7. COGENERATION

Syllabus

Cogeneration: Definition, Need, Application, Advantages, Classification, Saving potentials

7.1 Need for Cogeneration

Thermal power plants are a major source of electricity supply in India. The conventional method of power generation and supply to the customer is wasteful in the sense that only about a third of the primary energy fed into the power plant is actually made available to the user in the form of electricity (Figure 7.1). In conventional power plant, efficiency is only 35% and remaining 65% of energy is lost. The major source of loss in the conversion process is the heat rejected to the surrounding water or air due to the inherent constraints of the different thermodynamic cycles employed in power generation. Also further losses of around 10–15% are associated with the transmission and distribution of electricity in the electrical grid.

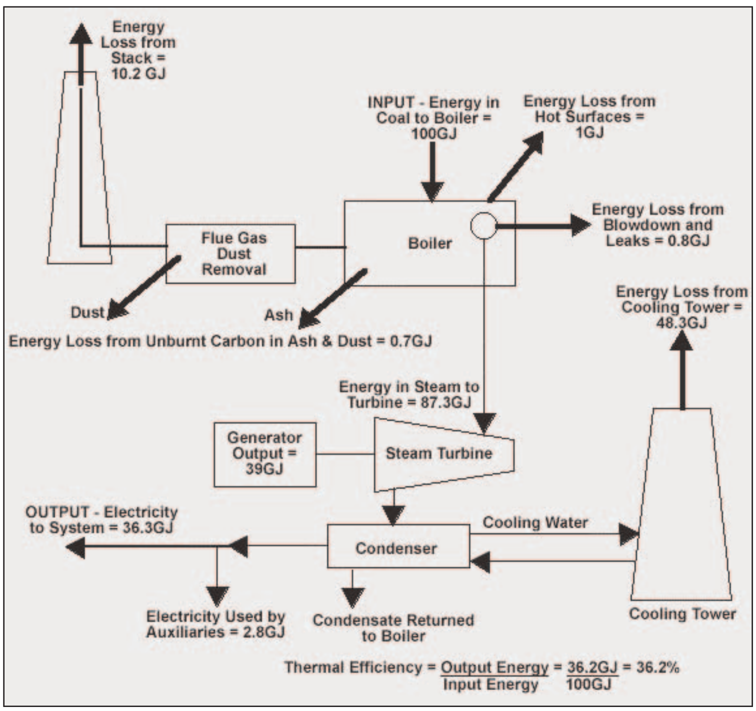


Figure 7.1 BALANCE IN TYPICAL COAL FIRED POWER STATION For an Input Energy of 100 Giga Joules (GJ)

7.2 Principle of Cogeneration

Cogeneration or Combined Heat and Power (CHP) is defined as the sequential generation of two different forms of useful energy from a single primary energy source, typically mechanical energy and thermal energy. Mechanical energy may be used either to drive an alternator for producing electricity, or rotating equipment such as motor, compressor, pump or fan for delivering various services. Thermal energy can be used either for direct process applications or for indirectly producing steam, hot water, hot air for dryer or chilled water for process cooling.

Cogeneration provides a wide range of technologies for application in various domains of economic activities. The overall efficiency of energy use in cogeneration mode can be up to 85 per cent and above in some cases.

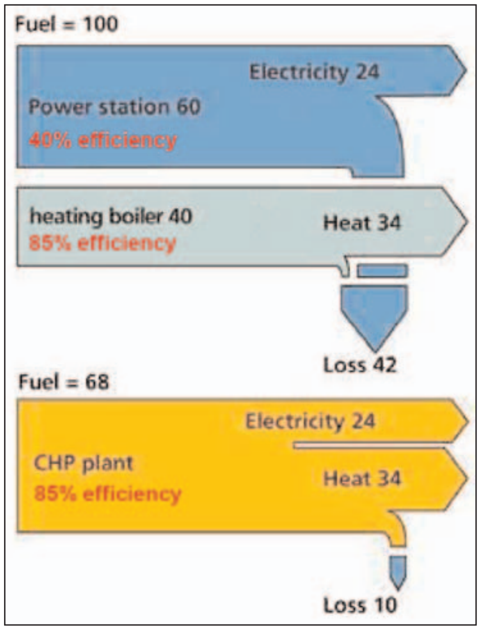


Figure 7.2 Cogeneration Advantage

For example in the scheme shown in Figure 7.2, an industry requires 24 units of electrical energy and 34 units of heat energy. Through separate heat and power route the primary energy input in power plant will be 60 units (24/0.40). If a separate boiler is used for steam generation then the fuel input to boiler will be 40 units (34/0.85). If the plant had cogeneration then the fuel input will be only 68 units (24+34)/0.85 to meet both electrical and thermal energy requirements. It can be observed that the losses, which were 42 units in the case of, separate heat and power has reduced to 10 units in cogeneration mode.

Along with the saving of fossil fuels, cogeneration also allows to reduce the emission of greenhouse gases (particularly CO_2 emission). The production of electricity being on-site, the burden on the utility network is reduced and the transmission line losses eliminated.

Cogeneration makes sense from both macro and micro perspectives. At the macro level, it allows a part of the financial burden of the national power utility to be shared by the private sector; in addition, indigenous energy sources are conserved. At the micro level, the overall energy bill of the users can be reduced, particularly when there is a simultaneous need for both power and heat at the site, and a rational energy tariff is practiced in the country.

7.3 Technical Options for Cogeneration

Cogeneration technologies that have been widely commercialized include extraction/back pressure steam turbines, gas turbine with heat recovery boiler (with or without bottoming steam turbine) and reciprocating engines with heat recovery boiler.

7.3.1 Steam Turbine Cogeneration systems

The two types of steam turbines most widely used are the backpressure and the extraction-Another variation of the steam turbine topping cycle cogeneration system is the extraction-back pressure turbine that can be employed where the end-user needs thermal energy at two different temperature levels. The full-condensing steam turbines are usually incorporated at sites where heat rejected from the process is used to generate power.

The specific advantage of using steam turbines in comparison with the other prime movers is the option for using a wide variety of conventional as well as alternative fuels such as coal, natural gas, fuel oil and biomass. The power generation efficiency of the emand for electricity is greater than one MW up to a few hundreds of MW. Due to the system inertia, their operation is not suitable for sites with intermittent energy demand.

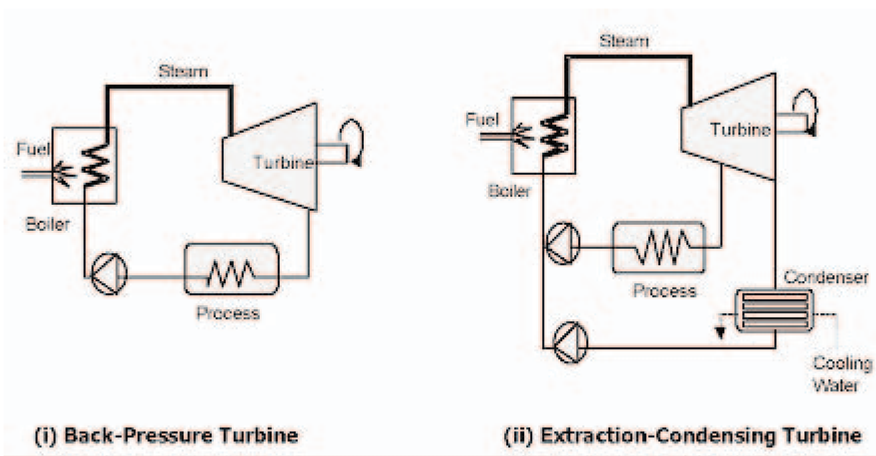


Figure 7.3 Schematic Diagrams of Steam Turbine Cogeneration Systems

7.3.2 Gasturbine Cogeneration Systems

Gas turbine cogeneration systems can produce all or a part of the energy requirement of the site, and the energy released at high temperature in the exhaust stack can be recovered for various heating and cooling applications (see Figure 7.4). Though natural gas is most commonly used, other fuels such as light fuel oil or diesel can also be employed. The typical range of gas turbines varies from a fraction of a MW to around 100 MW.

Gas turbine cogeneration has probably experienced the most rapid development in the recent years due to the greater availability of natural gas, rapid progress in the technology, significant reduction in installation costs, and better environmental performance. Furthermore, the gestation period for developing a project is shorter and the equipment can be delivered in a modular manner. Gas turbine has a short start-up time and provides the flexibility of intermittent operation. Though it has a low heat to power conversion efficiency, more heat can be recovered at higher temperatures. If the heat output is less than that required by the user, it is possible to have supplementary natural gas firing by mixing additional fuel to the oxygen-rich exhaust gas to boost the thermal output more efficiently.

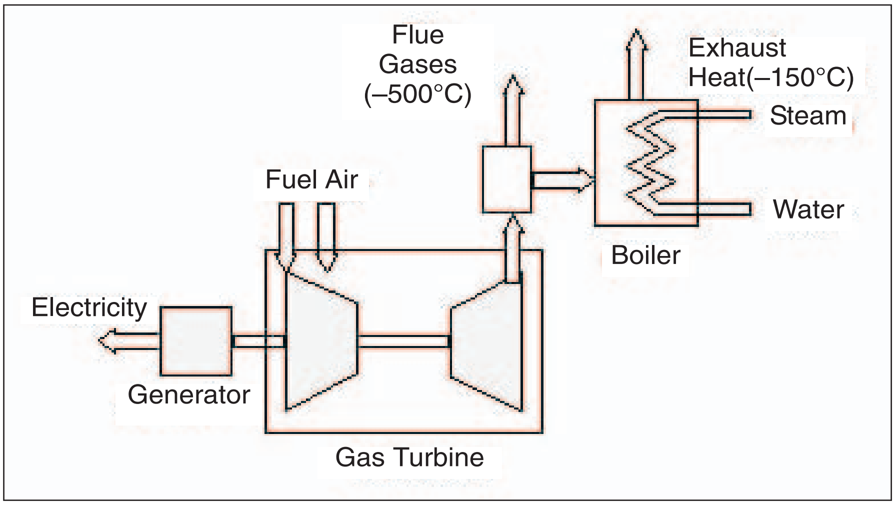


Figure 7.4 Schematic Diagram of Gas Turbine Cogeneration

On the other hand, if more power is required at the site, it is possible to adopt a combined cycle that is a combination of gas turbine and steam turbine cogeneration. Steam generated from the exhaust gas of the gas turbine is passed through a backpressure or extraction-condensing steam turbine to generate additional power. The exhaust or the extracted steam from the steam turbine provides the required thermal energy.

7.3.3 Reciprocating Engine Cogeneration Systems

Also known as internal combustion (I. C.) engines, these cogeneration systems have high power generation efficiencies in comparison with other prime movers. There are two sources of heat for recovery: exhaust gas at high temperature and engine jacket cooling water system at low temperature (see Figure 7.5). As heat recovery can be quite efficient for smaller systems, these systems are more popular with smaller energy consuming facilities, particularly those having a greater need for electricity than thermal energy and where the quality of heat required is not high, e.g. low pressure steam or hot water.

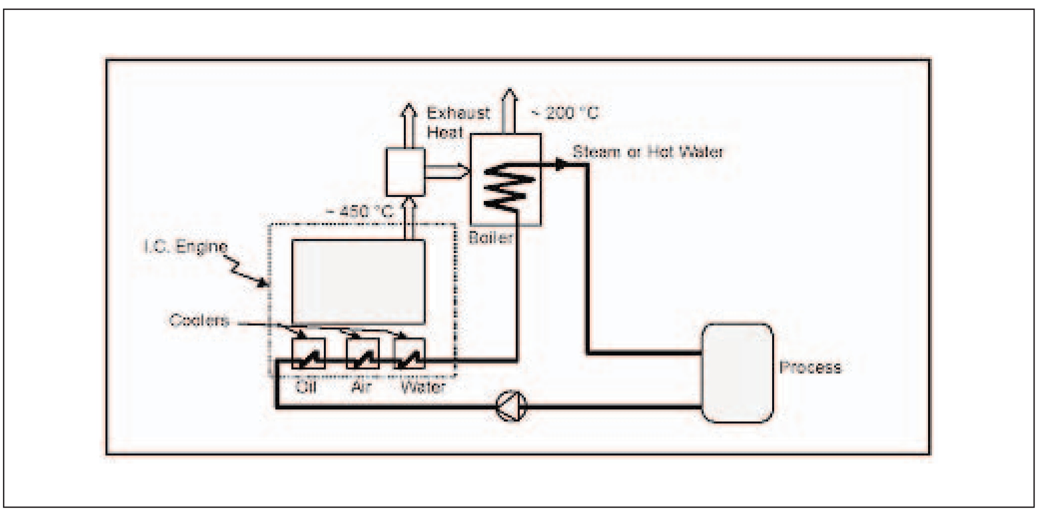


Figure 7.5 Schematic Diagram of Reciprocating Engine Cogeneration

Though diesel has been the most common fuel in the past, the prime movers can also operate with heavy fuel oil or natural gas. These machines are ideal for intermittent operation and their performance is not as sensitive to the changes in ambient temperatures as the gas turbines. Though the initial investment on these machines is low, their operating and maintenance costs are high due to high wear and tear.

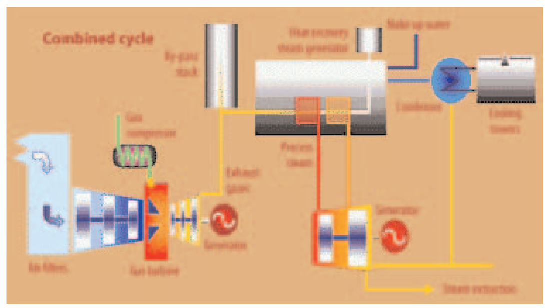
7.4 Classification of Cogeneration Systems

Cogeneration systems are normally classified according to the sequence of energy use and the operating schemes adopted.

A cogeneration system can be classified as either a topping or a bottoming cycle on the basis of the sequence of energy use. In a topping cycle, the fuel supplied is used to first produce power and then thermal energy, which is the by-product of the cycle and is used to satisfy process heat or other thermal requirements. Topping cycle cogeneration is widely used and is the most popular method of cogeneration.

Topping Cycle

The four types of topping cycle cogeneration systems are briefly explained in Table 7.1.

<table>
<tr><th colspan="2">TABLE 7.1 TYPES OF TOPPING CYCLES</th></tr>
<tr><td>A gas turbine or diesel engine producing electrical or mechanical power followed by a heat recovery boiler to create steam to drive a secondary steam turbine. This is called a combined-cycle topping system.</td><td>
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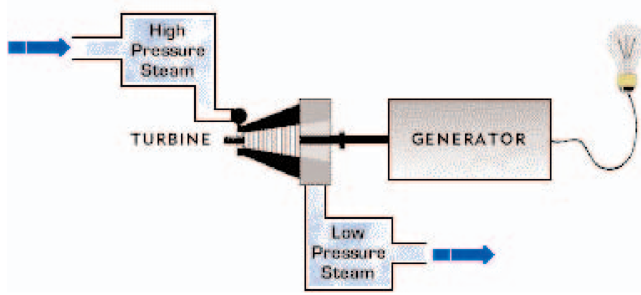
<tr><td>The second type of system burns fuel (any type) to produce high-pressure steam that then passes through a steam turbine to produce power with the exhaust provides low-pressure process steam. This is a steam-turbine topping system.</td><td>
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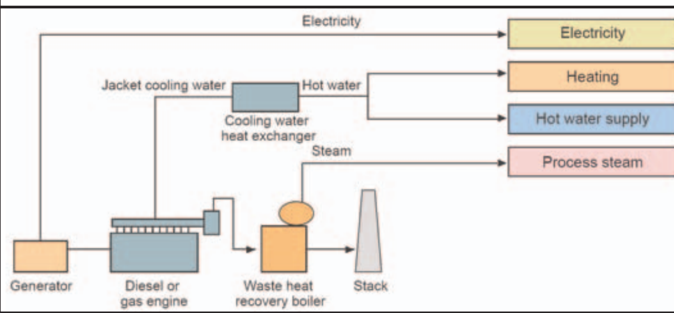
<tr><td>A third type employs heat recovery from an engine exhaust and/or jacket cooling system flowing to a heat recovery boiler, where it is converted to process steam / hot water for further use.</td><td>
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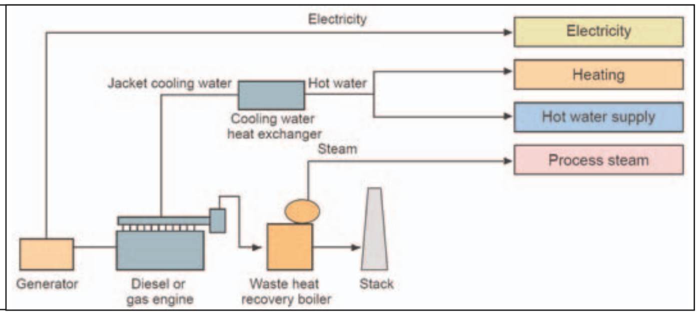
The fourth type is a gas-turbine topping system. A natural gas turbine drives a generator. The exhaust gas goes to a heat recovery boiler that makes process steam and process heat



Bottoming Cycle

In a bottoming cycle, the primary fuel produces high temperature thermal energy and the heat rejected from the process is used to generate power through a recovery boiler and a turbine generator. Bottoming cycles are suitable for manufacturing processes that require heat at high temperature in furnaces and kilns, and reject heat at significantly high temperatures. Typical areas of application include cement, steel, ceramic, gas and petrochemical industries. Bottoming cycle plants are much less common than topping cycle plants. The Figure 7.6 illustrates the bottoming cycle where fuel is burnt in a furnace to produce synthetic rutile. The waste gases coming out of the furnace is utilized in a boiler to generate steam, which drives the turbine to produce electricity.

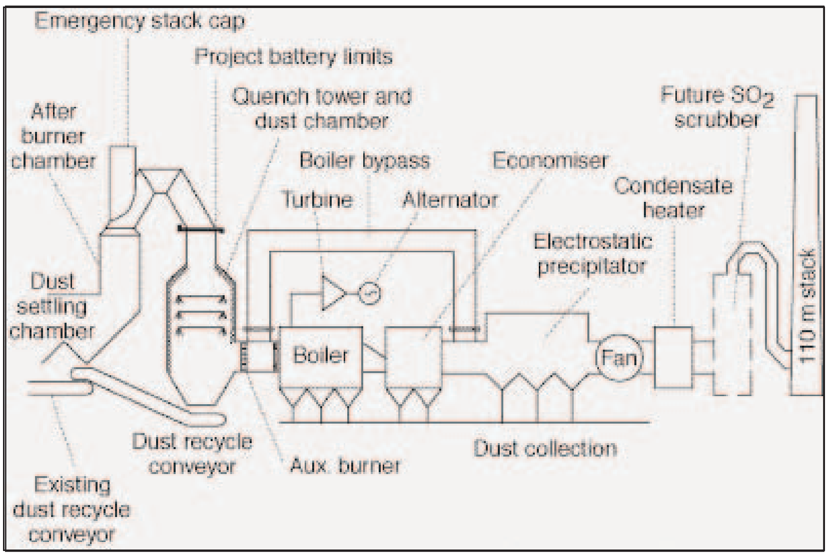


Figure 7.6 Bottoming Cycle

7.5 Factors Influencing Cogeneration Choice

The selection and operating scheme of a cogeneration system is very much site-specific and depends on several factors, as described below:

7.5.1 Base electrical load matching

In this configuration, the cogeneration plant is sized to meet the minimum electricity demand of the site based on the historical demand curve. The rest of the needed power is purchased from the utility grid. The thermal energy requirement of the site could be met by the cogeneration system alone or by additional boilers. If the thermal energy generated with the base electrical load exceeds the plant's demand and if the situation permits, excess thermal energy can be exported to neighbouring customers.

7.5.2 Base Thermal Load Matching

Here, the cogeneration system is sized to supply the minimum thermal energy requirement of the site. Stand-by boilers or burners are operated during periods when the demand for heat is higher. The prime mover installed operates at full load at all times. If the electricity demand of the site exceeds that which can be provided by the prime mover, then the remaining amount can be purchased from the grid. Likewise, if local laws permit, the excess electricity can be sold to the power utility.

7.5.3 Electrical Load Matching

In this operating scheme, the facility is totally independent of the power utility grid. All the power requirements of the site, including the reserves needed during scheduled and unscheduled maintenance, are to be taken into account while sizing the system. This is also referred to as a "stand-alone" system. If the thermal energy demand of the site is higher than that generated by the cogeneration system, auxiliary boilers are used. On the other hand, when the thermal energy demand is low, some thermal energy is wasted. If there is a possibility, excess thermal energy can be exported to neighbouring facilities.

7.5.4 Thermal Load Matching

The cogeneration system is designed to meet the thermal energy requirement of the site at any time. The prime movers are operated following the thermal demand. During the period when the electricity demand exceeds the generation capacity, the deficit can be compensated by power purchased from the grid. Similarly, if the local legislation permits, electricity produced in excess at any time may be sold to the utility.

7.6 Important Technical Parameters for Cogeneration

While selecting cogeneration systems, one should consider some important technical parameters that assist in defining the type and operating scheme of different alternative cogeneration systems to be selected.

7.6.1 Heat-to-Power Ratio

Heat-to-power ratio is one of the most important technical parameters influencing the selection of the type of cogeneration system. The heat-to-power ratio of a facility should match with the characteristics of the cogeneration system to be installed.

It is defined as the ratio of thermal energy to electricity required by the energy consuming facility. Though it can be expressed in different units such as Btu/kWh, kCal/kWh, lb./hr/kW, etc., here it is presented on the basis of the same energy unit (kW).

Basic heat-to-power ratios of the different cogeneration systems are shown in Table 7.2 along with some technical parameters. The steam turbine cogeneration system can offer a large range of heat-to-power ratios.

TABLE 7.2 HEAT-TO-POWER RATIOS AND OTHER PARAMETERS OF COGENERATION SYSTEMS

Cogeneration System	**Heat-to-power ratio** (kW_{th}/kW_e)	**Power output** (as percent of fuel input)	**Overall efficiency** per cent
Back-pressure steam turbine	4.0-14.3	14-28	84-92
Extraction-condensing steam turbine	2.0-10.0	22-40	60-80
Gas turbine	1.3-2.0	24-35	70-85
Combined cycle	1.0-1.7	34-40	69-83
Reciprocating engine	1.1-2.5	33-53	75-85

Cogeneration uses a single process to generate both electricity and usable heat or cooling. The proportions of heat and power needed (heat: power ratio) vary from site to site, so the type of plant must be selected carefully and appropriate operating schemes must be established to match demands as closely as possible. The plant may therefore be set up to supply part or all of the site heat and electricity loads, or an excess of either may be exported if a suitable customer is available. The following Table 7.3 shows typical heat: power ratios for certain energy intensive industries:

TABLE 7.3 TYPICAL HEAT: POWER RATIOS FOR CERTAIN ENERGY INTENSIVE INDUSTRIES

Industry	**Minimum**	**Maximum**	**Average**
Breweries	1.1	4.5	3.1
Pharmaceuticals	1.5	2.5	2.0
Fertilizer	0.8	3.0	2.0
Food	0.8	2.5	1.2
Paper	1.5	2.5	1.9

Cogeneration is likely to be most attractive under the following circumstances:

(a) The demand for both steam and power is balanced i.e. consistent with the range of steam: power output ratios that can be obtained from a suitable cogeneration plant.

(b) A single plant or group of plants has sufficient demand for steam and power to permit economies of scale to be achieved.

(c) Peaks and troughs in demand can be managed or, in the case of electricity, adequate backup supplies can be obtained from the utility company.

The ratio of heat to power required by a site may vary during different times of the day and seasons of the year. Importing power from the grid can make up a shortfall in electrical output from the cogeneration unit and firing standby boilers can satisfy additional heat demand.

Many large cogeneration units utilize supplementary or boost firing of the exhaust gases in order to modify the heat: power ratio of the system to match site loads.

7.6.2 Quality of Thermal Energy Needed

The quality of thermal energy required (temperature and pressure) also determines the type of cogeneration system. For a sugar mill needing thermal energy at about 120°C, a topping cycle cogeneration system can meet the heat demand. On the other hand, for a cement plant requiring thermal energy at about 1450°C, a bottoming cycle cogeneration system can meet both high quality thermal energy and electricity demands of the plant.

7.6.3 Load Patterns

The heat and power demand patterns of the user affect the selection (type and size) of the cogeneration system. For instance, the load patterns of two energy consuming facilities shown in Figure 7.7 would lead to two different sizes, possibly types also, of cogeneration systems.

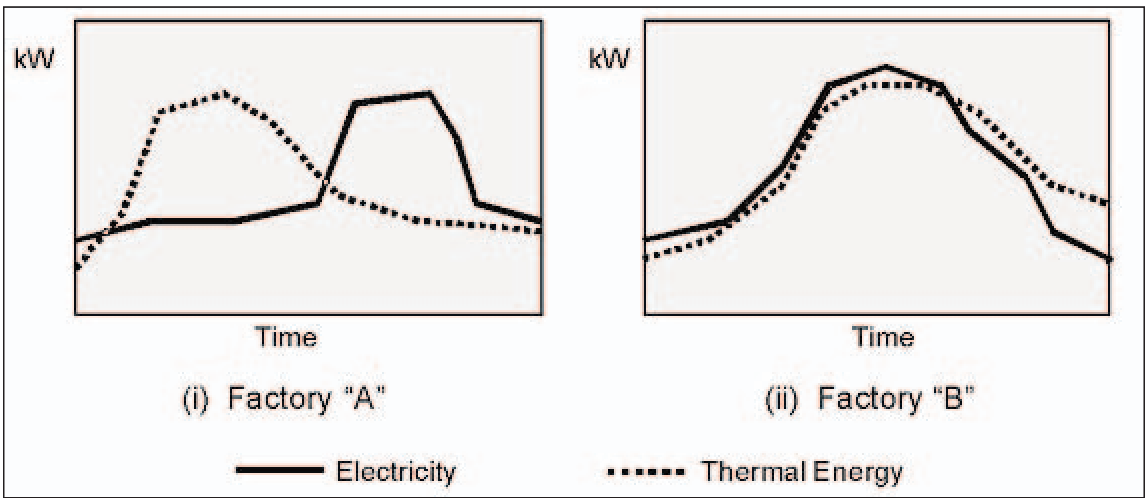


Figure 7.7 Different Heat and Power Demand Patterns in two Factories

7.6.4 Fuels Available

Depending on the availability of fuels, some potential cogeneration systems may have to be rejected. The availability of cheap fuels or waste products that can be used as fuels at a site is one of the major factors in the technical consideration because it determines the competitiveness of the cogeneration system.

A rice mill needs mechanical power for milling and heat for paddy drying. If a cogeneration system were considered, the steam turbine system would be the first priority because it can use the rice husk as the fuel, which is available as waste product from the mill.

7.6.5 System Reliability

Some energy consuming facilities require very reliable power and/or heat; for instance, a pulp and paper industry cannot operate with a prolonged unavailability of process steam. In such instances, the cogeneration system to be installed must be modular, i.e. it should consist of more than one unit so that shut down of a specific unit cannot seriously affect the energy supply.

7.6.6 Grid Dependent System Versus Independent System

A grid-dependent system has access to the grid to buy or sell electricity. The grid-independent system is also known as a "stand-alone" system that meets all the energy demands of the site. It is obvious that for the same energy consuming facility, the technical configuration of the cogeneration system designed as a grid dependent system would be different from that of a stand-alone system.

7.6.7 Retrofit Versus New Installation

If the cogeneration system is installed as a retrofit, the system must be designed so that the existing energy conversion systems, such as boilers, can still be used. In such a circumstance, the options for cogeneration system would depend on whether the system is a retrofit or a new installation.

7.6.8 Electricity Buy-back

The technical consideration of cogeneration system must take into account whether the local regulations permit electric utilities to buy electricity from the cogenerators or not. The size and type of cogeneration system could be significantly different if one were to allow the export of electricity to the grid.

7.6.9 Local Environmental Regulation

The local environmental regulations can limit the choice of fuels to be used for the proposed cogeneration systems. If the local environmental regulations are stringent, some available fuels cannot be considered because of the high treatment cost of the polluted exhaust gas and in some cases, the fuel itself.

7.7 Prime Movers for Cogeneration

7.7.1 Steam Turbine

Steam turbines (Figure 7.8) are the most commonly employed prime movers for cogeneration applications In the steam turbine, the incoming high pressure steam is expanded to a lower pressure level, converting the thermal energy of high pressure steam to kinetic energy through nozzles and then to mechanical power through rotating blades.

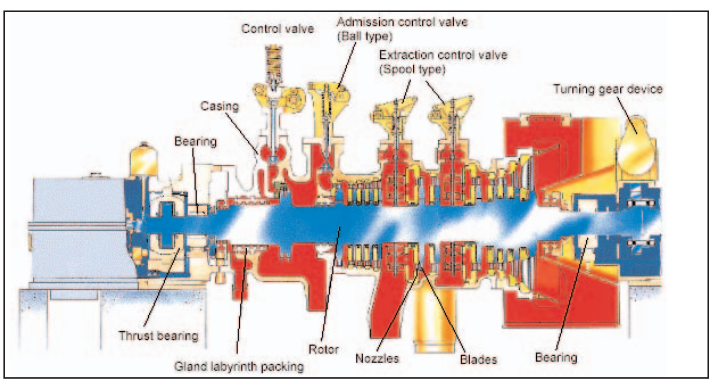


Figure 7.8 Steam Turbine

Back Pressure turbine: In this type steam enters the turbine chamber at High Pressure and expands to Low or Medium Pressure. Enthalpy difference is used for generating power / work.

Depending on the pressure (or temperature) levels at which process steam is required, backpressure steam turbines can have different configurations as shown in Figure 7.9.

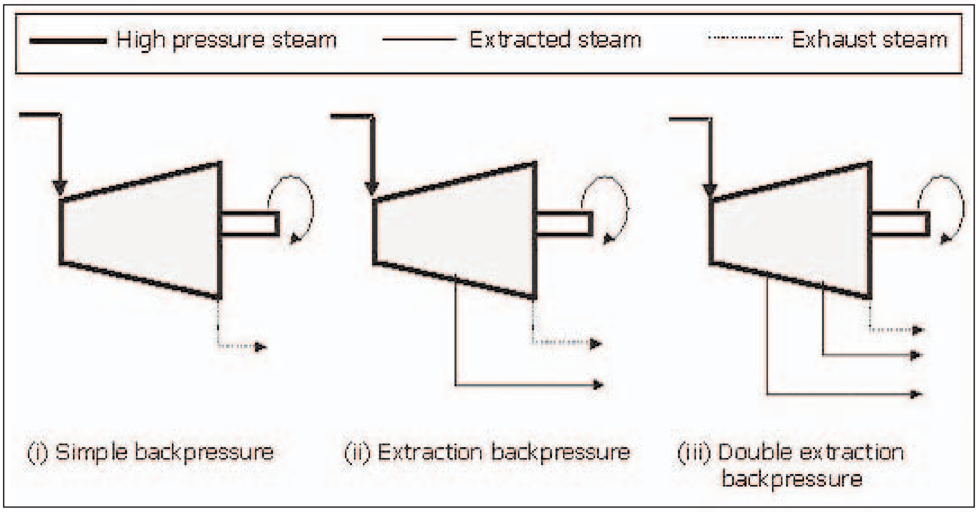


Figure 7.9 Different Configurations for Back Pressure Steam Turbines

In extraction and double extraction backpressure turbines, some amount of steam is extracted from the turbine after being expanded to a certain pressure level. The extracted steam meets the heat demands at pressure levels higher than the exhaust pressure of the steam turbine.

The efficiency of a backpressure steam turbine cogeneration system is the highest. In cases where 100 per cent backpressure exhaust steam is used, the only inefficiencies are gear drive and electric generator losses, and the inefficiency of steam generation. Therefore, with an efficient boiler, the overall thermal efficiency of the system could reach as much as 90 per cent.

Extraction Condensing turbine: In this type, steam entering at High / Medium Pressure is extracted at an intermediate pressure in the turbine for process use while the remaining steam continues to expand and condenses in a surface condenser and work is done till it reaches the Condensing pressure.(vacuum).

In Extraction cum Condensing steam turbine as shown in Figure 7.10, high Pressure steam enters the turbine and passes out from the turbine chamber in stages. In a two stage extraction cum condensing turbine MP steam and LP steam pass out to meet the process needs. Balance quantity condenses in the surface condenser. The Energy difference is used for generating Power. This configuration meets the heat-power requirement

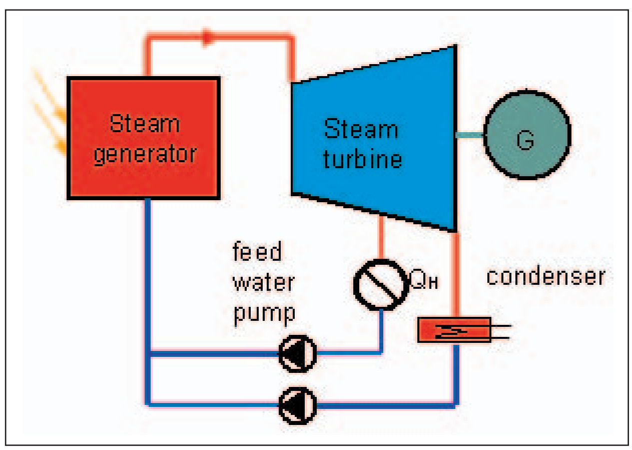


Figure 7.10 Extraction Condensing Turbine

of the process.

The extraction condensing turbines have higher power to heat ratio in comparison with back-pressure turbines. Although condensing systems need more auxiliary equipment such as the condenser and cooling towers, better matching of electrical power and heat demand can be obtained where electricity demand is much higher than the steam demand and the load patterns are highly fluctuating.

The overall thermal efficiency of an extraction condensing turbine cogeneration system is lower than that of back pressure turbine system, basically because the exhaust heat cannot be utilized (it is normally lost in the cooling water circuit). However, extraction condensing cogeneration systems have higher electricity generation efficiencies

7.7.2 Gas Turbine

The fuel is burnt in a pressurized combustion chamber using combustion air supplied by a compressor that is integral with the gas turbine. In conventional Gas turbine (Figure 7.11), gases enter the turbine at a temperature range of 900 to 1000°C and leave at 400 to 500°C. The very hot pressurized gases are used to turn a series of turbine blades, and the shaft on which they are mounted, to produce mechanical energy. Residual energy in the form of a high flow of hot exhaust gases can be used to meet, wholly or partly, the thermal (steam) demand of the site. Waste gases are exhausted from the turbine at 450°C to 550°C, making the gas turbine particularly suitable for high-grade heat supply.

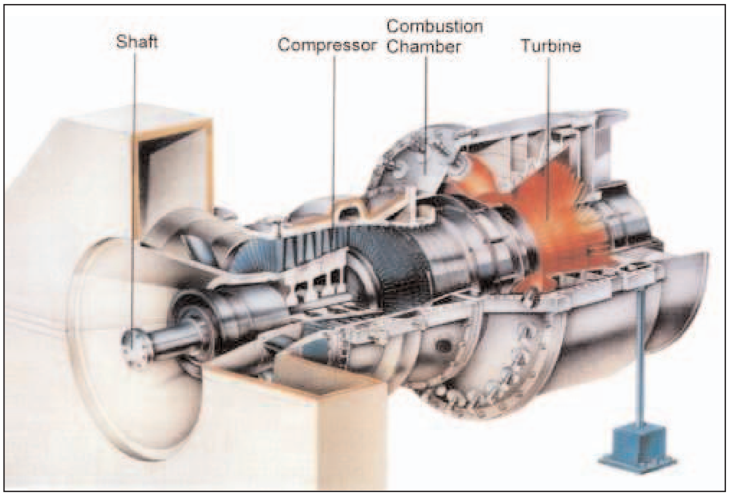


Figure 7.11 Gas Turbine

The available mechanical energy can be applied in the following ways:

- to produce electricity with a generator (most applications);
- to drive pumps, compressors, blowers, etc.

A gas turbine operates under exacting conditions of high speed and high temperature. The hot gases supplied to it must therefore be clean (i.e. free of particulates which would erode the blades) and must contain not more than minimal amounts of contaminants, which would cause corrosion under operating conditions. High-premium fuels are therefore most often used, particularly natural gas. Distillate oils such as gas oil are also suitable, and sets capable of using both are often installed to take advantage of cheaper interruptible gas tariffs. LPGs and Naphtha are also suitable, LPG being a possible fuel in either gaseous or liquid form.

Gas Turbine Efficiency

Turbine Efficiency is the ratio of actual work output of the turbine to the net input energy supplied in the form of fuel. For stand alone Gas Turbines, without any heat recovery system the efficiency will be as low as 35 to 40%. This is attributed to the blade efficiency of the rotor, leakage through clearance spaces, friction, irreversible turbulence etc.

Since Exhaust gas from the Gas Turbine is high, it is possible to recover energy from the hot gas by a Heat Recovery Steam Generator and use the steam for process.

Net Turbine Efficiency

Above efficiency figures did not include the energy consumed by air compressors, fuel pump and other auxiliaries. Air compressor alone consumes about 50 to 60% of energy generated by the turbine. Hence net turbine efficiency, which is the actual energy output available will be less than what has been calculated. In most Gas Turbine plants, air compressor is an integral part of Turbine plant.

7.7.3 Reciprocating Engine Systems

This system provides process heat or steam from engine exhaust. The engine jacket cooling water heat exchanger and lube oil cooler may also be used to provide hot water or hot air. There are, however, limited applications for this.

As these engines can use only fuels like HSD, distillate, residual oils, natural gas, LPG etc. and as they are not economically better than steam/gas turbine, their use is not widespread for co-generation. One more reason for this is the engine maintenance requirement.

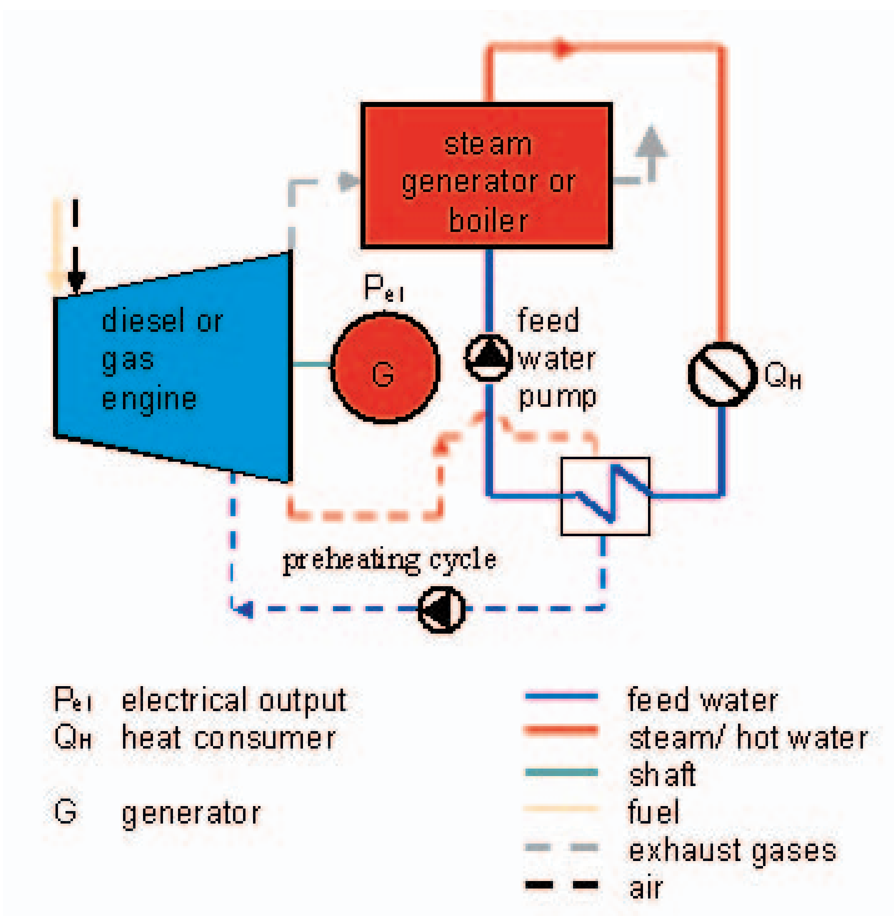


Figure 7.12

7.8 Typical Cogeneration Performance Parameters

The following Table 7.4 gives typical Cogeneration Performance Parameters for different Cogeneration Packages giving heat rate, overall efficiencies etc.

TABLE 7.4 TYPICAL COGENERATION PERFORMANCE PARAMETERS

Prime Mover in Cogen. Package	Nominal Range (Electrical)	Electrical Generation Heat Rate (kCal / kWh	Efficiencies, %		
			Electrical Conversion	Thermal Recovery	Overall Cogeneration
Smaller Reciprocating Engines	10–500 kW	2650–6300	20–32	50	74–82
Larger Reciprocating Engines	500–3000 kW	2400–3275	26–36	50	76–86
Diesel Engines	10–3000 kW	2770–3775	23–38	50	73–88
Smaller Gas Turbines	800–10000 kW	2770–3525	24–31	50	74–81
Larger Gas Turbines	10–20 MW	2770–3275	26–31	50	78–81
Steam Turbines	10–100 MW	2520–5040	17–34	–	–

Note: Adapted from Cogeneration Handbook California Energy Commission, 1982

7.9 Relative Merits of Cogeneration Systems

The following Table 7.5 gives the advantages and disadvantages of various co-generation systems:

TABLE7.5 ADVANTAGES AND DISADVANTAGES OF VARIOUS COGENERATION SYSTEMS

Variant	Advantages	Disadvantages
Back pressure	– High fuel efficiency rating	– Little flexibility in design and operation
Steam turbine & fuel firing in boiler	– Simple plant – Well-suited to low quality fuels	– More capital investment – Low fuel efficiency rating – High cooling water demand – More impact on environment High civil const. cost due to complicated foundations
Gas turbine with waste heat recovery boiler	– Good fuel efficiency – Simple plant – Low civil const. Cost – Less delivery period	– Moderate part load efficiency – Limited suitability for low quality fuels

	– Less impact on environment – High flexibility in operation	
Combined gas & steam turbine with waste heat recovery boiler	– Optimum fuel efficiency rating – Low relative capital cost – Less gestation period – Quick start up & stoppage – Less impact on environment – High flexibility in operation	– Average to moderate part-load efficiency – Limited suitability for low quality fuels
Diesel Engine & waste heat recovery Boiler & cooling water heat exchanger	– Low civil const. Cost due to block foundations & least no. of auxiliaries – High Power efficiency – Better suitability as stand by power source	– Low overall efficiency – Limited suitability for low quality fuels – Availability of low temperature steam – Highly maintenance prone.

7.10 Case Study

Economics of a Gas Turbine based co-generation System

Alternative I – Gas Turbine Based Co-generation

<u>Gas turbine Parameters</u>

Capacity of gas turbine generator	:	4000 kW
Plant operating hours per annum	:	8000 hrs.
Plant load factor	:	90 %
Heat rate as per standard given by gas.turbine supplier	:	3049.77 kCal / kWh
Waste heat boiler parameters – unfired steam output	:	10 TPH
Steam temperature	:	200 °C
Steam pressure	:	8.5 kg /cm_2.
Steam enthalpy	:	676.44 kCal / Kg.
Fuel used	:	Natural gas
Calorific value – LCV	:	9500 kCal/ sm_3
Price of gas	:	Rs 3000 /1000 sm_3
Capital investment for total co-generation plant	:	Rs. 1300 Lakhs

Cost Estimation of Power & Steam From Cogeneration Plant

1. Estimated power generation from Cogeneration plant at 90% Plant Load Factor (PLF)	:	PLF × Plant Capacity × no. of operation hours (90/100)×4000×8000 288.00×10^5 kWh per annum
2. Heat input to generate above units	:	Units (kWh) × heat rate $288 \times 10^5 \times 3049.77$ 878333.76×10^5 kCal
3. Natural gas quantity required per annum	:	Heat input / Calorific value (LCV) of natural gas
	:	878333.76×10^5 / 9500

4. Cost of fuel per annum	:	92.46 × 105 sm_3 Annual gas consumption. × Price 92.46 × 10^5× Rs.3000./1000 sm_3 Rs. 277.37 lakhs
5. Cost of capital and operation charges/annum	:	Rs. 298.63. lakhs
6. Overall cost of power from cogeneration Plant	:	Rs. 576.00.lakhs per annum
7. Cost of power	:	Rs. 2.00 /kWh

Alternative-II: Electric Power from State Grid & Steam from Natural Gas Fired Boiler

Boiler Installed in Plant:

Cost of electric power from state grid – average electricity cost with demand & energy charges	:	Rs. 3.00/kWh
Capital investment for 10 TPH, 8.5 kg/sq.cm.200)°C Natural gas fired fire tube boiler & all auxiliaries	:	Rs. 80.00 lakh

Estimation of cost for electric power from grid & steam from direct conventional fired boiler:

1. Cost of Power from state grid for 288 lakh kWh	:	Rs. 864.00 lakh per annum
2. Fuel cost for steam by separate boiler		
(i) Heat output in form of 10 TPH steam per annum	:	Steam quantity × Enthalphy × Operations/annum 10 × 1000 × 676.44 × 8000 =541152 × 10^5 kCals
(ii) Heat Input required to generate 10 TPH steam per annum @ 90% efficiency	:	Heat output/boiler efficiency 541152 × 10^5/0.90
Heat Input	:	601280 × 10^5 kCal per annum
(iii) Natural Gas Quantity	:	Heat Input/Calorific

		value (LCV) of natural gas $601280 \times 10^5/9500$ 63.29×10^5 sm_3 per annum
(iv) Cost of fuel per annum	:	Annual gas consumption × price $63.29 \times 10^5 \times 3000$ /1000 sm_3 Rs. 189.88.lakh per annum
(v) Total cost for Alternative-II	:	Cost of grid power + fuel cost for steam Rs. 864 + Rs.189.88 (lakh) Rs. 1053.88 lakh per annum
Alternative I - Total cost	:	Rs. 576.00 lakh
Alternative II - Total cost	:	Rs. 1053.88 lakh
Differential cost	:	Rs. 477.88 lakh

(Note: In case of alternative-II, there will be some additional impact on cost of steam due to capital cost required for a separate boiler).

In the above case, Alternative 1 gas turbine based cogeneration system is economical compared to Alternative 2 i.e. electricity from State Grid and Steam from Natural Gas fired boiler.

QUESTIONS	
1.	Explain what do you mean by cogeneration.
2.	Explain how cogeneration is advantageous over conventional power plant.
3.	What is meant by wheeling?
4.	What is meant by combined cycle cogeneration?
5.	Explain the term topping cycles with examples.
6.	Explain the term bottoming cycles with examples.
7.	Explain the term heat-to-power ratio.
8.	Explain with diagrams cogeneration systems using the back pressure turbine, extraction-condensing turbine and double extraction back pressure turbine.
9.	The efficiency of which of the following is the highest (a) condensing (b) back pressure (c) extraction condensing (d) double extraction condensing
10.	Explain the principle of operation of a steam turbine.
11.	Explain the principle of operation of a gas turbine.
12.	What are the common fuels used in gas turbines?
13.	Clean fuels are used in gas turbines because (a) the operate at high speed and high temperature (b) pollution act requires it (c) combustion would be affected (d) they are inexpensive
14.	The system efficiencies of gas turbine units are (a) 35 to 40% (b) 85 to 90% (c) 75 to 80% (d) 55 to 60%
15.	A heat recovery steam generator is used with (a) gas turbines (b) stem turbines (c) back pressure turbines (d) condensing turbines
16.	List the circumstances under which cogeneration will become attractive.
17.	What are the sources of waste heat in a diesel engine?
18.	Explain how you will go about an energy audit of a steam turbine based fully back pressure cogeneration system.

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