1B and C1C of Figure 1.9 indicate three different arrangements at the load. Note that in all three locations extra switches are not required, since the capacitor is either switched with the motor starter or the breaker before the starter. Case C1A is recommended for new installation, since the maximum benefit is derived and the size of the motor thermal protector is reduced. In Case C1B, as in Case C1A, the capacitor is energized only when the motor is in operation. Case C1B is recommended in cases where the installation already exists and the thermal protector does not need to be re-sized. In position C1C, the capacitor is permanently connected to the circuit but does not require a separate switch, since capacitor can be disconnected by the breaker before the starter.

It should be noted that the rating of the capacitor should not be greater than the no-load magnetizing kVAR of the motor. If this condition exists, damaging over voltage or transient torques can occur. This is why most motor manufacturers specify maximum capacitor ratings to be applied to specific motors.

The next preference for capacitor locations as illustrated by Figure 1.9 is at locations C2 and C3. In these locations, a breaker or switch will be required. Location C4 requires a high voltage breaker. The advantage of locating capacitors at power centres or feeders is that they can be grouped together. When several motors are running intermittently, the capacitors are permitted to be on line all the time, reducing the total power regardless of load.

From energy efficiency point of view, capacitor location at receiving substation only helps the utility in loss reduction. Locating capacitors at tail end will help to reduce loss reduction within the plants distribution network as well and directly benefit the user by reduced consumption. Reduction in the distribution loss % in kWh when tail end power factor is raised from PF1 to a new power factor PF2, will be proportional to

$$\left[1 - (PF_1 / PF_2)^2 \right] \times 100$$

2.7 Harmonics

In any alternating current network, flow of current depends upon the voltage applied and the impedance (resistance to AC) provided by elements like resistances, reactances of inductive and capacitive nature. As the value of impedance in above devices is constant, they are called linear whereby the voltage and current relation is of linear nature.

However in real life situation, various devices like diodes, silicon controlled rectifiers, PWM systems, thyristors, voltage & current chopping saturated core reactors, induction & arc furnaces are also deployed for various requirements and due to their varying impedance characteristic, these NON LINEAR devices cause distortion in voltage and current waveforms which is of increasing concern in recent times. Harmonics occurs as spikes at intervals which are multiples of the mains (supply) frequency and these distort the pure sine wave form of the supply voltage & current.

Harmonics are multiples of the fundamental frequency of an electrical power system. If, for example, the fundamental frequency is 50 Hz, then the 5th harmonic is five times that frequency, or 250 Hz. Likewise, the 7th harmonic is seven times the fundamental or 350 Hz, and so on for higher order harmonics.

Harmonics can be discussed in terms of current or voltage. A 5th harmonic current is simply a current flowing at 250 Hz on a 50 Hz system. The 5th harmonic current flowing through the system impedance creates a 5th harmonic voltage. Total Harmonic Distortion (THD) expresses the amount of harmonics. The following is the formula for calculating the THD for current:

$$THD_{current} = \sqrt{\sum_{n=2}^{n=\infty} \left(\frac{I_n}{I_1} \right)^2} \times 100$$

Then...

$$I_{THD} = \sqrt{\left[\left(\frac{50}{250} \right)^2 + \left(\frac{35}{250} \right)^2 \right]} \times 100 = 24\%$$

When harmonic currents flow in a power system, they are known as “poor power quality” or “dirty power”. Other causes of poor power quality include transients such as voltage spikes, surges, sags, and ringing. Because they repeat every cycle, harmonics are regarded as a steady-state cause of poor power quality.

When expressed as a percentage of fundamental voltage THD is given by,

$$THD_{voltage} = \sqrt{\sum_{n=2}^{n=\infty} \left(\frac{V_n}{V_1} \right)^2} \times 100$$

where V_1 is the fundamental frequency voltage and V_n is n^{th} harmonic voltage component.

1. Major Causes of Harmonics

Devices that draw non-sinusoidal currents when a sinusoidal voltage is applied create harmonics. Frequently these are devices that convert AC to DC. Some of these devices are listed below:

- Electronic Switching Power Converters
- Computers, Uninterruptible power supplies (UPS), Solid-state rectifiers
- Electronic process control equipment, PLC's, etc
- Electronic lighting ballasts, including light dimmer
Reduced voltage motor controllers

Arcing Devices

- Discharge lighting, e.g. Fluorescent, Sodium and Mercury vapor
- Arc furnaces, Welding equipment, Electrical traction system

Ferromagnetic Devices

- Transformers operating near saturation level
- Magnetic ballasts (Saturated Iron core)
- Induction heating equipment, Chokes, Motors

Appliances

- TV sets, air conditioners, washing machines, microwave ovens
- Fax machines, photocopiers, printers

These devices use power electronics like SCRs, diodes, and thyristors, which are a growing percentage of the load in industrial power systems. The majority use a 6-pulse converter. Most loads which produce harmonics, do so as a steady-state phenomenon. A snapshot reading of an operating load that is suspected to be non-linear can determine if it is producing harmonics. Normally each load would manifest a specific harmonic spectrum.

Many problems can arise from harmonic currents in a power system. Some problems are easy to detect; others exist and persist because harmonics are not suspected. Higher RMS current and voltage in the system are caused by harmonic currents, which can result in any of the problems listed below:

1. [Blinking of Incandescent Lights - Transformer Saturation](#)
2. [Capacitor Failure - Harmonic Resonance](#)
3. [Circuit Breakers Tripping - Inductive Heating and Overload](#)
4. [Conductor Failure - Inductive Heating](#)
5. [Electronic Equipment Shutting down - Voltage Distortion](#)
6. [Flickering of Fluorescent Lights - Transformer Saturation](#)
7. [Fuses Blowing for No Apparent Reason - Inductive Heating and Overload](#)
8. [Motor Failures \(overheating\) - Voltage Drop](#)
9. [Neutral Conductor and Terminal Failures - Additive Triplen Currents](#)
10. [Electromagnetic Load Failures - Inductive Heating](#)
11. [Overheating of Metal Enclosures - Inductive Heating](#)
12. [Power Interference on Voice Communication - Harmonic Noise](#)
13. [Transformer Failures - Inductive Heating](#)

2.7.2 Overcoming Harmonics

[Tuned Harmonic filters consisting of a capacitor bank and reactor in series are designed and adopted for suppressing harmonics, by providing low impedance path for harmonic component.](#)

[The Harmonic filters connected suitably near the equipment generating harmonics help to reduce THD to acceptable limits. In present Indian context where no Electro Magnetic Compatibility regulations exist as an application of Harmonic filters is very relevant for industries having diesel power generation sets and co-generation units.](#)

2.8 Electric Motors

[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 \(enclosure\).](#)

9. Electric Motor Types

1. Induction Motors

Induction motors are the most commonly used prime mover for various equipments in industrial applications. In induction motors, the induced magnetic field of the stator winding induces a current in the rotor. This induced rotor current produces a second magnetic field, which tries to oppose the stator magnetic field, and this causes the rotor to rotate.

The 3-phase squirrel cage motor is the workhorse of industry; it is rugged and reliable, and is by far the most common motor type used in industry. These motors drive pumps, blowers and fans, compressors, conveyers and production lines. The 3-phase induction motor has three windings each connected to a separate phase of the power supply.

2. Direct-Current Motors

Direct-Current motors, as the name implies, use direct-unidirectional, current. Direct current motors are used in special applications- where high torque starting or where smooth acceleration over a broad speed range is required.

3. Synchronous Motors

AC power is fed to the stator of the synchronous motor. The rotor is fed by DC from a separate source. The rotor magnetic field locks onto the stator rotating magnetic field and rotates at the same speed. The speed of the rotor is a function of the supply frequency and the number of magnetic poles in the stator. While induction motors rotate with a slip, i.e., rpm is less than the synchronous speed, the synchronous motor rotate with no slip, i.e., the RPM is same as the synchronous speed governed by supply frequency and number of poles. The slip energy is provided by the D.C. excitation power.

10. Losses in Induction Motors

1. Stator and Rotor I²R Losses

These losses are major losses and typically account for 55% to 60% of the total losses. I²R losses are heating losses resulting from current passing through stator and rotor conductors. I²R losses are the function of a conductor resistance, the square of current. Resistance of conductor is a function of conductor material, length and cross sectional area. The suitable selection of copper conductor size will reduce the resistance. Reducing the motor current is most readily accomplished by decreasing the magnetizing component of current. This involves lowering the operating flux density and possible shortening of air gap. Rotor I²R losses are a function of the rotor conductors (usually aluminium) and the rotor slip. Utilisation of copper conductors will reduce the winding resistance. Motor operation closer to synchronous speed will also reduce rotor losses.

2. Core Losses

Core losses are those found in the stator-rotor magnetic steel and are due to hysteresis effect and eddy current effect during 50 Hz magnetization of the core material. These losses are independent of load and account for 20 – 25 % of the total losses.

The hysteresis losses which are a function of flux density, are reduced by utilizing low loss grade of silicon steel laminations. The reduction of flux density is achieved by suitable increase in the core length of stator and rotor. Eddy current losses are generated by circulating current within the core steel laminations. These are reduced by using thinner laminations.

3. Friction and Windage Losses

Friction and windage losses result from bearing friction, windage and circulating air through the motor and account for 8 – 12 % of total losses. These losses are independent of load. The reduction in heat generated by stator and rotor losses permit the use of smaller fan. The windage losses also reduce with the diameter of fan leading to reduction in windage losses.

2.10.4 Stray Load-Losses

These losses vary according to square of the load current and are caused by leakage flux induced by load currents in the laminations and account for 4 to 5 % of total losses. These losses are reduced by careful selection of slot numbers, tooth/slot geometry and air gap.

11. Motor Efficiency

Two important attributes relating to efficiency of electricity use by A.C. Induction motors are efficiency (η), defined as the ratio of the mechanical energy delivered at the rotating shaft to the electrical energy input at its terminals, and power factor (PF). Motors, like other inductive loads, are characterized by power factors less than one. As a result, the total current draw needed to deliver the same real power is higher than for a load characterized by a higher PF. An important effect of operating with a PF less than one is that resistance losses in wiring upstream of the motor will be higher, since these are proportional to the square of the current. Thus, both a high value for η and a PF close to unity are desired for efficient overall operation in a plant.

Squirrel cage motors are normally more efficient than slip-ring motors, and higher-speed motors are normally more efficient than lower-speed motors. Efficiency is also a function of motor temperature. Totally-enclosed, fan-cooled (TEFC) motors are more efficient than screen protected, drip-proof (SPDP) motors. Also, as with most equipment, motor efficiency increases with the rated capacity.

12. Energy-Efficient Motors

Energy-efficient motors (EEM) are the ones in which, design improvements are incorporated specifically to increase operating efficiency over motors of standard design. Design improvements focus on reducing intrinsic motor losses. Improvements include the use of lower-loss silicon steel, a longer core (to increase active material), thicker wires (to reduce resistance), thinner laminations, smaller air gap between stator and rotor, copper instead of aluminum bars in the rotor, superior bearings and a smaller fan, etc.

Energy-efficient motors now available in India operate with efficiencies that are typically 3 to 4 percentage points higher than standard motors. In keeping with the stipulations of the BIS, energy-efficient motors are designed to operate without loss in efficiency at loads between 75 % and 100 % of rated capacity. This may result in major benefits in varying load applications. The power factor is about the same or may be higher than for standard motors. Furthermore, energy-efficient motors have lower operating temperatures and noise levels, greater ability to accelerate higher-inertia loads, and are less affected by supply voltage fluctuations.

2.13 Factors Affecting Energy Efficiency & Minimizing Motor Losses in Operation

Motor performance is affected considerably by the quality of input power, that is the actual volts and frequency available at motor terminals vis-à-vis rated values as well as voltage and frequency variations and voltage unbalance across the three phases. Motors in India must comply with standards set by the Bureau of Indian Standards (BIS) for tolerance to variations in input power quality. The BIS standards specify that a motor should be capable of delivering its rated output with a voltage variation of +/- 6 % and frequency variation of +/- 3 %. Fluctuations much larger than these are quite common in utility-supplied electricity in India. Voltage fluctuations can have detrimental impacts on motor performance.

Voltage unbalance, the condition where the voltages in the three phases are not equal, can be still more detrimental to motor performance and motor life. Unbalance typically occurs as a result of supplying single-phase loads disproportionately from one of the phases. It can also result from the use of different sizes of cables in the distribution system.

Example2.1:

A three phase, 10 kW motor has the name plate details as 415 V, 18.2 amps and 0.9 PF. Actual input measurement shows 415 V, 12 amps and 0.7 PF which was measured with power analyzer during motor running. Determine the motor loading?

Rated output at full load = 10 kW

Rated input at full load = $\square 3 \times V \times I \times \cos\Phi = 1.732 \times 0.415 \times 18.2 \times 0.9 = 11.8 \text{ kW}$

The rated efficiency of motor at full load = $(10 \times 100) / 11.8 = 85\%$

Measured (Actual) input power = $1.732 \times 0.415 \times 12 \times 0.7 = 6.0 \text{ kW}$

$$\text{Motor loading \%} = \frac{\text{Measured kW}}{\text{Rated kW}} \times 100 = \frac{6.0}{11.8} \times 100 = 51.2\%$$

Example 2.2:

A 400 Watt mercury vapor lamp was switched on for 10 hours per day. The supply volt is 230 V. Find the power consumption per day? (Volt = 230 V, Current = 2 amps, PF = 0.8)

$$\begin{aligned} \text{Electricity consumption (kWh)} &= V \times I \times \cos\Phi \times \text{No of Hours} \\ &= 0.230 \times 2 \times 0.8 \times 10 = 3.7 \text{ kWh or Units} \end{aligned}$$

Example 2.3:

An electric heater of 230 V, 5 kW rating is used for hot water generation in an industry. Find electricity consumption per hour (a) at the rated voltage (b) at 200 V.

- (a) Electricity consumption (kWh) at rated voltage = $5 \text{ kW} \times 1 \text{ hour} = 5 \text{ kWh}$.
 (b) Electricity consumption at 200 V (kWh) = $(200 / 230)^2 \times 5 \text{ kW} \times 1 \text{ hour} = 3.78 \text{ kWh}$.

Example 2.4:

The utility bill shows an average power factor of 0.72 with an average KW of 627. How much kVAr is required to improve the power factor to .95 ?

Using formula

$$\text{Cos } \Phi 1 = 0.72, \text{ tan } \Phi 1 = 0.963$$

$$\text{Cos } \Phi 2 = 0.95, \text{ tan } \Phi 2 = 0.329$$

$$\begin{aligned} \text{kVAr required} &= P (\text{tan } \Phi 1 - \text{tan } \Phi 2) \\ &= 627 (0.964 - 0.329) \\ &= 398 \text{ kVAr} \end{aligned}$$

2.14 Motor Efficiency Computation

Example 2.5:

Motor Specifications

Rated power = 34 kW/45 HP

Voltage = 415 Volt

Current = 57 Amps

Speed = 1475 rpm

Insulation class = F

Frame = LD 200 L

Connection = Delta

No load test Data

Voltage, V = 415 Volts

Current, I = 16.1 Amps

Frequency, F = 50 Hz

Stator phase resistance at 30°C = 0.264 Ohms

No load power, P_{nl} = 1063.74 Watts

- a) Calculate iron plus friction and windage losses
- b) Calculate stator resistance at 120°C

$$R_2 = R_1 \times \frac{235 + t_2}{235 + t_1}$$

- c) Calculate stator copper losses at operating temperature of resistance at 120°C
- d) Calculate full load slip(s) and rotor input assuming rotor losses are slip times rotor input.
- e) Determine the motor input assuming that stray losses are 0.5 % of the motor rated power
- f) Calculate motor full load efficiency and full load power factor

Solution

- a) Let Iron plus friction and windage loss, P_i + f_w
No load power, P_{nl} = 1063.74 Watts

Stator Copper loss, $P_{st-30^{\circ}C}$ ($P_{st.cu}$)

$$= 3 \times (16.1 / \sqrt{3})^2 \times 0.264$$

$$= 68.43 \text{ Watts}$$

$$P_i + f_w = P_{nl} - P_{st.cu}$$

$$= 1063.74 - 68.43$$

$$= 995.3 \text{ W}$$

b) Stator Resistance at $120^{\circ}C$,

$$R_{120^{\circ}C} = 0.264 \times \frac{120 + 235}{30 + 235}$$

$$= 0.354 \text{ ohms per phase}$$

c) Stator copper losses at full load, $P_{st.cu}$ $120^{\circ}C$

$$= 3 \times (57 / \sqrt{3})^2 \times 0.354$$

$$= 1150.1 \text{ Watts}$$

d) Full load slip

$$S = (1500 - 1475) / 1500$$

$$= 0.0167$$

$$\begin{aligned} \text{Rotor input, } P_r &= P_{\text{output}} / (1-S) \\ &= 34000 / (1-0.0167) \\ &= 34577.4 \text{ Watts} \end{aligned}$$

e) Motor full load input power, P_{input}

$$= P_r + P_{st.cu} \text{ } 120^{\circ}C + (P_i + f_w) + P_{\text{stray}}$$

$$= 34577.4 + 1150.1 + 995.3 + (0.005^* \times 34000)$$

$$= 36892.8 \text{ Watts}$$

*where, stray losses = 0.5% of rated output (assumed)

f) Motor efficiency at full load

$$\text{Efficiency} = \frac{P_{\text{output}}}{P_{\text{input}}} \times 100$$

$$= \frac{34000}{36892.8} \times 100$$

$$= 92.2 \%$$

15. Lighting

Lighting is provided in industries, commercial buildings, indoor and outdoor for providing comfortable working environment.

Lighting is an area, which provides a major scope to achieve energy efficiency at the design stage, by incorporation of modern energy efficient lamps, luminaires and gears, apart from good operational practices.

16. Lumen

It is a unit of light flow or luminous flux. The lumen rating of a lamp is a measure of the total light output of the lamp. The most common measurement of light output (or luminous flux) is the lumen. Light sources are labeled with an output rating in lumens.

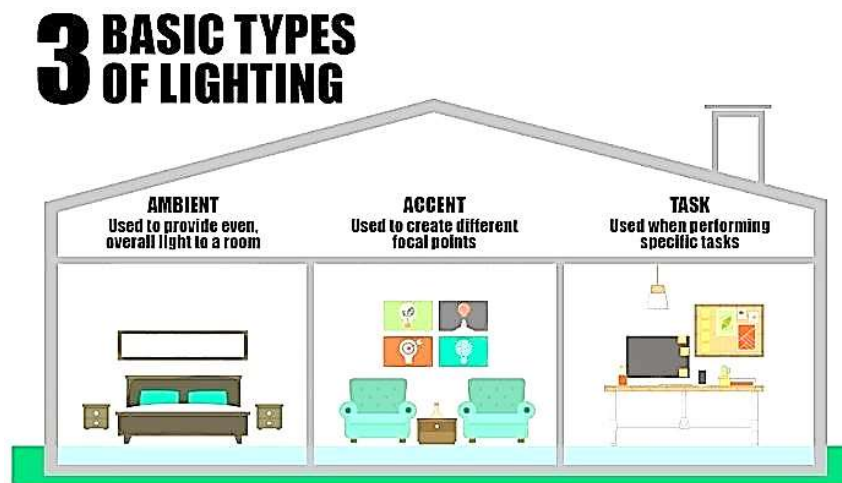
17. Lux

It is the metric unit of measure for illuminance of a surface. One lux is equal to one lumen per square meter.

18. Lamp Circuit Efficacy

It is the amount of light (lumens) emitted by a lamp for each watt of power consumed by the lamp circuit, i.e. including control gear losses. This is a more meaningful measure for those lamps that require control gear. Unit: lumens per circuit watt (lm/W).

19. Types of Lightings



1. Ambient Indoor Lighting

General or ambient lighting is intended to light up a room in its entirety, to provide a uniform level of illumination throughout the space, independently of other lighting sources.

Moreover, its purpose is to ensure safe and easy traffic, as well as to create an overview of the room. The ambient light ‘bounces’ off the walls to illuminate as much space as possible.

Types of fixtures that can provide general ambient indoor lighting:

- Chandelier
- Ceiling mounted fixture
- Wall-mounted fixture
- Traditional recessed fixtures and/or LED Downlights
- Track light
- Floor lamp
- Table lamp

2. Ambient Outdoor Lighting

Outdoor lighting is usually installed in order to ensure visibility and increase security around a building. It is also recommended to light up the exterior of the building, entrances and stairs to reduce and perhaps eliminate the risk of injury that can occur when entering and leaving the building.

Types of fixtures that provide ambient outdoor lighting:

- Spotlight
- Hanging fixture
- Garage and canopy lighting
- Post lantern
- Wall lighting
- Recessed fixture used in overhanging structures

3. Task Lighting

Task lighting sheds light on the tasks a person carries out in a given space such as reading, cooking, computer work, for which a brighter light is required in a smaller focal point of the room.

For a more pleasant lighting, it is often best to avoid harsh lights or lighting that casts

troublesome shadows. It is also practical to install a single switch for focal lighting, independent from the room's overall lighting switch.

Types of Fixtures that Provide Task Lighting:

- Directional gimbal recessed fixture or downlight
- Pendant lighting
- Slim line bar and undercabinet
- Tape and extrusion
- Portable or desk lamp

4. Accent Lighting

Accent lighting is used mainly to focus on a specific point of interest or to achieve a desired effect. This type of lighting gives the impression of a larger room; it is more frequently used to highlight an architectural feature, a plant (in outdoor layout), a sculpture, or a collection of objects.

As a general rule, effective accent lighting requires the installation of three times more light on the focal point than ambient lighting generally provides.

Types of Fixtures that Provide Accent Lighting:

- Track light
- Slim line bar and undercabinet
- Tape and extrusion
- Directional recessed fixture or downlight
- Wall-mounted fixtures

20. LED Lighting

The LEDs have the following merits over the filament lamps.

- Lesser power consumption (Less than 1 W/lamp)
- Withstand high voltage fluctuation in the power supply.
- Longer operating life (more than 1,00,000 hours)

21. Encon Measures in Lighting

- Install energy efficient fluorescent lamps in place of "Conventional" fluorescent lamps.
- Install Compact Fluorescent Lamps (CFL's) in place of incandescent lamps. CFL's are highly suitable for places such as Living rooms, Hotel lounges, Bars, Restaurants, Pathways, Building entrances, Corridors, etc.
- Install metal halide lamps in place of mercury / sodium vapour lamps. These lamps are highly suitable for applications such as assembly line, inspection areas, painting shops, etc.
- Install High Pressure Sodium Vapour (HPSV) lamps for applications where colour rendering is not critical such as street lighting, yard lighting, etc.
- Install LED panel indicator lamps in place of filament lamps. These lamps are suitable in industries for monitoring, fault indication, signaling, etc.
- Grouping of lighting system, to provide greater flexibility in lighting control.
- Install microprocessor based controllers. Advanced lighting control system uses movement detectors or lighting sensors, to feed signals to the controllers.
- Ensure optimum usage of day lighting.
- Installation of "exclusive" transformer for lighting. This provides a better voltage regulation for the lighting. This will reduce the voltage related problems, which in turn increases the efficiency of the lighting system.
- Install servo stabilizer for lighting feeder for improving lighting efficiency
- Installation of high frequency (HF) electronic ballasts in place of conventional ballasts

UNIT III - THERMAL SYSTEMS

1. Stoichiometry

Stoichiometry is the study of the relationship between relative amounts of substances. The formula of a compound provides information about the relative amount of each element present in either one molecule of the compound or one mole of the compound. For example, one molecule of CaCl_2 contains 1 mol Ca^{2+} ions and 2 mol Cl^- ions.

Stoichiometry can be used to determine the chemical formula of a compound by studying the relative amounts of elements present or can be used to study the relative amounts of compounds that are consumed and produced during a chemical reaction.

2. Efficiency computation of Boilers

Efficiency testing helps us to find out how far the boiler efficiency drifts away from the best efficiency. Any observed abnormal deviations could therefore be investigated to pinpoint the problem area for necessary corrective action. Hence it is necessary to find out the current level of efficiency for performance evaluation, which is a pre requisite for energy conservation action in industry.

Most standards for computation of boiler efficiency, including IS 8753 and BS845 are designed for spot measurement of boiler efficiency. Basically Boiler efficiency can be tested by the following methods:

- 1) **The Direct Method:** Where the energy gain of the working fluid (water and steam) is compared with the energy content of the boiler fuel.
- 2) **The Indirect Method:** Where the efficiency is the difference between the losses and the energy input.

3.2.1 The Direct Method Testing

This is also known as 'input-output method' due to the fact that it needs only the useful output (steam) and the heat input (i.e. fuel) for evaluating the efficiency. This efficiency can be evaluated using the formula:

$$\text{Boiler Efficiency} = \frac{\text{Heat Output}}{\text{Heat Input}} \times 100$$

$$\text{Boiler Efficiency} = \frac{\text{Steam flow rate} \times (\text{steam enthalpy} - \text{feed water enthalpy})}{\text{Fuel firing rate} \times \text{Gross calorific value}} \times 100$$

Example 3.1

Water consumption and coal consumption were measured in a coal-fired boiler at hourly intervals. Weighed quantities of coal were fed to the boiler during the trial period. Simultaneously water level difference was noted to calculate steam generation during the trial period. Blow down was avoided during the test. The measured data is given below.

Type of boiler: Coal fired Boiler

Heat output data

Quantity of steam generated (output)	: 8 TPH
Steam pressure / temperature	: 10 kg/cm ² (g)/ 180°C
Enthalpy of steam(dry & Saturated) at 10 kg/cm ² (g) pressure	: 665 kCal/kg
Feed water temperature	: 85°C
Enthalpy of feed water	: 85 kCal/kg

Heat input data

Quantity of coal consumed (Input)	: 1.6 TPH
GCV of coal	: 4000 kCal/kg

Calculation

$$\text{Boiler efficiency } (\eta) = \frac{Q \times (H - h) \times 100}{(q \times \text{GCV})}$$

Where Q = Quantity of steam generated per hour (kg/hr)
 q = Quantity of fuel used per hour (kg/hr)
 GCV = Gross calorific value of the fuel (kCal/kg)
 H = Enthalpy of steam (kCal/kg)
 h = Enthalpy of feed water (kCal/kg)

$$\begin{aligned} \text{Boiler efficiency } (\eta) &= \frac{8 \text{ TPH} \times 1000\text{kg/T} \times (665 - 85) \times 100}{1.6 \text{ TPH} \times 1000\text{kg/T} \times 4000 \text{ kCal/kg}} \\ &= 72.5\% \end{aligned}$$

1. Merits and Demerits of Direct Method

Merits

- [Plant people can evaluate quickly the efficiency of boilers](#)
- [Requires few parameters for computation](#)
- [Needs few instruments for monitoring](#)

Demerits

- [Does not give clues to the operator as to why efficiency of system is lower](#)
- [Does not calculate various losses accountable for various efficiency levels](#)
- [Evaporation ratio and efficiency may mislead, if the steam is highly wet due to water carryover](#)

2. Energy Conservation Opportunities in Boilers

1. Stack Temperature

[The stack temperature \(Temperature used to remove water vapor in the exhaust condenses on the stack walls\) should be as low as possible. An estimated 1% efficiency loss occurs with every 22 °C increase in stack temperature.](#)

2. Feed Water Preheating using Economizer

Feed Water Preheating using economizer would reduce the exit temperature to 65 °C, thereby increasing thermal efficiency by 5%.

3. Combustion Air Preheat

Combustion air preheating is an alternative to feed water pre-heating. In order to improve thermal efficiency by 1%, the combustion air temperature must be raised by 20 °C using pre-heater.

4. Incomplete Combustion

Incomplete combustion can arise from a shortage of air or surplus of fuel or poor distribution of fuel. It is usually obvious from the colour or smoke, and must be corrected immediately.

5. Excess Air Control

Controlling excess air to an optimum level always results in reduction in flue gas losses; for every 1% reduction in excess air there is approximately 0.6% rise in efficiency.

6. Radiation and Convection Heat Loss

Repairing or augmenting insulation can reduce heat loss through boiler walls and piping.

7. Automatic Blow down Control

Uncontrolled continuous blow down is very wasteful. Automatic blow down controls can be installed that sense and respond to boiler water conductivity and pH. A 10% blow down in a 15 kg/cm² boiler results in 3% efficiency loss.

8. Reduction of 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. It is estimated that 3 mm of soot can cause an increase in fuel consumption by 2.5% due to increased flue gas temperatures. Periodic off-line cleaning of radiant furnace surfaces, boiler tube banks, economizers and air heaters may be necessary to remove stubborn deposits.

9. Variable Speed Control for Fans, Blowers and Pumps

The possibility of replacing the dampers by a VSD should be improve the system efficiency.

10. Effect of Boiler Loading on Efficiency

The maximum efficiency of the boiler does not occur at full load, but at about two-thirds of the full load.

11. Proper Boiler Scheduling

Operate a fewer number of boilers at higher loads, than to operate a large number at low loads.

12. Boiler Replacement

The potential savings from replacing a boiler depend on the anticipated change in overall efficiency. A change in a boiler can be financially attractive if the existing boiler is :

- old and inefficient
- not capable of firing cheaper substitution fuel
- over or under-sized for present requirements
- not designed for ideal loading conditions

3.4 Efficiency computation of Furnaces

A furnace is an equipment to melt metals for casting or heat materials for change of shape (rolling, forging etc) or change of properties (heat treatment).

The efficiency of furnace can be judged by measuring the amount of fuel needed per unit weight of material.

$$\text{Thermal efficiency of the furnace} = \frac{\text{Heat in the stock}}{\text{Heat in the fuel consumed for heating the stock}}$$

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

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

Where

Q = Quantity of heat of stock in kCal

m = Weight of the stock in kg

C_p = Mean specific heat of stock in kCal/kg°C

t₁ = Final temperature of stock desired, °C

t₂ = Initial temperature of the stock before it enters the furnace, °C

Example 3.2

An oil-fired reheating furnace has an operating temperature of around 1340°C. Average fuel consumption is 400 litres/hour. The flue gas exit temperature is 750 °C after air pre-heater. Air is preheated from ambient temperature of 40 °C to 190 °C through an air pre-heater. The furnace has 460 mm thick wall (x) on the billet extraction outlet side, which is 1 m high (D) and 1 m wide. The other data are as given below. Find out the efficiency of the furnace by direct method.

Exit flue gas temperature = 750°C

Ambient temperature = 40°C

Preheated air temperature = 190°C

Specific gravity of oil = 0.92

Average fuel oil consumption = 400 Litres / hr

= $400 \times 0.92 = 368 \text{ kg/hr}$

Calorific value of oil = 10000 kCal/kg

Average O2 percentage in flue gas = 12%

Weight of stock = 6000 kg/hr

Specific heat of Billet = 0.12 kCal/kg/°C

Average surface temperature of heating + soaking zone = 122 °C

Average surface temperature of area other than heating and soaking zone = 80 °C

Area of heating + soaking zone = 70.18 m²

Area other than heating and soaking zone = 12.6 m²

Solution:

Heat input = 400 litres / hr

= 368 kg/hr

Heat output = $m \times C_p \times \Delta T$

= $6000 \text{ kg} \times 0.12 \times (1340 - 40)$

= 936000 kCal

Efficiency = $936000 \times 100 / (368 \times 10000)$

= 25.43 %

= 25% (app)

Losses = 75% (app)

5. Energy Conservation measures in Furnaces

- 1) Complete combustion with minimum excess air
- 2) Correct heat distribution
- 3) Operate furnace at the desired temperature
- 4) Reduce heat losses from furnace openings
- 5) Maintain correct amount of furnace draught
- 6) Optimum capacity utilization of furnace will give maximum thermal efficiency
- 7) Waste heat recovery from the flue gases improves system efficiency
- 8) Minimum refractory losses

The appropriate choice of refractory and insulation materials goes a long way in achieving fairly high fuel savings in industrial furnaces

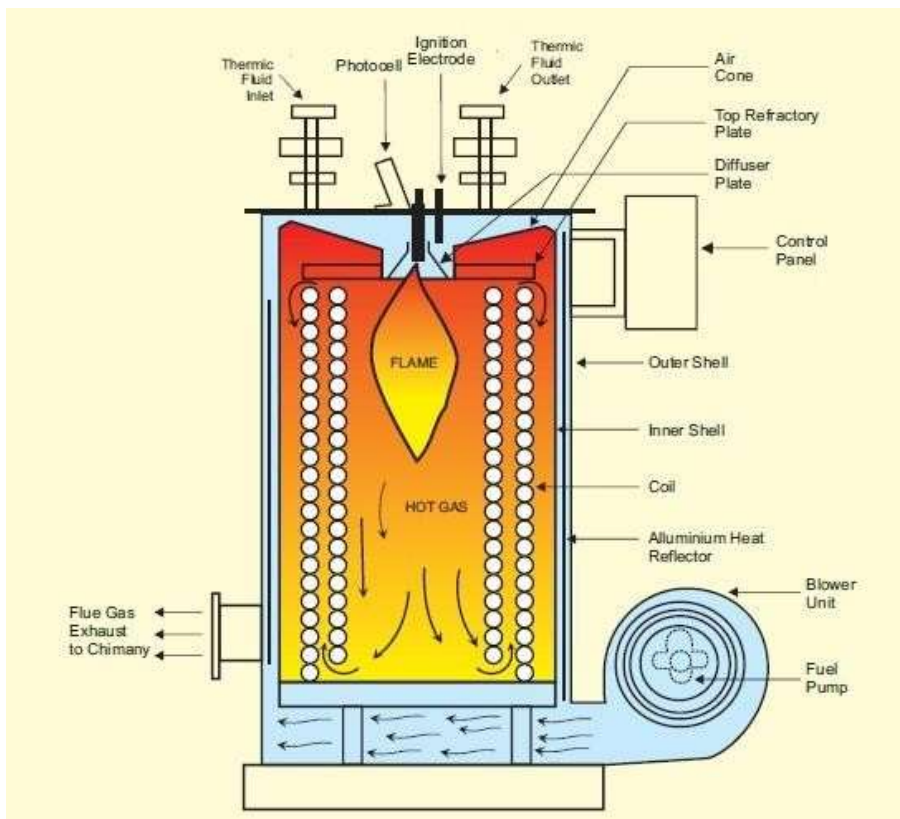
- 9) Use of Ceramic Coatings in furnace chamber promotes rapid and efficient transfer of heat, thereby extended life of refractories.

5. Thermic Fluid Heaters

Thermic Fluid is used as a heat transfer mechanism in some industrial process and heating applications. Thermic Fluid may be a vegetable or mineral based oil and the oil may be raised to a high temperature without the need for any pressurization. The relatively high flow and return temperatures may limit the potential for flue gas heat recovery unless some other system can absorb this heat usefully. Careful design and selection is required to achieve best energy efficiency.

Thermic fluid heaters are used just to heat the water, not necessarily producing steam.

Water is heated by passing hot thermic fluid in tubes submerged in water. This arrangement is similar to the fire-tube boiler.



The combustion air enters through the fan inlet, travels upwards through the space between the inner shell & the outer shell, gets pre-heated & enters the top mounted burner. Hot flue gases travel down the full length of the vessel creating the first (radiant) pass. The flue gases then travel upwards through the space between the inner coil & the outer coil creating the second (convection) pass. The third (convection) pass is downwards through the space between the outer coil & the inner shell to the flue gas outlet.

3.7 Steam: Concept, Properties & Usage

Steam has been a popular mode of conveying energy since the industrial revolution.

Steam is used for generating power and also used in process industries such as sugar, paper, fertilizer, refineries, petrochemicals, chemical, food, synthetic fiber and textiles.

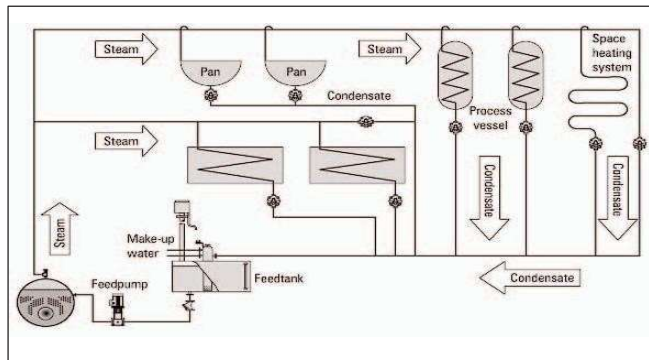
The following characteristics of steam make it so popular and useful to the industry:

- Highest specific heat and latent heat
- Highest heat transfer coefficient
- [Easy to control and distribute](#)
- [Cheap and inert](#)

[Water can exist in the form of solid \(ice\), liquid \(water\) and gas \(steam\) respectively. If heat energy is added to water, its temperature rises until a value is reached at which the water can no longer exist as a liquid. We call this the "saturation" point and with any further addition of energy, some of the water will boil off as steam. This evaporation requires relatively large amounts of energy, and while it is being added, the water and the steam released are both at the same temperature. Equally, if steam is made to release the energy that was added to evaporate it, then the steam will condense and water at same temperature will be formed.](#)

[3.8 Steam Distribution](#)

[The steam distribution system is the essential link between the steam generator and the steam user. Whatever the source, an efficient steam distribution system is essential if steam of the right quality and pressure is to be supplied, in the right quantity, to the steam using equipment. Installation and maintenance of the steam system are important issues, and must be considered at the design stage.](#)



[Figure 3.2 Steam Distribution System](#)

As steam condenses in a process, flow is induced in the supply pipe. Condensate has a very small volume compared to the steam, and this causes a pressure drop, which causes the steam to flow through the pipes. The steam generated in the boiler must be conveyed through pipe work to the point where its heat energy is required. Initially there will be one or more main pipes, or 'steam mains', which carry steam from the boiler in the general direction of the steam using plant. Smaller branch pipes can then carry the steam to the individual pieces of equipment. A typical steam distribution system is shown in Figure 3.2.

3.9 Steam Traps

The purpose of installing the steam traps is to obtain fast heating of the product and equipment by keeping the steam lines and equipment free of condensate, air and non-condensable gases. A steam trap is a valve device that discharges condensate and air from the line or piece of equipment without discharging the steam.

The three important functions of steam traps are:

- To discharge condensate as soon as it is formed.
- Not to allow steam to escape.
- To be capable of discharging air and other incondensable gases.

3.9.1 Types of Steam Traps

There are three basic types of steam trap into which all variations fall, all three are classified by International Standard ISO 6704:1982.

Thermostatic (operated by changes in fluid temperature) - The temperature of saturated steam is determined by its pressure. In the steam space, steam gives up its enthalpy of evaporation (heat), producing condensate at steam temperature. As a result of any further heat loss, the temperature of the condensate will fall. A thermostatic trap will pass condensate when this lower temperature is sensed. As steam reaches the trap, the temperature increases and the trap closes.

Mechanical (operated by changes in fluid density) - This range of steam traps operates by sensing the difference in density between steam and condensate. These steam traps include 'ball float traps' and 'inverted bucket traps'. In the 'ball float trap', the ball rises in the presence of condensate, opening a valve which passes the denser condensate. With the 'inverted bucket trap', the inverted bucket floats when steam reaches the trap and rises to shut the valve. Both are essentially 'mechanical' in their method of operation.

Thermodynamic (operated by changes in fluid dynamics) - Thermodynamic steam traps rely partly on the formation of flash steam from condensate. This group includes 'thermodynamic', 'disc', 'impulse' and 'labyrinth' steam traps.

3.10 Condensate Recovery

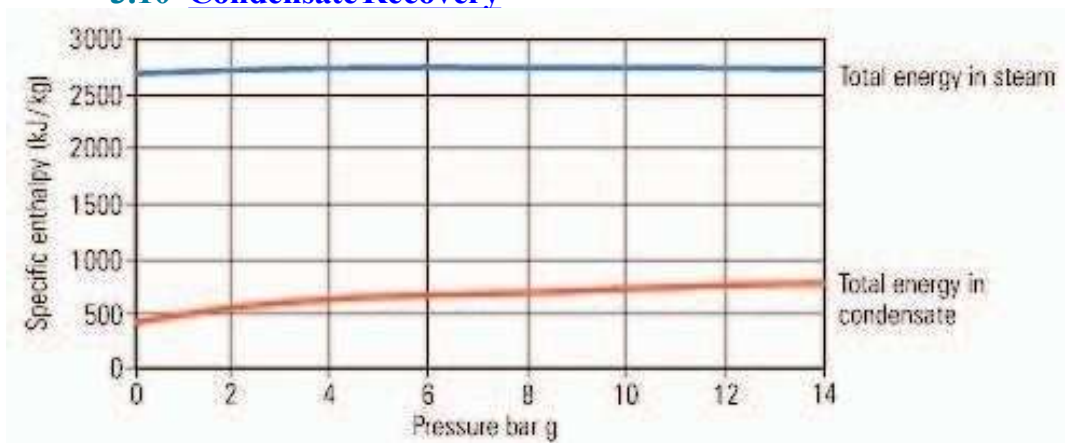


Figure 3.3 Heat Content of Steam and Condensate at the Same Pressure

The 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 in the steam leaves the process equipment as hot water. Figure 3.3 compares the amount of energy in a kilogram of steam and condensate at the same pressure. The percentage of energy in condensate to that in steam can vary from 18% at 1 bar g to 30% at 14 bar g; clearly the liquid condensate is worth reclaiming. If this water is returned to the boiler house, it will reduce the fuel requirements of the boiler. For every 60°C rise in the feed water temperature, there will be approximately 1% saving of fuel in the boiler.

3.10.1 Benefits of Condensate Recovery

- Water charges are reduced.
- Effluent charges and possible cooling costs are reduced.
- Fuel costs are reduced.
- More steam can be produced from the boiler.
- Boiler blowdown is reduced - less energy is lost from the boiler.
- Chemical treatment of raw make-up water is reduced.

3.11 **Flash Steam Recovery**

Flash steam is produced when condensate at a high pressure is released to a lower pressure and can be used for low pressure heating.

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

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

$$\text{Flash steam available \%} = (S_1 - S_2) / L_2$$

Where: S_1 is the sensible heat of higher pressure condensate.

S_2 is the sensible heat of the steam at lower pressure (at which it has been flashed). L_2 is the latent heat of flash steam (at lower pressure).

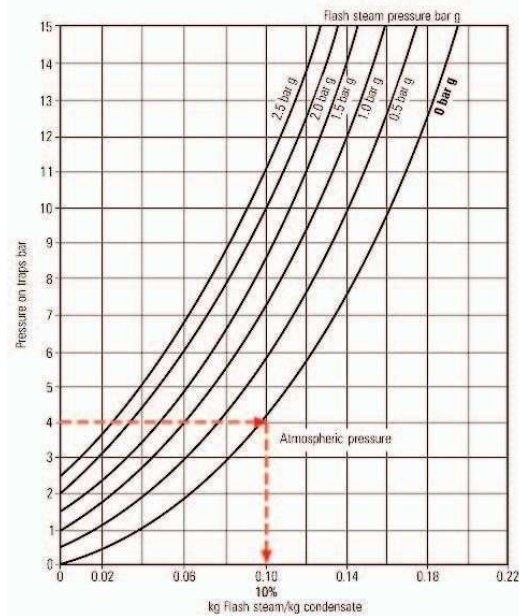


Figure 3.4 Quantity of Flash Steam Graph

Flash steam can be used on low pressure applications like direct injection and can replace an equal quantity of live steam that would be otherwise required. The demand for flash steam should exceed its supply, so that there is no build up of pressure in the flash vessel and the consequent loss of steam through the safety valve. Generally, the simplest method of using flash steam is to flash from a machine/equipment at a higher pressure to a machine/equipment at a lower pressure, thereby augmenting steam supply to the low pressure equipment.

In general, a flash system should run at the lowest possible pressure so that the maximum amount of flash is available and the backpressure on the high pressure systems is kept as low as possible.

Flash steam from the condensate can be separated in an equipment called the 'flash vessel'. This is a vertical vessel as shown in the Figure 3.5. The diameter of the vessel is such that a considerable drop in velocity allows the condensate to fall to the bottom of the vessel from where it is drained out by a steam trap preferably a float trap. Flash steam itself rises to leave the vessel at the top. The height of the vessel should be sufficient

enough to avoid water being carried over in the flash steam.

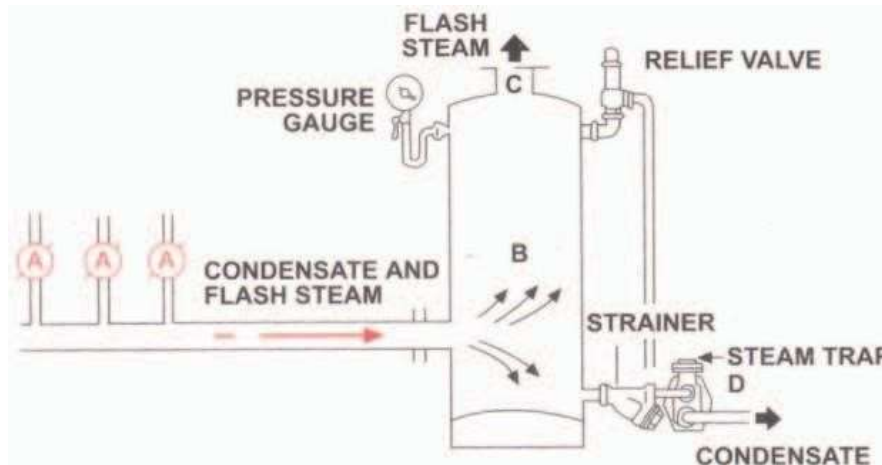


Figure 3.5 Flash Steam Recovery

The condensate from the traps (A) along with some flash steam generated passes through vessel (B). The flash steam is let out through (C) and the residual condensate from (B) goes out through the steam trap (D). The flash vessel is usually fitted with a 'pressure gauge' to know the quality of flash steam leaving the vessel. A 'safety valve' is also provided to vent out the steam in case of high pressure build up in the vessel.

Purpose of Insulation

A thermal insulator is a poor conductor of heat and has a low thermal conductivity. Insulation is used in buildings and in manufacturing processes to prevent heat loss or heat gain. Although its primary purpose is an economic one, it also provides more accurate control of process temperatures and protection of personnel. It prevents condensation on cold surfaces and the resulting corrosion. Such materials are porous, containing large number of dormant air cells. Thermal insulation delivers the following benefits:

- Reduces over-all energy consumption
- Offers better process control by maintaining process temperature.
- Prevents corrosion by keeping the exposed surface of a refrigerated system above dew point
- Provides fire protection to equipment
- Absorbs vibration

Refractories: Properties and Types

1. Meaning of Refractories
2. Properties of Refractories
3. Refractory Fibres
4. Uses.

Meaning of Refractories:

The term refractories embraces all materials used in the arts for the construction of heat resisting containers, using the word in its broadest sense, whether it be to afford space for the evolution of gases in combustion processes or the holding of molten charges or of solids undergoing heat-treatment.

The two principal functions involved in the use of refractory materials are to those of thermal insulation and conduction. In the outside walls of a furnace, refractories serve the purpose of confining the heat and preventing excessive loss to the atmosphere; in a muffle or retort, they serve to conduct the heat through the walls to the charge.

Although, in general, the heat resisting quality of refractories is of paramount importance, this is by no means the only requirement and may at times be only a secondary consideration. Refractories may be expected to be relatively unaffected by high temperatures under stress whether negligible or heavy; to resist mechanical abrasion at various temperatures; to resist the intrusion of molten metals, slags or metallic vapours, as well the action of superheated steam and hydrocarbons, sulphurous oxide, chlorine or other gases; and to withstand sudden temperature changes.

Under one set of conditions, high thermal conductivity may be required and under another high insulation value, while in still other cases high electrical resistance at moderately high temperatures may be demanded. It is obvious that no single refractory will completely fulfill all these functions, and hence the proper selection of a suitable material is often a complicated task.

Properties of Refractories:

A good refractory material should have the following properties:

1. It should be able to withstand high temperatures generated in the furnace.
2. It should be able to withstand sudden alternating heating and cooling, i.e., thermal

shocks.

3. It should be able to withstand abrasion and rough usage.

4. Its contraction and expansion due to the inevitable temperature variation should be minimum possible.

5. It should be able to withstand fluxing action of the slags and the corrosive action of gases.

6. It should have good heat insulating properties.

7. It should be chemically inactive at elevated temperatures.

8. It should be impermeable to gases and liquids as far as possible.

9. If used in electric furnaces, it must have low electrical conductivity.

Types of Refractories:

According to their chemical behaviour, the refractory materials which are mainly oxides or carbides of metals or non-metals or their mixtures, are classified as follows:

1. Acid refractories.
2. Basic refractories.
3. Neutral refractories.

1. Acid Refractories:

Acid refractories are those which really combine with bases and are therefore, termed “Acid”. They are materials consisting of silica or containing silica as their chief constituent greatly in excess of the bases present. The important acid refractories are quartz, sand, ganister, dinas rock etc. Most fire-clays contain SiO_2 in excess of the amount indicated by the formula $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$ and are therefore, classed as acid.

Silica:

The pure silica fuses at a very high temperature, viz., 1713°C , but when heated in contact with basic substances it forms silicates, some of which fuse easily. Therefore, the presence of bases in silica to be used as refractory materials is to be guarded against. Silica occurs as quartzite, Dinas rock and ganister. Ganister is a naturally occurring high siliceous rock (98% SiO_2). In the prepared state it is used in the form of bricks. Good deposits of silica in India occur in the Gaya and Monghyr districts of Bihar.

Silica bricks are made from hard, dense fine grained quartzite (known as ganister). After crushing, the rock is ground with water and mixed with about 2 percent lime. From this mixture, bricks may be moulded by hand or by power press; after drying in hot air, they

are baked for proper time and at the proper temperature. The lime being base reacts chemically with acidic SiO_2 and fuses at a number of places in the brick and gives its strength. The bricks expand 3.5 percent after the baking is finished.

Silica bricks possess the following properties:

1. Low porosity and free from air pockets.
2. Good thermal expansion and conductivity.
3. Remarkable load bearing capacity especially at high temperatures.
4. Not susceptible to thermal spalling at temperatures above 400°C .
5. Ability to withstand thermal shock poor.

Silica bricks are extremely suitable for those parts of a furnace which are subjected to uniformly high temperature, e.g., fire bridges, roofs of Acid and Basic Open and Hearth, Electric furnaces, copper smelting and refining furnaces etc.

Fire Clay:

The main constituent of fire-clay is kaolinite, $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$. The fire clays, however, contain varying proportions of alumina and silica. Impurities in fire clays such as alkalis, sand, oxides of iron and silicates of calcium and magnesium adversely affect their properties. At high temperature the fire clays lose their water of hydration and mainly consist of alumina and silica.

The fireclay bricks are manufactured in the same manner as silica bricks. The clay in a finely crushed state is mixed with a definite amount of water in a pug mill. The mixture is then pressed into moulds, dried and finally burnt. To control the shrinkage, and accelerate the rate of production about 20 to 80% of burnt or calcined clay called Grog is mixed in the clay, while using flint clay, plastic clay is employed as binder. By altering the properties of flint clay and plastic clay in the brick mixture the properties of the bricks made can be controlled.

Important properties of fire-clay bricks are:

1. Coefficient of thermal expansion is low.
2. Sufficient strength at high temperature.
3. Resist spalling.
4. Not so refractory as silica bricks but much cheaper.

Fire clay bricks are used for the following:

1. Linings of blast furnaces for the melting of iron, copper, lead ores etc.
2. The linings of flues and shocks.
3. Heat treatment furnaces.
4. Glass furnaces.
5. Checker-work of regenerative furnaces.
6. Reverberatory furnaces.
7. Pottery kilns.

2. Basic Refractories:

Basic refractories consists mainly of basic oxides without free silica and resist the action of bases. The most common basic refractories are Magnesite, Dolomite, lime etc. But lime, because of its dehydrating tendency is never used as a refractory.

Magnesite:

This is most important basic refractory material. It is made by “dead burning” the mineral magnesite which is essentially magnesium carbonate. At any temperature above about 700°C, magnesite is dissociated to magnesia and carbon dioxide, but the properties of the resultant product differ greatly according to the temperature of burning.

Below 900°C the product is “caustic magnesia”, which is readily hydrated to magnesium hydroxide, and is used in cement. Microscopic examination shows no crystals, so that it is often called amorphous magnesia. Prolonged firing at 1800°C gives an insoluble, unreactive “dead burnt” magnesite, easily recognized as the crystalline mineral.

In the manufacture, magnesite is first “dead burnt” to remove shrinkage as much as possible, then crushed, graded for minimum porosity, bonded, and moulded under hydraulic pressure. Bonding is done by adding an organic binder, or by use of a little caustic magnesia, which sets to a hydrated cement with water, or the crushed, dead burnt magnesite itself is allowed to stand in water for some days until the surface of the particles has undergone hydration.

Magnesite possesses the following properties:

1. Thermal conductivity greater than that for fire-clays and silica.
2. Highly resistant to the action of basic slags and iron oxide.

3. Starts losing strength at temperatures above 1500°C.

Magnesite bricks are not capable of resisting sudden changes of temperature and show a tendency to spall under such conditions. They are costlier than silica and fireclay bricks and used in the construction of those parts of a furnace which are required to withstand the corrosive action of basic slags.

They are used for:

1. Hearths of basic open-hearth and copper reverberatory furnaces.
2. Electric arc and induction furnaces.
3. Lining of L.D. crucible (in the manufacture of steel).

Dolomite:

It is a double carbonate of calcium and magnesium and occurs abundantly in India. It is burnt generally in shaft furnaces. Dolomitic bricks have low conductivity and refractoriness as compared to magnesite bricks. Calcium oxide present in the bricks has a tendency to combine with water and carbon dioxide present in the atmosphere, and causes disintegration of the bricks. They are cheaper than magnesite bricks but are poor in performance. It is extensively used for repairing the banks and the bottoms of the Basic Open- hearth furnaces.

Burned bricks made from dolomite have not been successful in service. It is possible to produce brick that will not hydrate under reasonable treatment, but the stabilizing agents added cause high shrinkage when the brick is heated to high temperature. Such bricks are also sensitive to spalling influences.

3. Neutral Refractories:

Neutral refractories are substances which do not combine with either acidic or basic oxides and for this reason constitute the most satisfactory furnace lining, e.g., chromite and carbon in graphite form.

Chromite:

Chromite refractories are made from core ores which mainly contain chromite, FeO . Al_2O_3 . The ore is finely powdered and mixed with a small amount of binding material, such as fire-clay, bauxite and magnesia. The mixture is moulded into bricks, dried and burnt in a kiln at a temperature of about 1500°C to 1700°C.

Chrome bricks possess the following properties:

1. Low porosity.
2. High resistant to both acid and basic slags
3. High thermal conductivity.
4. Low resistance to spalling.

Chrome bricks are extensively used in steel industry for lining open hearths and also in the bottom of soaking pits.

Graphite:

It is a form of pure carbon and is natural product. It occurs mixed with calcareous and siliceous rocks. It is employed in making graphite crucibles using clay as the bond.

Graphite bricks have the following properties:

1. Reduced oxidising action (on the metal) at high temperatures.
2. Resist acid and basic slags.
3. Free from scaffolds formation due to the adherence of metals to the lining.

Kaynite:

Its composition is $\text{Al}_2\text{O}_3 \cdot \text{SiO}_2$ (Disthene) and crystals are triclinic. It decomposes at a temperature of $1350^\circ\text{--}1330^\circ\text{C}$. Its hardness is 5 to 7 mhos.

Sillimanite:

It occurs naturally in Assam and Rewa in India. Its composition is $\text{Al}_2\text{O}_3 \cdot \text{Si}_2$ (fibrolite) and occurs as long needle-shaped crystals. It has high softening point (above 1800°C). It has very low electrical conductivity. It is employed for making blocks, bricks, crucibles, refractory fittings for electrical goods and tubes for surface combustion.

In the Table 6.1 are shown the common refractory materials with their chemical composition, melting point etc.

Refractory Fibres:

These are made from high purity alumina and silica grains melted in electric furnace and blasted by high velocity gases into light fibres.

Ceramic fibres are available in the form of felts, blocks and blankets.

The heat losses through ceramic fibres are low compared to other refractory materials.

They have excellent temperature resistance, outstanding thermal stability and good

resistance to vibration.

Refractory fibres, in general, are considered in four broad categories namely:

- (i) Alumina silica fibres.
- (ii) Pure silica fibres.
- (iii) Pure metal oxide fibres.
- (iv) High silica leached fired glass fibres.

Uses of Refractories:

1. Because of low thermal conductivity the refractory ceramic fibres are fast replacing and are used for lining of furnaces, kilns and other high temperature equipment.
2. Silica fibres are very expensive, hence, limited industrial use. They find applications in aerospace industry.
3. Alumina silica fibres are generally used from 1000 to 1500°C temperature because of their low cost and good thermal properties (they have average diameter ranging from 1.5 to 3.0 microns).
4. Metallic oxide, alumina fibres are used for 1500 to 1600°C.

UNIT IV - ENERGY CONSERVATION IN MAJOR UTILITIES

4.1 Energy Efficiency / Saving Measures in Pumps

$$\text{Pump efficiency} = \frac{\text{Hydraulic power, } P_h}{\text{Power input to the pump shaft}} \times 100$$

Where,

$$\text{Hydraulic power } P_h(\text{kW}) = Q \times (h_d - h_s) \times \rho \times g / 1000$$

Q = Volume flow rate (m^3 / s), ρ = density of the fluid (kg/m^3), g = acceleration due to gravity (m/s^2), $(h_d - h_s)$ = Total head in metres

- A pump is a device that moves fluids (liquids or gases), or sometimes slurries, by mechanical action, typically converted from electrical energy into hydraulic energy.
- Pumps operate by some mechanism (typically reciprocating or rotary), and consume energy to perform mechanical work moving the fluid. Pumps operate via many energy sources, including manual operation, electricity, engines, or wind power, and come in many sizes, from microscopic for use in medical applications, to large industrial pumps.

• Ensure availability of basic instruments at pumps like pressure gauges, flow meters.

• Operate pumps near best efficiency point.

• Modify pumping system and pumps losses to minimize throttling.

• Adapt to wide load variation with variable speed drives or sequenced control of multiple units.

• Stop running multiple pumps - add an auto-start for an on-line spare or add a booster pump in the problem area.

• Use booster pumps for small loads requiring higher pressures.

- Increase fluid temperature differentials to reduce pumping rates in case of heat exchangers.
- Repair seals and packing to minimize water loss by dripping.
- Balance the system to minimize flows and reduce pump power requirements.
- Avoid pumping head with a free-fall return (gravity); Use siphon effect to advantage:
- Conduct water balance to minimize water consumption
- Avoid cooling water re-circulation in DG sets, air compressors, refrigeration systems, cooling towers feed water pumps, condenser pumps and process pumps.
- In multiple pump operations, carefully combine the operation of pumps to avoid throttling
- Provide booster pump for few areas of higher head
- Replace old pumps by energy efficient pumps
- In the case of over designed pump, provide variable speed drive, or downsize / replace impeller or replace with correct sized pump for efficient operation.
- Optimize number of stages in multi-stage pump in case of head margins
- Reduce system resistance by pressure drop assessment and pipe size optimization.

4.2 Energy Efficiency / Saving Measures in Fans & Blowers

Fans and blowers provide air for ventilation and industrial process requirements. Fans generate a pressure to move air (or gases) against a 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.

A centrifugal fan is a mechanical device for moving air or other gases in a direction at an angle to the incoming fluid. Centrifugal fans often contain a ducted housing to direct outgoing air in a specific direction or across a heat sink; such a fan is also called a blower, blower fan, or squirrel-cage fan.

	Fan	Blower
Definition	A fan circulates air around an entire room, or space.	A blower circulates the air only on the specific or pointed area.
Pressure	It is uses less pressure to produce large amounts of gas.	It is uses high pressure to produce large amounts of gas.
Pressure ratio	The ratio of pressure is below 1.1.	The ratio of pressure is from 1.1 to 1.2.
Air area	It provides air in the complete area.	It provides air in a specific location or point.
Types	<ul style="list-style-type: none"> • Axial flow fans. • Centrifugal fans. • Cross- flow fans. 	<ul style="list-style-type: none"> • Centrifugal blowers. • Positive-displacement blowers.
Consists of	It consists of a motor and blades, which run on electricity.	It consists of a fan, outer cover, inlet, out-let.

1. Minimizing excess air level in combustion systems to reduce FD fan and ID fan load.
2. Minimizing air in-leaks in hot flue gas path to reduce ID fan load, especially in case of 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 as a bottleneck for boiler / furnace itself.
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.

The findings of performance assessment trials will automatically indicate potential areas for improvement, which could be one or a more of the following:

1. Change of impeller by a high efficiency impeller along with cone.
2. Change of fan assembly as a whole, by a higher efficiency fan
3. Impeller de-rating (by a smaller dia impeller)
4. Change of 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
5. Fan speed reduction by pulley dia modifications for derating
6. Option of two speed motors or variable speed drives for variable duty conditions
7. Option of energy efficient flat belts, or, cogged raw edged V belts, in place of conventional V belt systems, for reducing transmission losses.
8. Adopting inlet guide vanes in place of discharge damper control
9. Minimizing system resistance and pressure drops by improvements in duct system

4.3 Energy Efficiency / Saving Measures in Compressed Air System

- Air compressors account for significant amount of electricity used in Indian 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, and balance 70 – 90% of energy of the power of the prime mover being converted to unusable heat energy and to a lesser extent lost in form of friction, misuse and noise.
- Ensure air intake to compressor is not warm and humid by locating compressors in well ventilated area or by drawing cold air from outside. Every 4°C rise in air inlet temperature will increase power consumption by 1 percent.
- Clean air-inlet filters regularly. Compressor efficiency will be reduced by 2 percent for every 250 mm WC pressure drop across the filter.

- Keep compressor valves in good condition by removing and inspecting once every six months. Worn-out valves can reduce compressor efficiency by as much as 50 percent.
- Install manometers across the filter and monitor the pressure drop as a guide to replacement of element.
- Minimize low-load compressor operation; if air demand is less than 50 percent of compressor capacity, consider change over to a smaller compressor or reduce compressor speed appropriately (by reducing motor pulley size) in case of belt driven compressors.
- Consider the use of regenerative air dryers, which uses 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 intercoolers 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 should handle the load variations whereas other compressors will 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 case of large compressors.
- Consideration should be given to two-stage or multistage 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.
- Keep the minimum possible range between load and unload pressure settings.
- Automatic timer controlled drain traps wastes compressed air every time the valve opens. So frequency of drainage should be optimized.
- 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-cycle.
- Compressed air leakage of 40 – 50 percent 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 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 off from the central compressor house, instead of supplying air through lengthy pipelines.
- All pneumatic equipment should be properly lubricated, which will reduce friction, 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's components which leads to further energy wastage.
- Pneumatic transport can be replaced by mechanical system as the former consumed about 8 times more energy. Highest possibility of energy savings is by reducing compressed air use.
- 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 over globe valves in compressed air lines.

4.4 Energy Efficiency / Saving Measures in Refrigeration System

a) Cold Insulation

Insulate all cold lines / vessels using economic insulation thickness to minimize heat gains; and choose appropriate (correct) insulation.

b) Building Envelope

Optimize air conditioning volumes by measures such as use of false ceiling and segregation of critical areas for air conditioning by air curtains.

c) Building Heat Loads Minimization

Minimize the air conditioning loads by measures such as roof cooling, roof painting, efficient lighting, pre-cooling of fresh air by air- to-air heat exchangers, variable volume air system, optimal Thermo static setting of temperature of air conditioned spaces, sun film applications, etc.

e) Process Heat Loads Minimization

Minimize process heat loads in terms of TR capacity as well as refrigeration level, i.e., temperature required, by way of:

- i) Flow optimization
- ii) Heat transfer area increase to accept higher temperature coolant
- iii) Avoiding wastages like heat gains, loss of chilled water, idle flows.
- iv) Frequent cleaning / de-scaling of all heat exchangers

f) At the Refrigeration A/C Plant Area

- i) Ensure regular maintenance of all A/C plant components as per manufacturer guidelines.
- ii) Ensure adequate quantity of chilled water and cooling water flows, avoid bypass flows by closing valves of idle equipment.
- iii) Minimize part load operations by matching loads and plant capacity on line; adopt variable speed drives for varying process load.
- iv) Make efforts to continuously optimize condenser and evaporator parameters for minimizing specific energy consumption and maximizing capacity.
- v) Adopt VAR system where economics permit as a non-CFC solution.

5. Energy Efficiency / Saving Measures in A/C

- Ensure air intake to compressor is not warm and humid by locating compressors in well ventilated area or by drawing cold air from outside. Every 4°C rise in air inlet temperature will increase power consumption by 1 percent.
- Clean air-inlet filters regularly. Compressor efficiency will be reduced by 2 percent for every 250 mm WC pressure drop across the filter.

- Keep compressor valves in good condition by removing and inspecting once every six months. Worn-out valves can reduce compressor efficiency by as much as 50 percent.
- Install manometers across the filter and monitor the pressure drop as a guide to replacement of element.
- Minimize low-load compressor operation; if air demand is less than 50 percent of compressor capacity, consider change over to a smaller compressor or reduce compressor speed appropriately (by reducing motor pulley size) in case of belt driven compressors.
- Consider the use of regenerative air dryers, which uses 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 intercoolers 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 should handle the load variations whereas other compressors will 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 case of large compressors.

- Consideration should be given to two-stage or multistage 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.
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- Provide extra air receivers at points of high cyclic-air demand which permits operation without extra compressor capacity.
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- All pneumatic equipment should be properly lubricated, which will reduce friction, 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's components which leads to further energy wastage.
- Pneumatic transport can be replaced by mechanical system as the former consumed about 8 times more energy. Highest possibility of energy savings is by reducing compressed air use.
- 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 over globe valves in compressed air lines.

6. Energy Saving Opportunities in Cooling Towers

- Follow manufacturer's recommended clearances around cooling towers and relocate or modify structures that interfere with the air intake or exhaust.
- Optimize cooling tower fan blade angle on a seasonal and/or load basis.
- Correct excessive and/or uneven fan blade tip clearance and poor fan balance.
- On old counter-flow cooling towers, replace old spray type nozzles with new square spray ABS practically non-clogging nozzles.
- Replace splash bars with self-extinguishing PVC cellular film fill.
- Install new nozzles to obtain a more uniform water pattern
- Periodically clean plugged cooling tower distribution nozzles.
- Balance flow to cooling tower hot water basins.
- Cover hot water basins to minimize algae growth that contributes to fouling.
- Optimize blow down flow rate, as per COC limit.
- Replace slat type drift eliminators with low pressure drop, self extinguishing, PVC cellular units.

- Restrict flows through large loads to design values.
- Segregate high heat loads like furnaces, air compressors, DG sets, and isolate cooling towers for sensitive applications like A/C plants, condensers of captive power plant etc. A 1°C cooling water temperature increase may increase A/C compressor kW by 2.7%. A 1°C drop in cooling water temperature can give a heat rate saving of kCal/kWh in a thermal power plant.
- Monitor L/G ratio, CW flow rates w.r.t. design as well as seasonal variations. It would help to increase water load during summer and times when approach is high and increase air flow during monsoon times and when approach is narrow.
- Monitor approach, effectiveness and cooling capacity for continuous optimization efforts, as per seasonal variations as well as load side variations.
- Consider COC improvement measures for water savings.
- Consider energy efficient FRP blade adoption for fan energy savings.
- Consider possible improvements on CW pumps with respect to efficiency improvement.
- Control cooling tower fans based on leaving water temperatures especially in case of small units.
- Optimize process CW flow requirements, to save on pumping energy, cooling load, evaporation losses (directly proportional to circulation rate) and blow down losses.

7. Energy Saving Measures in DG Set

- a) Ensure steady load conditions on the DG set, and provide cold, dust free air at intake (use of air washers for large sets, in case of dry, hot weather, can be considered).
- b) Improve air filtration.

- c) Ensure fuel oil storage, handling and preparation as per manufacturers' guidelines/oil company data.
- d) Consider fuel oil additives in case they benefit fuel oil properties for DG set usage.
- e) Calibrate fuel injection pumps frequently.
- f) Ensure compliance with maintenance checklist.
- g) Ensure steady load conditions, avoiding fluctuations, imbalance in phases, harmonic loads.
- h) In case of a base load operation, consider waste heat recovery system adoption for steam generation or refrigeration chiller unit incorporation. Even the Jacket Cooling Water is amenable for heat recovery, vapour absorption system adoption.
- i) In terms of fuel cost economy, consider partial use of biomass gas for generation. Ensure tar removal from the gas for improving availability of the engine in the long run.
- j) Consider parallel operation among the DG sets for improved loading and fuel economy therefore.
- k) Carryout regular field trials to monitor DG set performance, and maintenance planning as per requirements.

Unit 5 - Energy Economics

1. Energy Economics

In the process of energy management, at some stage, investment would be required for reducing the energy consumption of a process or utility. Investment would be required for modifications/retrofitting and for incorporating new technology. It would be prudent to adopt a systematic approach for merit rating of the different investment options vis-à-vis the anticipated savings.

It is essential to identify the benefits of the proposed measure with reference to not only energy savings but also other associated benefits such as increased productivity, improved product quality etc.

The cost involved in the proposed measure should be captured in totality viz.

- Direct project cost
- Additional operations and maintenance cost
- Training of personnel on new technology etc.

Based on the above, the energy economics can be carried out by the energy management team. Energy manager has to identify how cost savings arising from energy management could be redeployed within his organization to the maximum effect. To do this, he has to work out how benefits of increased energy efficiency can be best sold to top management as,

- Reducing operating /production costs
- Increasing employee comfort and well-being
- Improving cost-effectiveness and/or profits
- Protecting under-funded core activities
- Enhancing the quality of service or customer care delivered
- Protecting the environment

2. Cost-Benefit Analysis

Within any organization there are many worthy causes, each of which requires funding and it is the job of senior management to invest in capital where it is going to obtain the greatest

return. In order to make a decision about any course of action, management needs to be able to appraise all the costs involved in a project and determine the potential benefits.

This however, is not quite as simple as it might first appear. The capital value of plant or equipment usually decreases with time and it often requires more maintenance as it gets older. If money is borrowed from a bank to finance a project, then interest will have to be paid on the loan. Inflation too will influence the value of any future energy savings that might be achieved. It is therefore important that the cost-benefit analysis allows for all these factors, with the aim of determining which investments should be undertaken, and of optimizing the benefits achieved. To this end a number of accounting and financial appraisal techniques have been developed which help energy managers and auditors make correct and objective decisions.

When appraising the cost-benefit involved in a project it is important to understand the difference between fixed and variable costs. Variable costs are those which vary directly with the output of a particular plant or production process, such as fuel costs. Fixed costs are those costs, which are not dependent on plant or process output, such as site-rent and insurance. The total cost of any project is therefore the sum of the fixed and variable costs.

6.3 Discount Rate or Rate of Return

The rate of return is the amount you receive after the cost of an initial investment, calculated in the form of a percentage. The percentage can be reflected as a positive, which is considered a gain or profit. When the percentage is negative, it reflects a loss. This information is very useful in determining whether or not the initial investment you made was a good one.

6.3.1 The Rate of Return Formula

There are two major numbers needed to calculate the rate of return:

Current value = the current value of the item.

Original value = the price at which you purchased the item.

Then, apply these values to the

Rate of return formula = ((Current value - original value) / original value) x 100

Example 6.1

Let's say that in 2002 you purchased a home for Rs 2,000,000. In the next few years, homes in your neighborhood have been selling well due to the new shopping plaza a couple of miles away, which increased the market value of your home. So in 2007, you decided to downsize and sell your home. Based on the current market value during this time, you were able to sell your home for Rs 2,500,000. Using the formula, let's calculate the rate of return on your investment:

Current value = 2500,000

Original value = 2,000,000

Then

$$\begin{aligned} \text{rate of return formula} &= ((\text{Current value} - \text{original value}) / \text{original value}) \times 100 = \\ \text{rate of return} &= ((2,500,000 - 2,000,000) / 2,000,000) \times 100 = \\ &= 25\% \end{aligned}$$

Here the positive percentage indicates the business is profitable.

6.4 Simple Pay-Back Period

Simple Payback Period (SPP) is defined as the time (number of years) required to recovering the initial investment (First Cost), considering only the Net Annual Saving:

The simple payback period is usually calculated as follows:

$$\text{Simple payback period} = \frac{\text{First cost}}{\text{Yearly benefits} - \text{Yearly costs}}$$

1. Advantages

A widely used investment criterion, the payback period seems to offer the following advantages:

- It is simple, both in concept and application. Obviously a shorter payback generally indicates a more attractive investment. It does not use tedious calculations.
- It favors projects, which generate substantial cash inflows in earlier years, and discriminates against projects, which bring substantial cash inflows in later years but not in earlier years.

2. Limitations

- It fails to consider the time value of money
- It ignores cash flows beyond the payback period.

Example 6.2

A new small cogeneration plant installation is expected to reduce a company's annual energy bill by Rs.4,86,000. If the capital cost of the new boiler installation is Rs.22,20,000 and the annual maintenance and operating costs are Rs. 42,000, the expected payback period for the project can be worked out as.

Solution

$$PB = 22,20,000 / (4,86,000 - 42,000) = 5.0 \text{ years}$$

6.5 Internal Rate of Return

This method calculates the rate of return that the investment is expected to yield. The internal rate of return (IRR) method expresses each investment alternative in terms of a rate of return (a compound interest rate). The expected rate of return is the interest rate for which total discounted benefits become just equal to total discounted costs (i.e net present benefits or net annual benefits are equal to zero, or for which the benefit / cost ratio equals one). The criterion for selection among alternatives is to choose the investment with the highest rate of return.

The rate of return is usually calculated by a process of trial and error, whereby the net cash flow is computed for various discount rates until its value is reduced to zero.

The internal rate of return (IRR) of a project is the discount rate, which makes its net present value (NPV) equal to zero. It is the discount rate in the equation:

$$0 = \frac{CF_0}{(1 + \kappa)^0} + \frac{CF_1}{(1 + \kappa)^1} + \dots + \frac{CF_n}{(1 + \kappa)^n} = \sum_{t=0}^n \frac{CF_t}{(1 + \kappa)^t}$$

where CF_t = cash flow at the end of year "t"

k = discount rate

n = life of the project.

6.6 Net Present Value

The net present value method calculates the present value of all the yearly cash flows (i.e. capital costs and net savings) incurred or accrued throughout the life of a project, and summates them.

The net present value (NPV) of a project is equal to the sum of the present values of all the cash flows associated with it. Symbolically,

$$NPV = \frac{CF_0}{(1 + \kappa)^0} + \frac{CF_1}{(1 + \kappa)^1} + \dots + \frac{CF_n}{(1 + \kappa)^n} = \sum_{t=0}^n \frac{CF_t}{(1 + \kappa)^t}$$

Where NPV = Net Present Value

CF_t = Cash flow occurring at the end of year 't' (t=0,1,...n)

n = life of the project

k = Discount rate

The discount rate (k) employed for evaluating the present value of the expected future cash flows should reflect the risk of the project.

1. Advantages

The net present value criterion has considerable merits.

- It takes into account the time value of money.
- It considers the cash flow stream in its project life.

7. Life Cycle Costing (LCC)

Life cycle costing, or whole-life costing, is the process of estimating how much money you will spend on an asset over the course of its useful life. Whole-life costing covers an asset's costs from the time you purchase it to the time you get rid of it including the costs of acquisition, maintenance, repair, replacement, energy, and any other monetary costs (less any income amounts, such as salvage value) that are affected by the investment decision. The time value of money must be taken into account for all amounts, and the amounts must be considered over the relevant period.

To calculate an asset's life cycle cost, estimate the following expenses:

1. Purchase
2. Installation
3. Operating
4. Maintenance
5. Financing (example interest...)
6. Depreciation
7. Disposal

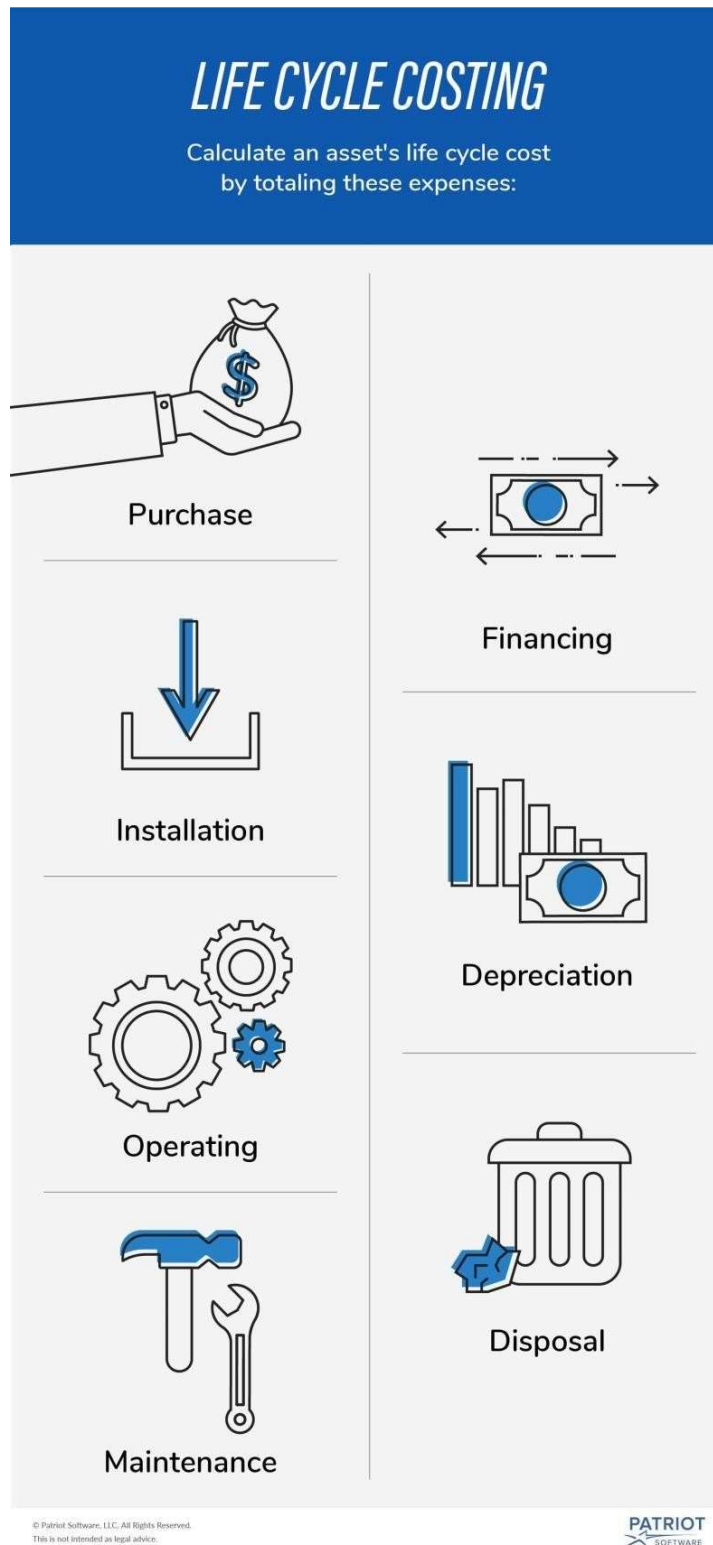


Figure 6.1 Stages of LCC

6.8 ESCO (Energy Saving Company) Concept

ESCOs are usually companies that provide a complete energy project service, from assessment to design to construction or installation, along with engineering and project management services, and financing. In one way or another, the contract involves the capitalization of all of the services and goods purchased, and repayment out of the energy savings that result from the project.

In performance contracting, an end-user (such as an industry, institution, or utility) seeking to improve its energy efficiency, contracts with ESCO for energy efficiency services and financing.

In some contracts, the ESCOs provide a guarantee for the savings that will be realized, and absorbs the cost if real savings fall short of this level. Typically, there will be a risk management cost involved in the contract in these situations. Insurance is sometimes attached, at a cost, to protect the ESCO in the event of a savings shortfall.

Energy efficiency projects generate incremental cost savings as opposed to incremental revenues from the sale of outputs. The energy cost savings can be turned into incremental cash flows to the lender or ESCO based on the commitment of the energy user (and in some cases, a utility) to pay for the savings.

ESCOs are not “bankers” in the narrow sense. Their strength is in putting together a package of services that can provide guaranteed and measurable energy savings that serve as the basis for guaranteed cost savings. But, the energy savings must be measurable. The figure shows ESCOs role.

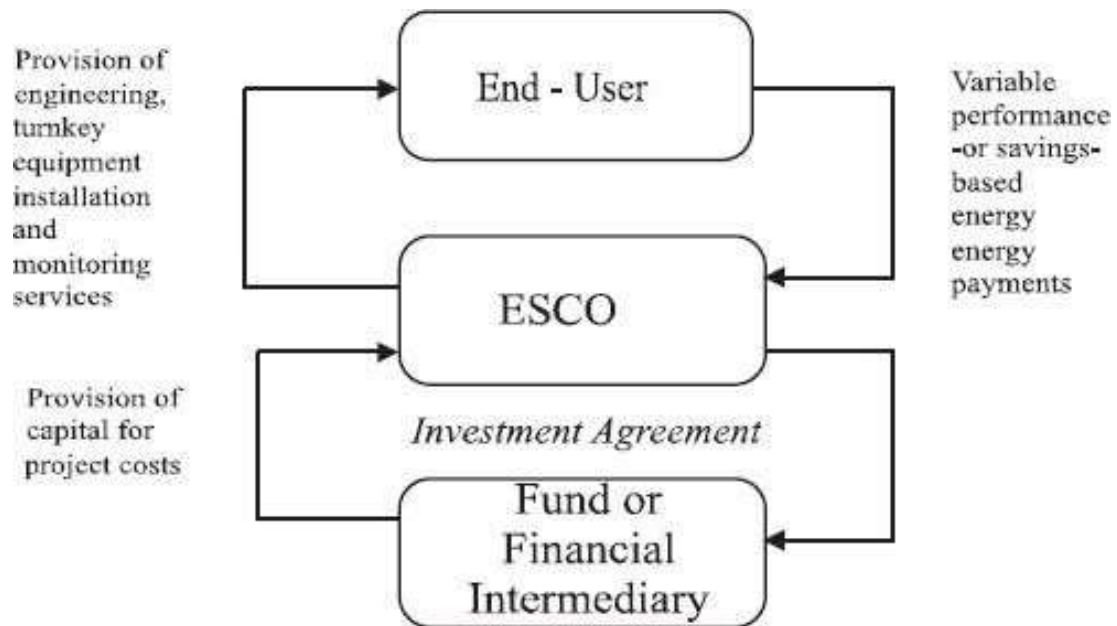


Figure 6.2 Role of ESCO