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COGENERATION: ENVIRONMENTALLY SOUND ENERGY EFFICIENT TECHNOLOGY

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ABSTRACT

Energy is the byword of the 80s. The main problems are to be faced for energy, where to find it?, how to get it?, and how to conserve it? Solutions to the problems are numerous and manifold. One solution that is practical now as well as beneficial in the long term is cogeneration. In this article some technical methods of cogeneration and its environmental benefits are discussed. The technologies included in this report include diesel engines, natural gas engines, steam turbines, gas turbines, micro-turbines and fuel cells. In this context, cogeneration presents an important option to meet the demand for electricity and heat in a most cost-effective manner.

KEYWORDS: Steam Turbine Systems, Gas Turbine Systems, Reciprocating Systems, Trigeneration, Electricity Production, Heat to Power Ratio

INTRODUCTION

Electric energy is an essential ingredient for the industrial and all-round development of any country. It can be adapted easily and efficiently to domestic and industrial applications. The per capita consumption of electrical energy is a reliable indicator of a country's state of development. It is around 170 units per annum for India against 9000 units in USA and 4000 units in UK [1]. Power sector in India has grown at a phenomenal rate during the last four decades to meet the rapidly growing demand for electricity as a commercial fuel. Electric utilities have in the past adopted the conventional approach of adding new generating capacities to meet the demand [2]. However, financial constraints aggravated by sub-optimal operations of the existing facilities of power generation and supply have resulted in both energy and peak shortages since mid seventies. Electricity generated can be used to meet the internal electric requirements and thus reduce the demand for utility power and additionally the surplus, if any could be sold to the utilities. Thus it provides an alternative to the conventional utility power and reduces the overall emissions from the power sector [3].

Cogeneration first appeared in late 1880s in Europe and in the U.S.A. during the early parts of the 20th century, when most industrial plants generated their own electricity using coal-fired boilers and steam-turbine generators. Many of the plants used the exhaust steam for industrial processes. It is defined as the production of electric power and other forms of useful energy such as heat or process steam from the same facility [4]. Several of those most directly associated with these energy conserving technique have suggested the definition should be, "Cogeneration is the simultaneously production of two forms of energy e.g. steam and electricity from a single power plant" [5]. Cogeneration is also known as, "in plant generation (IPG)", "by product power", "total energy", "combined heat and power (CHP)" [6-7]. Cogeneration transfers the waste energy from one expended resource driving a single process to two or more. Cogeneration can manifest itself electrically or mechanically [8]. Cogeneration is hardly anything more than an economically sound method for the conservation of resources and pollution mitigation. Conventional power generation on average is only 35% efficient and up to 65 % of the energy potential is released as waste heat. Cogeneration reduces this loss by using heat for industry, commerce and home heating. In conventional electricity generation, further losses of around 5-10% are associated with the transmission and distribution (T&D) of electricity from relatively remote power stations via the electricity grid; but in case of cogeneration the electricity generated is normally used locally thus T&D losses will be negligible. CHP systems can deliver energy with efficiencies exceeding 90%, while significantly reducing emissions per delivered MW [9]. It offers energy savings ranging 15-40% when compared to conventional power stations [4]. In addition to energy conservation, cost savings, cogeneration yields significant environmental benefits through using fossil fuels more efficiently. These are explicitly shown in Figure 1 and Figure 2 respectively.

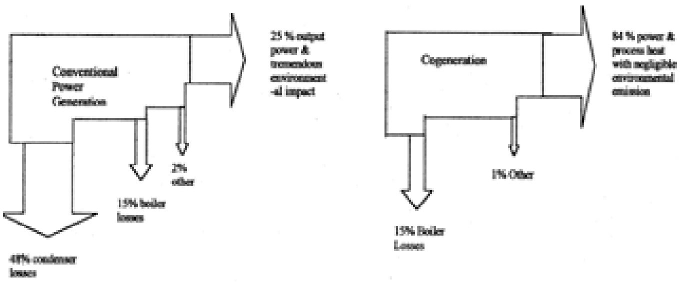

Figure 1: Conventional Versus Cogeneration Power Generation

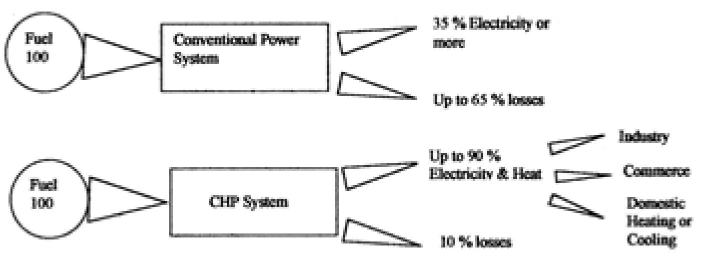

Figure 2: Comparison Between Conventional and CHP Power System

Where is Cogeneration Suitable?

Cogeneration has a long history of user in many types of industry, particularly in the paper and bulk chemicals industries, which have large concurrent heat and power demands. In recent years the greater availability and wider choice of suitable technology has meant that cogeneration has become an attractive and practical proposition for a wide range of applications. These include the process industries, commercial and public sector buildings and district heating schemes, all of which have considerable heat demand. These applications are summarised below:

Industrial

Pharmaceuticals & fine chemicals, paper manufacture, brewing, distilling, malting, ceramics, brick, cement, food processing, textile processing, minerals processing, oil refineries, iron and steel, motor industry, timber processing.

Buildings

District heating, hotels, hospitals, swimming pools, college campus, airports, supermarkets, office buildings, and individual houses. An ideal site for cogeneration has the following characteristics:

- a reliable power requirement;
- relatively steady electrical and thermal demand patterns;
- higher thermal energy demand than electricity;
- long operating hours in the year;
- inaccessibility to the grid or high price of grid electricity

How does Cogeneration Works?

Promotion of heat and power by cogeneration needed, heat power ratio which vary from site to site, so the type of plant must be selected carefully and an appropriate operating regime 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. Cogeneration plant consists of four basic elements; a prime mover, an electricity generator, a heat recovery system, and a control system. Depending on site requirements, the prime mover may be a steam turbine, reciprocating engine or gas turbine and combined cycle (gas and steam turbines). In the future new technology options will include micro-turbines, Stirling engines, and fuel cells.

Benefits of Cogeneration

Provided the cogeneration is optimized in the way described above (i.e. sized according to the heat demand), the following benefits arise:

- Increased efficiency of energy conversion and use.
- Lower emissions to the environment, in particular of CO2, the main greenhouse gases.
- In some cases, where there are biomass fuels and some waste materials such as refinery gases, process or agricultural waste (either anaerobically digested or gasified), these substances can be used as fuels for cogeneration schemes, thus increasing the cost-effectiveness and reducing the need for waste disposal.
- Large cost savings, providing additional competitiveness for industrial and commercial users, and offering affordable heat for domestic users.
- An opportunity to move towards more decentralized forms of electricity generation, where plant is designed to meet the needs of local consumers, providing high efficiency, avoiding transmission losses and increasing flexibility in system use. This will particularly be the case if natural gas is the energy carrier.
- Improved local and general security of supply - local generation, through cogeneration, can reduce the risk that consumers are left without supplies of electricity and/or heating. In addition, the reduced fuel need which cogeneration provides reduces the import dependency.
- An opportunity to increase the diversity of generation plant, and provide competition in generation. Cogeneration provides one of the most important vehicles for promoting liberalization in energy markets

- Increased employment - a number of studies have now concluded that the development of cogeneration systems is a generator of jobs.

COGENERATION TECHNOLOGY

A proper selection of a cogeneration system configuration, from a few basic system configurations described below, makes it feasible to produce first either electrical energy or thermal energy.

- Steam turbine based cogeneration system
- Gas turbine based cogeneration system
- Combined steam/gas turbine based cogeneration system
- Reciprocating engine based cogeneration system

Steam Turbine Cogeneration Systems

The two types of steam turbines most widely used are the backpressure and the extraction-condensing types, as shown in Figure 3. This system works on the principle of Rankine cycle of heat balance. In Rankine cycle, the fuel is first fired in a suitable boiler to generate high-pressure steam at predetermined parameters. The steam so produced is then expanded through a steam turbine to produce mechanical power/ electrical power and a low-pressure steam. The steam turbine could be of backpressure type, extraction-cum-condensed type or extraction-cum-back pressure type depending

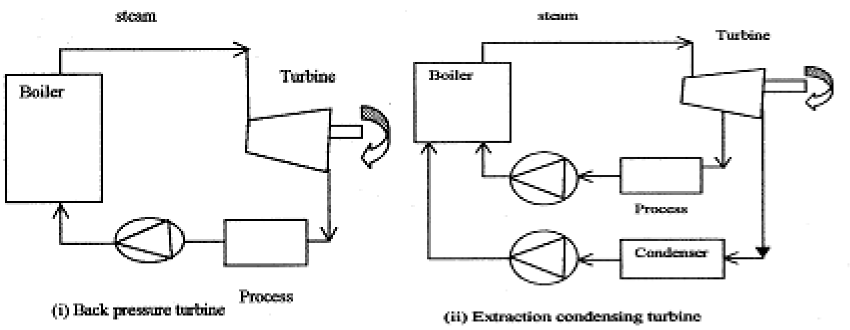

Figure 3: Schematic Diagram of Steam Turbine Cogeneration

On different levels and parameters at which the steam is required by the chemical process in that particular plant. The selection of steam turbine for a particular cogeneration application depends on process steam demand at one or more pressure/temperature levels, the electric load to be driven, power and steam demand variations, essentiality of steam for process, etc. The steam to power ratio also plays a role in selection of the steam turbine. Generation of very high-pressure steam and low back pressure at steam turbine exhaust would result into small steam to power ratio. Smaller value of ratio would indicate the lower utilisation value of steam for heating or process purpose. The flexibility in steam to power ratio can be obtained by using steam turbines with regulated extraction. The specific advan-tage of using Steam turbine based cogeneration systems in comparison with the other prime movers is the option for using a wide variety of fossil fuels like coal, lignite, furnace oil, residual fuel oil, natural gas or non-conventional fuels like bio-gas, bagasse, municipal waste, husk, etc. Hence, the fuel flexibility for this type of system is excellent. However, this configuration is not recommended for smaller installations as it is more expensive and maintenance oriented. It is also not feasible to adopt this system if the chemical industry is located nearer to a populated area, as it becomes a major source of environmental pollution depending upon type of fuel used, i.e. coal, lignite or furnace oil. The power generation efficiency of the cycle may be sacrificed to some extent in order to optimize heat supply. In backpressure cogeneration plants, there is no need for large cooling towers.

Gas Turbine Cogeneration Systems

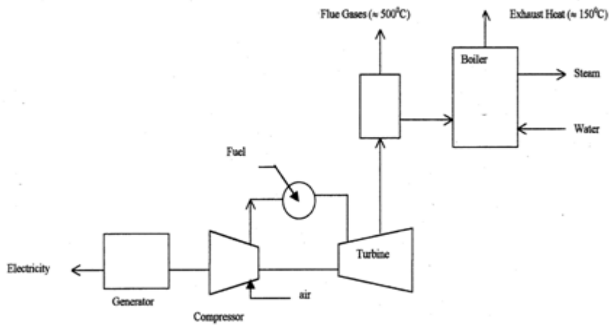

Figure 4: Diagram of Gas Turbine Cogeneration

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, as shown in Figure 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 [10]. 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. 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.

Reciprocating Engine Cogeneration Systems

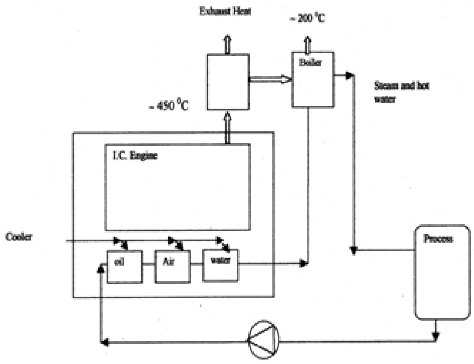

Figure 5: Reciprocating Engine Cogeneration System

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, as shown in Figure 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. Though diesel has been the most common fuel in the past, the prime movers can also operate with heavy fuel oil or natural gas. In urban areas where natural gas distribution network is in place, gas engines are finding wider application due to the ease of fuel handling and cleaner emissions from the engine exhaust. 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.

Trigeneration and Vapour Absorption Cooling

A typical trigeneration facility consists of a cogeneration plant, and a vapour absorption chiller, which produces cooling by making use of some of the heat, recovered from the cogeneration system, as shown in Figure 6. Trigeneration is the concept of deriving three different forms of energy from the primary energy source, namely, heating, cooling and power generation. Also referred to as CHCP (combined heating, cooling and power generation), this option allows having greater operational flexibility at sites with demand for energy in the form of heating as well as cooling. This is particularly relevant in tropical countries like India, where buildings need to be air-conditioned and many industries require process cooling. Although cooling can be provided by conventional vapour compression chillers driven by electricity, low quality heat (i.e. low temperature, low pressure) exhausted from the cogeneration plant can drive the absorption chillers so that the overall primary energy consumption is reduced. Absorption chillers have recently gained widespread acceptance due to their capability of not only integrating with cogeneration systems but also because they can operate with industrial waste heat streams. The benefit of power generation and absorption cooling can be realized through the following example that compares it with a power generation system with conventional vapour compression system.

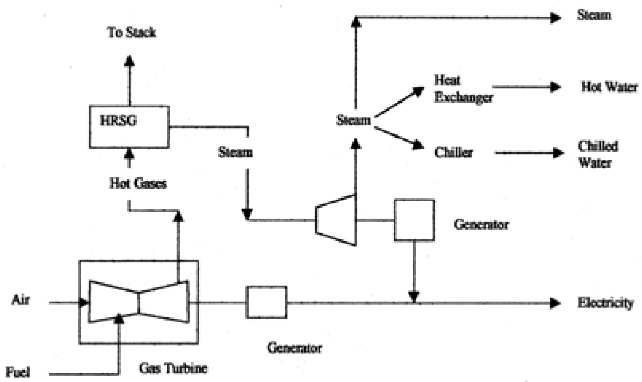

Figure 6: Gas Turbine Based Trigeneration Facility

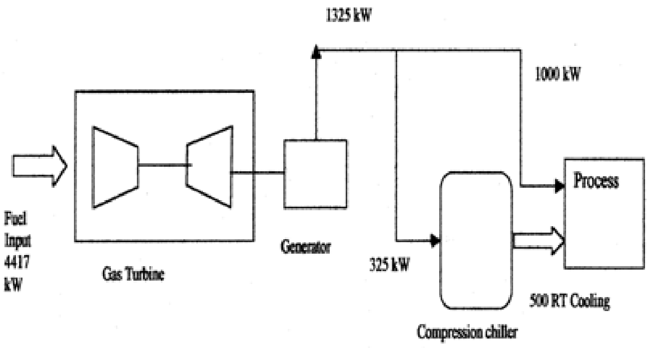

Figure 7: Power Generation and Cooling with Electricity

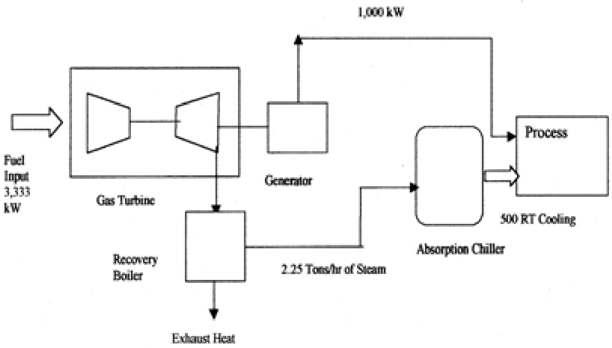

Figure 8: Power Generation and Absorption Cooling

A factory needs 1 MW of electricity and 500 refrigeration tons (RT). Let us first consider the gas turbine that generates electricity required for the processes as well as the conventional vapour compression chiller. Assuming an electricity demand of 0.65 kW / RT, the compression chiller needs 325 kW of electricity to obtain 500 RT of cooling. Hence, a total of 1325 kW of electricity must be provided to this factory. If the gas turbine efficiency has an efficiency of 30 per cent, primary energy consumption would be 4417 kW. A schematic diagram of the system is shown in Figure 7. However, a cogeneration system with an absorption chiller can provide the same energy service (power and cooling) by consuming only 3,333 kW of primary energy. A schematic diagram of the system is shown in Figure 8. It can be seen that the cogeneration system incorporating an absorption chiller save about 24.5% of primary energy in comparison with the power generation system and vapour compression chiller. Furthermore, a smaller prime mover leads to not only lower capital cost but also less standby charge during the system breakdown because steam needed for the chiller can be generated by auxiliary firing of the waste heat boiler. Since many industries and commercial buildings in tropical countries, like India and other South Asian countries, need combined power and heating/cooling, the cogeneration systems with absorption cooling have very high potentials.

NEW TECHNOLOGY OPTIONS FOR COGENERATION

Stirling Engines

The Stirling engine is an external combustion device and therefore differs substantially from conventional combustion plant where the fuel burns inside the machine. Heat is supplied to the Stirling engine by an external source, such as burning gas, and this makes a working fluid, e.g. helium, expand and cause one of the two pistons to move inside a cylinder. This is known as the working piston. A second piston, known as a displacer, then transfers the gas to a cool zone where it is recompressed by the working piston. The displacer then transfers the compressed gas or air to the hot region and the cycle continues. The Stirling engine has fewer moving parts than conventional engines, and no valves, tappets, fuel injectors or spark ignition systems. It is therefore quieter than normal engines, a feature also resulting from the continuous, rather than pulsed, combustion of the fuel. Stirling engines also require little maintenance and emissions of particulates, nitrogen oxides, and unburned hydrocarbons are low. The efficiency of these machines is potentially greater than that of internal combustion or gas turbine devices. There is some low capacity Stirling engines in development or in the market. The electrical efficiency is still not very high and in the range of 10% (350 We engine), 12.5% (800 We engine) up to 25% (3,000 We engine), but it should be possible to design then with at least 25% electrical efficiency and total efficiency of 90%.

Microturbines

As explained in the previous section on gas turbines systems that the smaller than 1 MWe (Mega Watt electrical) have so far been uneconomic, but this is starting to change. Manufacturers are developing smaller and smaller systems and nowadays there are microturbines as small as 25 kWe. In general, microturbines can generate anywhere from 25 kWe to 200 kWe of electricity. Microturbines are small high-speed generator power plants that include the turbine, compressor, generator, all of which are on a single shaft as well as the power electronics to deliver the power to the grid. Microturbines have only one moving part, use air bearings and do not need lubricating oil. They are primarily fuelled with natural gas, but they can also operate with diesel, gasoline or other similar high-energy fossil fuels. Research is ongoing on using biogas. Micro-turbines are smaller are smaller than conventional reciprocating engines, and capital and maintenance costs are lower. There are environmental advantages, including low NOx emissions of 10-25 ppm (02 – 15% equivalent) or lower. Microturbines can be used as a distributed generation resource for power producers and consumers, including industrial, commercial and, in the future, even residential users of electricity.

Fuel Cells

Fuel cells convert the chemical energy of hydrogen and oxygen directly into electricity without combustion and mechanical work such as in turbines or engines. In fuel cells, the fuel and oxidant (air) are continuously fed to the cell. All fuel cells are based on the oxidation of hydrogen. The hydrogen used as fuel can be derived from a variety of sources, including natural gas, propane, coal and renewable such as biomass, or, through electrolysis, wind and solar energy. A typical single cell delivers up to 1 volt. In order to get sufficient power; a fuel cell stack is made of several single cells connected in series. Even if fuelled with natural gas as a source of hydrogen, the emissions are negligible: 0.045 ppm NOx, 2 ppm CO, 4 ppm HC.

COGENERATION & CAPTIVE POWER PRODUCTION IN INDIA

Industries and commercial buildings all over the world are the major energy end users [6]. Industrial sector is one of the largest consumers of electrical energy in India. However, a number of industries are now increasingly relying on their own generation (captive & cogeneration) rather than on grid supply, primarily for following reasons:

- Non availability of adequate grid supply
- Poor quality & reliability of grid supply

As a result, the captive & cogeneration potential has been increasing over the years and it is estimated that nearly 30 %

of the requirement of the industrial sector is met from in-house generation. Some of the recently published statistics indicate a captive power potential of 12,000 MW & cogeneration potential of 15000 MW in India.

Cogeneration Plants in India

The estimated potential of cogeneration is between 17,000 to 20,000 MW, based on conservative estimates. It is difficult to give an accurate figure as many small-scale industrial applications and industrial estimates may also have cogeneration plants and no estimates are available for these areas. Table 1 shows the cogeneration potential in India.

Table 1: Cogeneration Potential in India

Private Industry	Potential (Mw)	Private Industry	Potential (Mw)
Alumina	59	Petrochemical	250-500
Caustic soda	394	Plywood manufacturing industry	50
Cement	78-100	Rice mills	1000
Cotton textile	506	Solvent extraction	220-350
Iron & steel	362	Sponge iron	225
Manmade fibres	144	Tyre plants	160-200
Breweries	250-400	Paper & pulp	850
Coke oven batteries	200	Refineries	232
Commercial sector	175-350	Sugar	5200
Dairies	70	Sulphuric acid	74-125
Distilleries	2900	Total	14628-15586
Fertilizer	850-1000		

Source: Cogeneration, Policies, potential and technologies, TERI, 1997

Captive Plants in India

Industries representing primary producers of infrastructure material such as aluminium, cement, fertilizers, iron & steel, paper, and sugar have significant captive capacity to meet a significant part of their energy requirements. Notably, about 30 per cent of the electricity requirements of the Indian industries are met from the in-house power plants. Table 2 shows the captive contribution by various industries and Table 3 gives state-wise captive capacity in India.

Table 2 & 3: Captive Contribution by Various Industries and States in India

Private Industry	Capacity (MW)	% Share
Cement	1223	9.9
Chemicals	2076	16.8
Electronics	59	0.5
Engineering	2479	20.1
Jute	207	1.7
Metals & Minerals	2404	19.5
Miscellaneous	784	6.4
Paper	473	3.8
Services	80	0.6
Sugar	706	5.7
Textile	1303	10.6
Unclassified	530	4.3
Total	**12322**	**100.0**

PrivateState	Captive Capacity (MW)
Andhra Pradesh	1220
Assam	-
Bihar	614
Delhi	-
Gujarat	1505
Haryana	335
Himachal Pradesh	32
Jammu & Kashmir	3
Karnataka	1045
Kerala	151
Madhya Pradesh	1333
Maharashtra	570
Meghalaya	-
Orissa	1544
Punjab	311
Rajasthan	528
Tamil Nadu	1107
Uttar Pradesh	1240
West Bengal	786
Total	**12322**

Source: Captive report 2010, Power line research

PRESENT STATUS OF COGENERATION TECHNOLOGIES AVAILABLE IN INDIA

A brief status report on the technology and availability of some of the components of a cogeneration system in India is given below:

Boilers

The major boiler manufacturers are BHEL, Thermax, Walchandnagar Industries, Texmaco, ISGEC, IBPL, Lipi, ACC - Babcock and others. Most of the major boiler manufacturers have collaborations with leading boiler manufacturers in the world, e.g., Combustion Engineering, Babcock and Wilcox, John Thompson, etc. Both conventional and fluidized bed combustion (FBC) boilers are being manufactured in India. Convention boilers are available as packaged or field erected units in a wide range of capacities and with fuel capability ranging from oil, gas and coal to rice husk and bagasse. Typical examples of large size boilers supplied are 275 tph for coal fired boilers and 130 tph for oil/gas fired boilers. Packaged oil/gas fired boilers of 80 tph are also in use. The large 275 tph boilers (supplied to electric utilities) supply steam at a pressure of 96 kg/cm^2 at a temperature of 530^{0}C. Boilers with steam pressures up to 110 kg/cm^2 at 465^{0}C have also been supplied for industrial applications. Discussion with major manufacturers indicates that they have the capacity to manufacture higher-pressure boilers. FBC boilers are also available in the country and BHEL, Cethar Vessels, Thermax, Kavery Engineering, Walchandnagar Industries, are among the major manufacturers of these boilers. FBC boilers have been manufactured in a wide range of capacities are being manufactured to fire a variety of fuels such as high sulphur and high ash coal, rice husk, rice straw and even low grade fuels such as coal washery rejects.

Steam Turbines

There are three manufacturers of steam turbines in India. They are APE Belliss, Triveni Engineering Works and BHEL. APE Belliss and Triveni manufacture turbines in the lower rating range starting from a few hundred kilowatts to 5-6 MW. BHEL manufactures steam turbines in a wider range of capacities from 1 MW to 500 MW (for thermal power plants). These turbines are available in different configurations, i.e., simple backpressure, condensing, extraction condensing and multiple extraction turbines. In the lower range of capacity (up to 5 MW) steam turbines are being manufactured to operate at pressures of 30 to 45 kg/cm^2. Most of these turbines are supplied to the sugar industry, and these turbines conform to specifications as laid down by the National Federation of Cooperative Sugar Factories Limited. Manufacturers of these turbines claim to have the capability to manufacture turbines rated higher than 65 kg/cm^2 with maximum extraction at about 22 kg/cm^2 for the extraction steam turbines. BHEL manufacturers steam turbines operating at pressures up to 100 kg/cm^2 and have the capacities to manufacture machines at higher pressures. BHEL also offers multiple extraction steam turbines with extraction at pressures higher than 22 kg/cm^2. Single-stage backpressure turbines typically operate at efficiency of 30-40% and for multistage backpressure turbines the efficiency is in the range of 40-50%. For condensing turbines, typical efficiencies are in the range of 60-70%.

Gas Turbines

In India, gas turbines are available from BHEL, Triveni Engineering Works and DLF Energy Systems and Kirloskar oil engines. While BHEL and Triveni supply heavy-duty industrial gas turbines (typically in the range of 4.5 to 38 MW), DLF Energy Systems supply aero-derivative gas turbines (1-5 MW range). BHEL is the only manufacturer of gas turbines in the country and these machines are made in collaboration with General Electric. Triveni and DLF Energy Systems supply Ruston and Allison-GM machines respectively. Typically, gas turbines operate at an efficiency of 22-26% (typical Indian operating conditions) in the lower ratings up to 5 MW.

Diesel Engines

There are various manufacturers of diesel engines in the country manufacturing both high speed and medium speed engines. Low speed and medium speed engines are more suitable for cogeneration application. The major manufacturers in India are Kirloskar Pielstick, Garden Reach, K.G. Khosla and Wartsila. The new medium speed engines proposed to be manufactured in the country will be able to use heavy fuel oils of up to 700 centistoke (at 50^{0}C). These engines in the range of 4-6 MW would typically operate at an efficiency of 38-43%. In India, there are only a few installations of diesel engine based cogeneration systems with capacities up to 52 MW.

Waste Heat Boilers

The main manufacturers of waste heat boilers in the country are BHEL, Thermax, Cethar Vessels, ISGEC John Thompson, Texmaco, L&T, and Kaveri Engineering. Waste heat boilers of ratings up to 62 tph with single pressure and 105 tph with dual pressures are being manufactured in the country. Among smaller units, used for operation in a cogeneration system, is a 38 tph waste heat boiler used to produce steam at a pressure of 15 kg/cm^2 and 256^{0}C temperature. Installed in a refinery, it uses refinery gas as the heat source. However, most of these waste heat boilers have been supplied to fertilizer and chemical industries and refineries using process gas, natural gas and residual oil as the fuel.

COGENERATION TECHNOLOGY CHARACTERISTC

The characteristic of the cogeneration technologies is shown in Table 4.

Table 4: Cogeneration Technology Characteristics

Technology	Fuel	Size (Mwe)	Electrical Efficiency (%)	Overall Efficiency (%)	Average Capital Cost In $/Kwe	Average Maintenance in $/Kwh
Steam Turbine	Any	0.5-500	7-20	60-80	900-1800	0.0027
Gas turbine	Gaseous and Liquid	0.25-25	25-42	65-87	400-850	0.004-0.009
Combined cycle	Gaseous and Liquid	3-300	35-55	73-90	400-850	0.004-0.009
Diesel and Otto Engines	Gaseous and Liquid	0.003-20	25-45	65-92	300-1450	0.007-0.014
Micro turbines	Gaseous and Liquid	25-200 kWe	15-30	60-85	600-850	<0.006-0.01
Fuel cell	Gaseous and Liquid	0.003-3	37-50	85-90	-----	-----
Stirling engines	Gaseous and Liquid	0.003-1.5	40	65-85	-----	-----

COGENERATION HEAT TO POWER RATIO

Heat-to-power ratio is one of the most vital technical parameters influencing the selection of cogeneration system. If the heat-to-power ratio of industry can be matched with the characteristics of the cogeneration system being considered, the system optimisation would be achieved in real sense. Definition of heat-to-power ratio is thermal energy to electrical energy required by the industry. Basic heat-to power ratios of the cogeneration system variants are shown in Table 5 below along with some technical parameters. The steam turbine based cogeneration system can be considered over a large range of heat-to-power ratios.

Table 5: Heat-To-Power Ratios and Other Parameters of Cogeneration Systems

Cogeneration System	Heat-To Power Ratio (Kwth/Kwe)	Power Output (As Percent of Fuel Input)	Overall Efficiency %
Back-pressure steam turbine	4.0 – 14.3	14 – 28	84 – 92
Extraction-condensing steam turbine	2.0 – 10	22 – 40	60 – 80
Gas turbine	1.3 – 2.0	24 – 35	70 – 85
Combined cycle (Gas plus steam turbine)	1.0 – 1.7	34 – 40	69 – 83
Reciprocating engine	1.1 – 2.5	33 – 53	75 - 85

COGENERATION AND THE ENVIRONMENT

The high efficiency of cogeneration and efficient use of fuel guarantee a significant reduction of CO_2 emission. However, cogeneration can have environmental implications in the form of CO, SO_2 and NO_x emissions to the atmosphere. The quantity of each of the pollutant generated depends largely on the type of fuel used and the characteristics of the cogeneration technology adopted. CO is a poisonous gas produced due to incomplete combustion and can be reduced to negligible levels by assuring satisfactory air-fuel ratio control. SO_2 is an acidic gas produced when sulphur-containing fuels such as oil or coal are burned. Its emissions cause acid rain. Sulphur-containing exhaust gases are the main cause of corrosion of heat recovery devices when the SO_2 in the gas is cooled below its condensation temperature. NO_x is a mixture of nitrogen oxides produced due to the combustion of a fuel with air, and its formation is a function of the combustion condition, characterized by the air-fuel ratio, combustion temperature, and residence time. It also causes acid rain and can result in ozone and smog after undergoing several chemical reactions in the atmosphere.

Technologies, which have undergone rapid development, are those based on spark and compression ignition engines and gas turbines, primarily using natural gas as the fuel. Natural gas is considered the cleanest among the fossil fuels as it does not practically contain any sulfur, nitrogen and is free of dust particles. However, the emission of NO_x is greater, particularly for the prime movers operating at high temperatures. Appropriate designing of the combustion chambers and control of the flame characteristics are help to reduce NO_x formation in engines and turbines. Engine design alone cannot eliminate NO_x formation. Moreover, efforts to reduce NO_x emission can lead to increase in CO emissions while adversely affecting the power output and efficiency. Therefore, end-pipe NO_x abatement technologies such as those based on catalytic reduction systems must be applied to assure very low emission.

Gas Engine

Technical options adopted to minimize emissions from gas engines are optimal combustion process and flue gas cleaning. Lean-burn techniques are used for self-igniting engines using natural gas as fuel. With high load pressure and excess air (typically, 35 to 60 %), NO_x emission can be reduced to 200 mg/m^3, below the standards set by many industrialized countries. Flue gas can be cleaned with a 3-way catalyst; as its name implies, NO_x, CO and hydrocarbon emissions are reduced. In order for it to function efficiently, a constant NO_x-CO ratio needs to be maintained by proper control of air-fuel ratio and ignition.

Gas Turbine

Three commonly employed methods for eliminating NO_x emissions from gas turbines are water or steam injection, use of dry low NO_x burners, and selective catalytic reduction. Water or steam injection are well established techniques which boost the power output due to increased mass flow rate in the turbine. These also help to lower the flame temperature and the partial pressure of oxygen, thus inhibiting NO_x formation. There is an upper limit to NO_x reduction by this method without affecting gas turbine performance. Beyond a certain injection rate of water or steam, there is greater flame instability that leads to formation of CO and emission of unburned hydrocarbons. More modern gas turbines make use of dry low-NO_x systems instead of water or steam injection in order to avoid the costs of treating and pressurizing water or producing high quality steam. The fuel is mixed with combustion air to a homogeneous mixture in a mixing chamber before being sprayed into the flame; this reduces the peak flame temperature and assures less NO_x generation. Such systems are effective at high loads but perform poorly at partial loads. Where the cogeneration system is required to have a wide range of operating conditions, a hybrid design of low NO_x burners is employed which incorporates a small diffusion pilot flame for stabilizing flame at low loads. At sites where stringent environmental standards are applied, selective catalytic converters can be adopted as an end-of-pipe technique. A reducing agent, normally ammonia, is used to convert NO_x to nitrogen and water in the presence of a catalyst, the most common being vanadium oxide.

Steam Turbine

In steam turbine cogeneration systems, sulphur and nitrogen oxide emissions are important in oil-fired boilers whereas particulate and nitrogen oxides have to be considered in wood-fired boilers. As far as the boilers are concerned, technologically advanced equipment has been developed to meet increasingly stringent environmental requirements. A significant development is the use of a secondary combustion chamber where complete combustion of the unburned gases occurs. Better monitoring of combustion parameters through adequate instrumentation has allowed the operator to better regulate the combustion.

Four types of emission control devices widely used in boiler systems are electrostatic precipitation, fabric filters, multi-tube cyclones and wet scrubbers. Chemical agents such as lime, magnesium oxide, etc., are used for flue gas desulphurization. Commonly used techniques employed for NO_x emission abatement in steam turbine cycles include low NO_x burners, selective catalytic reduction, flue gas recirculation, ammonia injection, etc.

CONCLUSIONS

Cogeneration now a day's getting popularity due to rapidly increasing demand for electricity, constraints faced by the authorities to finance additional power generating capacities, and the growing concern to limit the environmental emission and pollution associated with the use of energy. Cogeneration is presently being recommended when there is plan for expansion of existing facilities, development of new industrial zones, replacement of outdated steam generation systems, or when the cost of energy is high and there is scope for selling power.

REFERENCES

1. Kothari, D. P., Co-Generation, Waste Heat Recovery and Energy Conservation, A Course for ONGC Engineers, ITMMEC, IIT Delhi, pp. 144-153, 20-21 September 1988.
2. Sethi, V. K., Power Scenario and Environmental Concerns- National and Global Perspective, Centre for Energy Technology, Osmania University, Hyderabad August 2001.
3. Nag, P.K., Power Plant Engineering. 2nd edn. Tata Mc Graw-Hill Publishing Company Ltd., New Delhi 2002.
4. Wilson, W. B., Conserving energy via cogeneration, Mechanical Engineering, 101, pp. 20-27, 1979.
5. Ingersoll, John G., Energy storage systems, the energy source book, American Institute of Physics, 1991.
6. Teller, Edward, Energy from heaven and earth, W. H. Freeman and company 1979.
7. Hall, M., Cogeneration: the promise is now, Mechanical Engineering, pp. 22-23, 1981.
8. Horlock, J. H., Combined power plants-past, present, and future, Transactions of the ASME, Journal of Engineering for Gas Turbine and Power, 117, pp. 608-616, 1995.
9. T. Casten, CHP – Policy Implications for Climate Change and Electric Deregulation, p2, May 1998.
10. Al-Rabghi, O.M., Beirutty, M., Akyurt, M., Najjar, Y., and Alp, T., Recovery and utilisation of waste heat, Heat Recovery Systems & CHP, 13(5), pp. 463-470, 1993.