Co-Generation

Introduction

When steam (in the case of steam turbine) or gas (in the case of gas turbine) expands through the turbine, nearly 60 to 70% of the input energy escapes with the exhaust steam or gas. If this energy in the exhaust steam or gas is utilised for meeting the process heat requirements, the efficiency of utilisation of the fuel increases. Such an application, where the electrical power and process heat requirements are met from the fuel, is termed "Cogeneration". Most of the industries need both heat and electrical energy. Hence, cogeneration can be a good investment for industries. Cogeneration system may be based on any type of fuel or heat source and with commercially available technology.

Cogeneration Schemes

Cogeneration, based on fuel, plant size and specific application, can be classified broadly under the following categories :

- Based on energy source . i.e. conventional solid, liquid gas fuels, renewable fuels, process gas etc.
- Based on primary equipment. i.e. gas turbine, fired boilers / heaters, waste heat boilers, steam turbines etc.

Options for Cogeneration

- Gas turbine with waste heat recovery boiler (WHRB) and extraction / back pressure turbines.
- Steam boiler with extraction / back pressure steam turbines.

In both the cases, the combustion of fuel releases heat energy. A portion of the heat energy is used for electric power generation, while another portion is used for meeting the process thermal energy requirements through steam.
An ideal cogeneration scheme will be such that, the fuel heat input is exactly equal to the sum of electrical energy and thermal energy requirement of the process plant. In such a case, since all the fuel heat will be fully utilised, the system efficiency will be 100% except for any practical heat release and heat utilisation losses. This however is nearly impossible to implement in practice, because of the in-compatibility of the ratio of the electrical and thermal energy requirements of the process plant. Thus, it becomes evident that any cogeneration scheme adopted would meet only one of the two (thermal and electric) energy needs of the plant fully. Since electricity needs can be supplemented with the power from grid also, it follows that the cogeneration scheme should strive to meet

the thermal energy requirements fully and generating whatever feasible electricity in the system. Such a system is called as a thermal balanced cogeneration system.In addition, some process plants (like sugar industry) generate fuel in the process. The heat energy content of the fuel so generated, would be much in excess of the sum of electrical and thermal energy needs of the plant. In such cases, the cogeneration scheme adopted would produce excess electric power (while exactly catering to the thermal energy needs of the process plant through low pressure steam) and the excess electricity can be pumped into the utility grid, which is ever starving for additional electrical power.

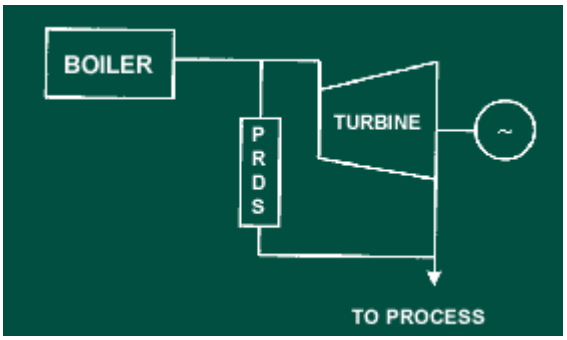
Having identified thermal energy balanced system as the best alternative for adoption, there would be still two options possible under this system, viz.,
a. Generate excess electricity and send the excess to the utility grid.
b. Generate less electricity and buy the balance electricity requirement from the grid.

When the combustion of fuel takes place in a gas turbine (GT) or an internal combustion engine, the exhaust gases from them (which contains the thermal energy for process use) are passed through Waste Heat Recovery Boilers (WHRB) for producing the steam required. It must be noted that, such cases would result in either auxiliary firing (when the energy at GT exhaust is short) or bypassing of some gas to atmosphere, when the energy at GT exhaust is more than the requirement.

Cogeneration Configuration

There are five (5) important configurations of cogeneration possible that will satisfy the above guidelines. They are described below:

Simple back pressure system :



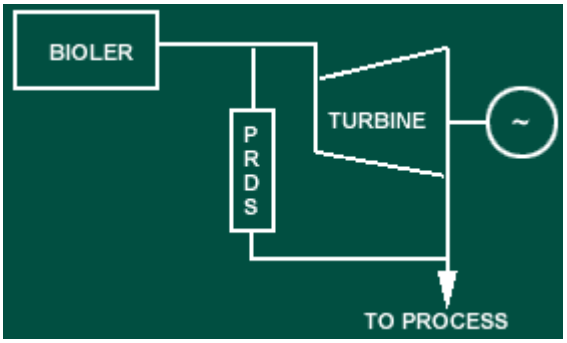
Case - A : Alternator in stand-alone mode :

In this case, the flow through the turbine depends on the electrical power needs of the plant. Any shortfall of the plant steam requirements, is met by drawing the main steam through a PRDS. However, this is a less efficient alternative and should be avoided, if possible.

Case - B : Alternator in parallel with grid :

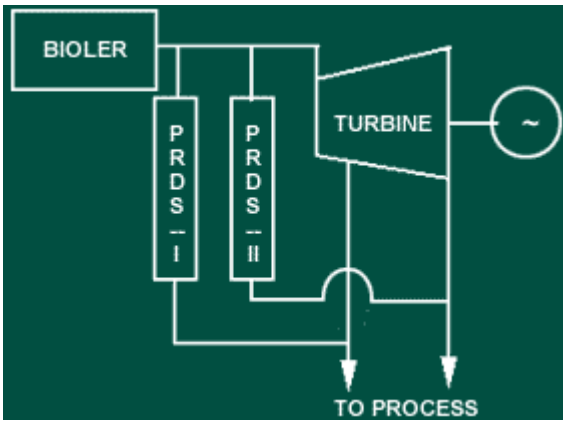
In this case, the flow through the turbine is controlled by the plant steam requirements. Any excess power or shortfall of power is adjusted with the grid. This system is very cost effective. However, it depends very much on the reliability of the grid. Hence, this is not a preferred alternative in most cases.

Extraction cum condensing system



This system can be operated either in stand alone mode or paralleled with the grid. The steam flow to the plant as well as the main steam generation can be varied depending on the needs of power and plant steam requirements. In most of the industrial cases, the turbines would accommodate a maximum of two extractions only. This is a very popular alternative because of its high flexibility, even though the overall thermodynamic efficiency would be relatively lower. In order to minimise such efficiency decrements, the quantity of steam condensed should be as low as possible.

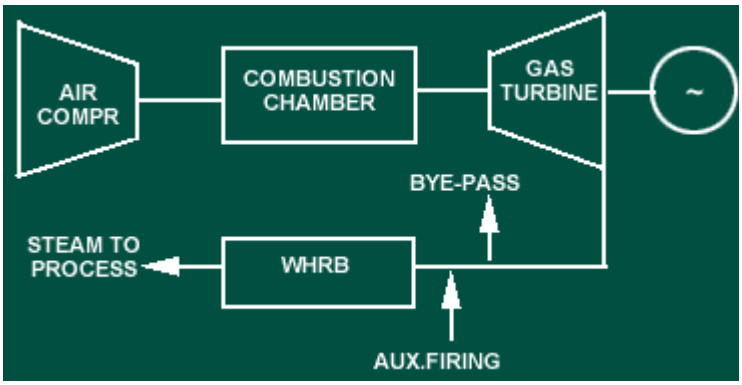
Extraction back pressure system :



This is adopted in such cases where the plant steam requirements are at more than one pressure level. The limitations with regard to number of extractions possible in industrial turbines, apply equally well in this case. This is in essence a more elaborate version of the

first alternative of Simple back pressure system and hence suffers / enjoys similar advantages and disadvantages.

Gas turbine / diesel sets with WHRB for meeting process steam :



In this case, the quantum of steam generated by the WHRB is totally dictated by the gas turbine exhaust gas quantity. Hence if the plant steam requirements are more than the quantity generated by WHRB, the shortfall will have to be met by adding auxiliary firing in the WHRB. Having thermally balanced the system, electrical output variations will have to be balanced by connecting the generator to the grid. However in some cases, the steam generated by the WHRB can be more than the plant requirements. In such cases, the steam balance is to be achieved by venting off some of the exhaust gases, byepassing the WHRB.

Gas turbine/diesel sets with WHRB and extraction-cum-condensing steam turbine :

This is a very efficient alternative and meets the fluctuations of steam and power demands of the plant. It is possible for such a system to be either paralleled with the grid or operated on stand alone mode.

In all the above alternatives, certain standard back up features like PRDS and additional boiler capacities will have to be built for meeting contingencies.

Design Considerations

A standardised design approach, in cogeneration, cannot be applied, since a number of variables affect the economic viability of the cogeneration plant. High pressure and high temperature cycles are essential for increasing the efficiency of the cycle (i.e. to decrease specific steam consumption rate) and the power out put from the cogeneration plants. The choice of level of pressure and temperature of the cycle depends on the type of the plant,

capability of the plant operators, quality of feed water, cost of the equipment and on the financial benefits.

From the thermo dynamic stand point, energy recovery from the Rankine cycle is more dependent on the temperature than the pressure. Hence, higher the steam temperature , higher the cycle efficiency. However, the limits on temperature are influenced by the metallurgy of the boiler tubing, piping and the turbine components. Carbon steel can be used upto a working metal temperature of 400℃. Beyond this temperature, alloy steels are extensively used. The characteristics of the fuel used in the boiler (e.g. : bagasse) also can pose limitations on the choice of steam temperature. The following are the steam parameters that are widely used in a process industry.

Pressure (kg/cm2(a))	Temperature (0C)
32	380
42	440
67	485
84	520
110	540

Process requirements

In most of the cogeneration configuration, the steam generator will be required to generate steam at a higher pressure for steam turbine. If steam turbine does not have provision for extracting low pressure steam to meet the requirements of deaeration and fuel heating, then the same has to be sourced from the steam generator. To conserve energy, as in the case of a waste heat boiler, multiple pressure steam generations can be considered to generate high and low pressure steam separately to suit the requirements.

One important thing that can contribute greatly to the success of the cogeneration is the process side steam economy. For e.g. many sugar plants in our country demand 50% (on cane) steam consumption compared to 40 to 45% in other parts of the world. The difference between 50% and 45% steam consumption, for a typical 2500 TCD plant, is about 1200 kW of surplus power. It is essential, before finalising the capacity of cogeneration plant equipment, to do a detailed thermal and power balance for the plant. It should be noted that the process steam requirement (or the thermal energy requirement) and power requirement at the battery point, are factors which influence the sizing of the various equipment.

The following is a typical range of steam pressure levels normally considered for drive applications and for the plant requirements :

Industry	Pressure level
Fertilizer/ Petrochemical	45 ata HP steam 25 ata MP steam 5 ata LP steam

Paper / Fibre	10 ata HP steam 5 ata LP steam
Sugar	2.5 ata LP steam

Steam quantity:

Individual process plants requires steam at various conditions. For a cogeneration plant, with the total requirements of process steam, and other requirement if any (like HP and LP heaters) we can arrive at the total steam that has to be generated from the steam generator. In order to arrive at the capacity of the steam generator a 10% margin can be considered for any process fluctuation and peaking.

Auxiliary power consumption:

In a cogeneration plant, the major source of auxiliary power consumption will be for feed pumps and water circulating pumps in the system dictated by the layout of the plant. The plant and equipment should be laid out to achieve an optimum routing of piping and hence power consumption. Similarly, in a fired boiler, the major source of auxiliary power consumption will be due to forced draft and induced draft fans.

The aspect of power consumption due to forced circulation or natural circulation in the boiler and power consumption due to gas side pressure drop is dealt in detail, in this manual under waste heat recovery systems.

The cogeneration plant should take into consideration the need for quick response of the components to the plant demands. A gas turbine is capable of springing into action and take up load in a matter of few minutes. However, a steam boiler, turbine combination will take few hours to start from cold and accept plant loads. The margin requirements as well as standby capacities required in the steam plants would therefore be more liberal when compared to gas turbine installations. The system auxiliaries and their margins are therefore to be decided based on individual situations, which can be significantly different.

Optimum extraction / condensing quantities and the range of extraction:

Extraction in the process industry depends on the various process conditions. Once we know the steam requirement for the plant, it can be matched by suitable selection of the type and number of extraction. When normal extraction steam quantity is calculated, the design flow through extraction can be suitably fixed by adding a 10 to 15% margin. With the extraction quantity, we can arrive at the amount of power generation that can be generated, considering the turbine efficiency. Further if we want to generate more power, then the additional power requirement can be met by additional steam generation in the boiler, but care should be taken to design the system with minimum of steam to condenser and avoid the energy loss in condenser.

Technical Criteria for Component Selection:

In order to select the most suitable turbine for a cogeneration plant, one should give emphasis to the following features in order to achieve a trouble free operation in TG sets.

a. Ability to absorb inlet parameters variation

In a cogeneration plant there can be following variations :
- Change in boiler fuel resulting in variation of fuel calorific values and subsequent changes in final steam parameters.
- Fluctuation in extraction flow
- Fluctuation in load demand or isolated operation of TG in case of grid failure

In view of the above, the turbine must have an inbuilt stability to meet the fluctuating temperature and pressure of steam throughout.

b. Reliability

Reliability is a guarantee for quick pay back on the investment. Normally, a good reference list worldwide and position of supplier vis-a-vis his reputation on quality will ensure this feature. A thorough check of manufacturer in-house quality programme will also be helpful.

c. Efficiency :

The steam requirement in a process plant will always be subjected to drastic variation. Hence the design of the turbine poses a challenge for optimisation in such a way to achieve best results always. A good prior analysis of operating scheme to be carried out during the selection of the set.

d. Governing

In view of the variation in operating conditions and export of power to grid, the turbine will have to be operated in any of the following modes :
- parallel operation
- controlled opera
- Isochronous operation

To take care of this, the turbine governor should be of electronic type with proven record on power plant usage.

Criteria for selection of boilers

The most important point, while selecting boilers would be the need for reliability. The track record of all thermal power plants in the past have indicated that nearly 50% of all thermal power plant outages are attributable to boilers. Once again, the failures of pressure parts (caused by improper water chemistry regime) constitute more than 50% of the boiler outages. The boiler manufacturer's recommendations with regard to feed and boiler water quality must be adhered to, for avoiding costly boiler outages. In the case of boilers working at pressures of 40 Kg/Sq.cm. and above, it is essential that DM water alone must be used for feed water make up. For all cogeneration boilers, it is necessary to adopt adequate instrumentation along with automatic control systems. For further details

on boiler selection requirements, the write up on boiler energy conservation methods may be referred.

Assessment of potential for Cogeneration in a Process Industry

The following factors influence the choice of the Cogeneration schemes :
- Fuel type and availability
- Steam and / or process heat demand
- Electricity demand
- Air quality requirement
- Financial objectives
- Space availability
- Existing steam generation facility
- Existing electrical load system

Benefits of Cogeneration

The following are the benefits of adopting Cogeneration
- Overall fuel savings by the coincident production of electricity and process heat and / or steam. - Power generation units located at their respective load centres with resulting decrease in transmission losses.
- Potential for overall emissions and environmental impact improvements
- Attractive return on increased capital
- Potential to utilise or overtake advantage of higher fuel costs by creating greater profits from the cogeneration plant.
- Higher reliability of power supply to the cogeneration
- Captive production of electricity by individual user