Cost Effective Use of CHP in Steel Industry

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COST EFFCTIVE USE OF CHP IN STEEL FURNACE INDUSTRY

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ABSTRACT

Combined heat and Power (CHP) generation or Cogeneration has now been widely used over the globe for its better efficiency, efficient use of natural and monetary resources and very less environment hazard. Priorly CHP has been used in power and steam generation in gas and steam turbines. Basic Principle of cogeneration is to utilize high temperatures effluents (gases, steam and water) in waste heat recovery mechanism to recover heat energy from the waste. Mainly CHP has been used in electrical power generation.

This study identifies the novel idea of the usage of cogeneration system. This research depicts the scenario of five electric generators working on natural gas exhaust CO_2 at the ambient temperature of 485 °C with the mass flow rate of 4473 Kg/hr. In this study, this effluent gas has been introduced to a reheating steel furnace which raises the temperature of the furnace up to 470 °C. These results have been verified using Ansys simulations.

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All the paises are attributed to the sole creator of the universe "The Almighty ALLAH", the Compassionate, the Merciful. the sorce of all the knowledge and wisdom, who bestowed upon me health, talent, sincere and cooperative teachers, friendly brothers and helping friends who gave me the strong courage and endurance to complete this thesis.

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Cooling is effected by a vapor assimilation cycle of refrigeration unit, which can work through boiling hot water, steam or hot gases [4].

It has been noticed at many places where power plants are in operational, a large sum of thermal energy has been wasted to open environment by using cooling (condensers, cooling towers etc.)The vast majority of this energy can be reused and used to cater energy needs, resulting in increased efficacy from 30-35% of a force plant to 80-90% of a cogeneration framework. A correlation in the middle of cogeneration and the different generation of electrical power and heat from the perspective of effectiveness, is given in Figure 1.1, based on characteristic values of efficiencies as shown.

1.2 Back ground of Cogeneration

Cogeneration initially showed up in late 1890's in Europe and in the America. Amid the early years of the 20th century modern plants created their own required energy utilizing boilers and power generators. A substantial counts of the plants operated the flue gases for steam generation for mechanical equipment. It has been evaluated that as much as

57.98% of the collective power delivered by on location mechanical energy plants in the American industries in 1900's were cogenerated[5].

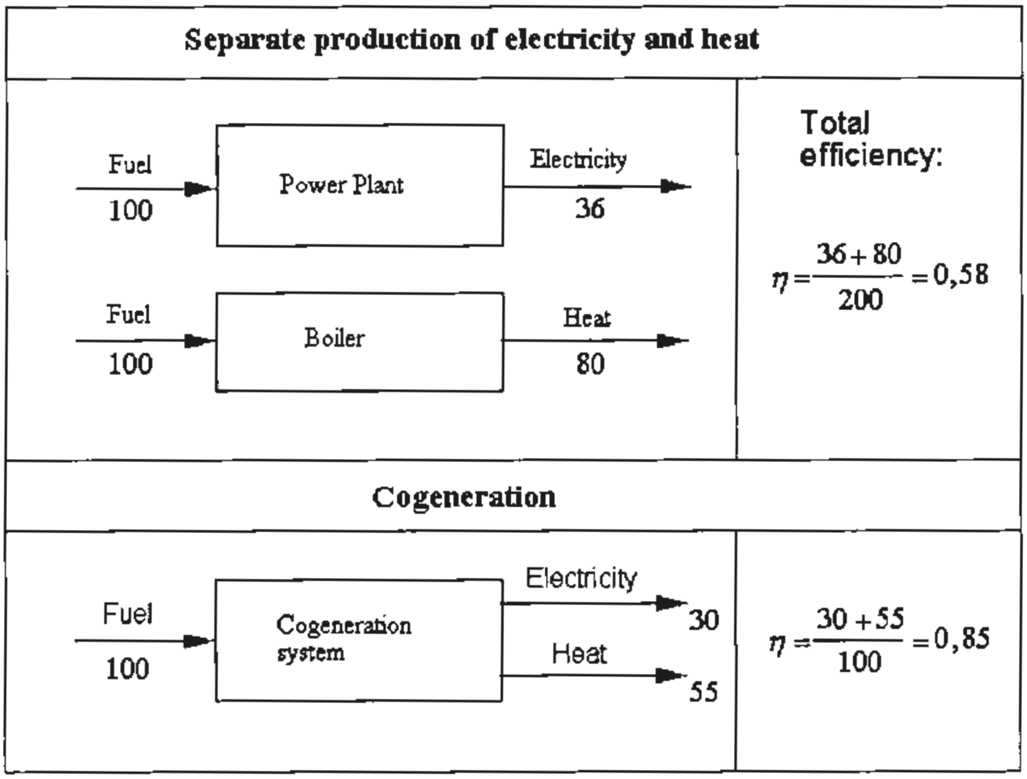

Figure 1.1Difference between efficiency of cogeneration and unique production of electrical and heat energy.[1]

At the point when focal electric force plants and dependable utility frameworks were built and the expenses of power diminished, numerous modern plants started acquiring power and quit delivering their own. Therefore, on location mechanical cogeneration represented just 14.9% of aggregate America's electrical regime limit by 1951 and dropped to around 5.1% by 1975.

There are number of factors which play their role in decreasing the usage of industrial cogeneration were strict regulations about the production of electrical power, obtaining low cost electricity per unit, using less industrial expenditure, progresses in innovation, for example, bundled boilers, accessibility of fluid or vaporous fuels at low costs, and fixing natural confinements.

The aforementioned pattern in cogeneration occurrence being decreased the first histrionic ascent of fuel expenses in 1973. Frameworks that are effective and can use option fuels have turned out to be more vital even with fuel price rises and vulnerability of fuel supplies. Notwithstanding diminished fuel utilization, cogeneration brings about a reduction of contamination emanations. As result of above factors European Union, America and Japan are eagerly willing to utilized cogeneration. Examination, advancement and exhibition undertakings acknowledged amid the most recent 25 years prompted a noteworthy change of the innovation, which now is developed. New methods are likewise in progress, for example, energy components.

Combined heat and Power (CHP) generation or Cogeneration has now been widely used over the globe for its better efficiency, efficient use of natural and monetary resources and very less environment hazard. Priorly CHP has been used in power and steam generation in gas and steam turbines. Basic Principle of cogeneration is to utilize high temperatures effluents (gases, steam and water) in waste heat recovery mechanism to recover heat energy from the waste. Mainly CHP has been used in electrical power generation.

This study identifies the novel idea of the usage of cogeneration system. This research depicts the scenario of five electric generators working on natural gas exhaust CO_2 at the ambient temperature of 485 °C with the mass flow rate of 4473 Kg/hr. In this study, this effluent gas has been introduced to a reheating steel furnace which raises the temperature of the furnace up to 470 °C. These results will be verified using Ansys simulations.

1.3 Advantages of Cogeneration

Major advantages of cogeneration system are as under;

Industrial Benefits:

- Reduced Energy Costs (e.g. , utilizing waste heat for power production can be less expensive than acquiring from utility);
- Enhanced dependability of power supply. By producing their own particular power all the more reliably, industrial utilities can either decrease or destroy the requirement for electrical power acquisitions from an electricity supplier;
- Improved nature of power supply. With their own cogeneration plants, industrial plants that oblige fantastic electric force can either control or dispense with inadmissible voltage changes and recurrence moves that may happen in utility creating.

1.3.1 National Benefits:

- Load shedding is the enormous problem now a days in this country. This study helps industries and other commercial facilities to cut off their rising demand of electricity and helps reduce power shortage.
- Pakistan imports 60% fuels for power generating sector. This process helps reduce this import of fuel thus millions of rupees.
- This study will help in saving construction time and cost of power plants used to generate electricity.
- If this technique implied properly at the national level the utility cost (Transmission, distribution, billing etc) of electricity can be reduced several folds

by adding local cogeneration facility's electricity to closer grid. This will create a positive impact on energy efficiency and utility cost.

1.4 Applications of Cogenerations systems

Application of cogeneration systems are typically classified in accordance with the:

- Utility sector,
- Industrial sector,
- Residential, Commercial, Institutional sector,

Utility sector it can be used for the bio gas production is an important example. In industrial sector cogeneration can be implemented here heating processes are required such as in cement industry and in buildings with cogeneration we can heat up the building or can be used to run vapor absorption cycle to provide cooling comfort[6].

1.5 Impacts of Cogeneration

Following significant impacts can be seen while cogeneration in power generation:

1. Impact on fuel utilization
2. Impact on environment

1.5.1 Impact on Fuel Consumption

All cogeneration systems have higher efficiency for the production of electricity and generation of heat for any process/operation as shown in Figure 1.2. For example, according to usual assumptions of figure 1.2, a steam-turbine cogeneration framework decreases fuel energy utilization by around 15.1% regarding the different production of power by a steam power plant by using the heat of kettle; a Diesel motor system diminishes fuel energy utilization by around 25.5% as for the different creation of power by a Diesel-motor generator and heat by an evaporator. On the other hand, whether a cogeneration framework spares a expensive, imported and non-renewable fuel, for example, furnace oil relies on utilization by the cogeneration framework and utilization by the frameworks for the different generation of power and heat energy, which are reduced [7].

Although it is more proficient than the different generation of power and heat: cogeneration systems spare fuel cost for another reason; for the most part they are introduced close to the load than focal power plants, in this way decreasing or notwithstanding dispensing with the misfortunes of electrical energy along the transportation and dispatching network, which can be as high as eight to ten percent of the electric energy at the source.

Although being more effective than the different power generation and heat: cogeneration frameworks spare fuel cost for many reasons; for the most part they are introduced close to the load than focal power plants, in this way lessening or removing troubles of electrical energy beside the transportation and dispatching mesh, which can be as greater as 8.2-11% of the electrical energy at the source.

1.5.2 Environmental Impacts

Besides the fuel and cost savings, cogeneration can likewise yield a less dangerous emissions, in light of the fact that it uses fuel all the more proficiently. The proficiency has an immediate effect on discharges, as it is demonstrated in Figure 1.3. Along with the immediate diminishing in emanations, the lessened fuel utilization is joined by a backhanded reduction in outflows. Following types of pollutions can be minimized by using the cogeneration system[8]:

1) Noise Pollution

2) Emission Pollution

1.5.2.1 Noise Pollution

Cogeneration systems have very positive impact on abatement of noise pollution, as these system is utilizing the exhaust heat so we have lowered the number of moving parts to combust the fuel whether using reciprocating or rotary mechanism.

1.5.2.2 Emission Poluttion

Cogeneration system reduces the carbon foot prints environment by using the flue gases or exhaust gases of existing system reducing the number of combustion cycles and consequently amount of fuel combust so the amount of the production of NOx, SOx and Cox and CO_2 can be drastically reduced by using cogeneration systems[9]

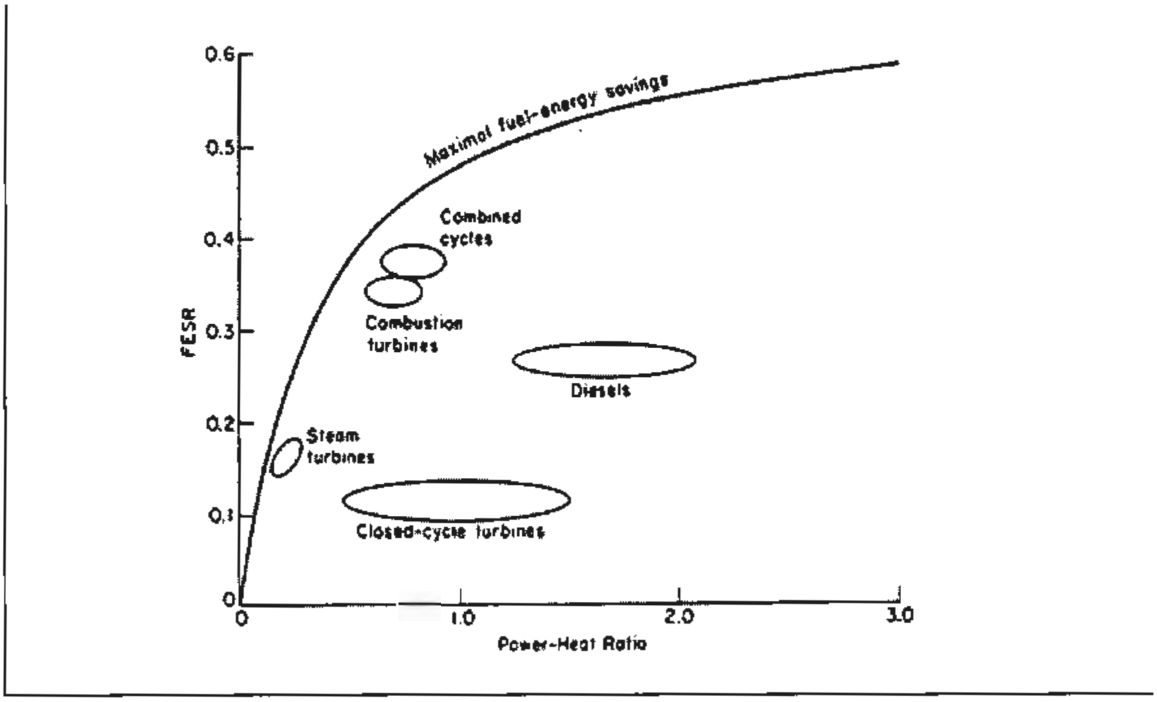

Figure 1.2 Impact of efficiency on noise pollutants [10]

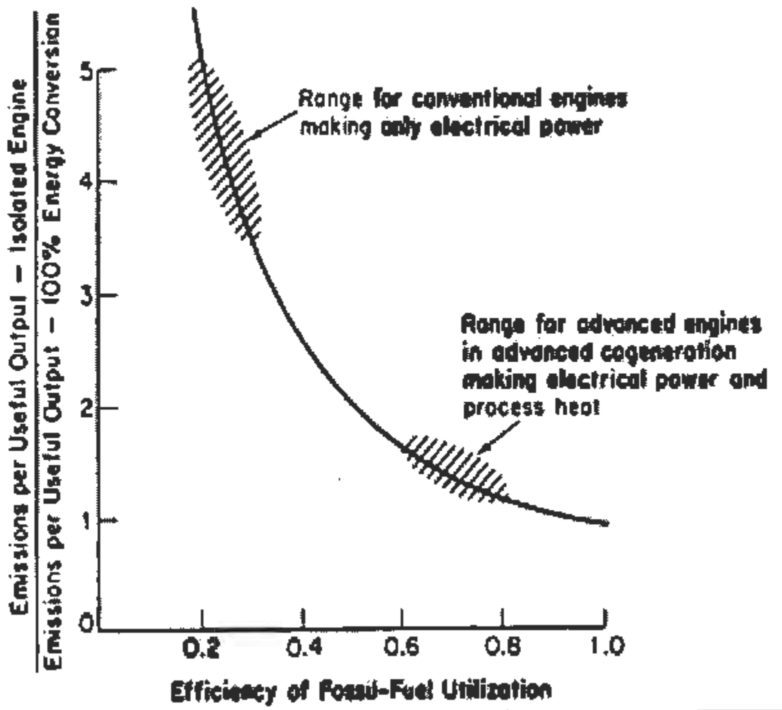

Figure 1.3 Impact of efficiency on emission of pollutant [10]

2 Basic Concepts

Combined heat and power (CHP, also known as cogeneration) can provide thermal energy for building heating/cooling and the energy to process industry. Not only this, it will also create a visible fraction of the electricity needed for facility nearby.

2.1 Types of Cogeneration Systems

In the broader sense, two basic type of cogeneration system, segregated on the basis of type of energy they produces; Thermal and Electrical Energy [10].

2.1.1 Topping Cycle

In this type, primary purpose of the cogeneration is to generate electricity, while the high temperature flue gases will help in producing thermal energy.

2.1.2 Bottoming Cycle

In this type, primary purpose of the cogeneration system is to produce thermal energy, however waste steam can further processed to create electricity using e.g combine cycle gas turbines.

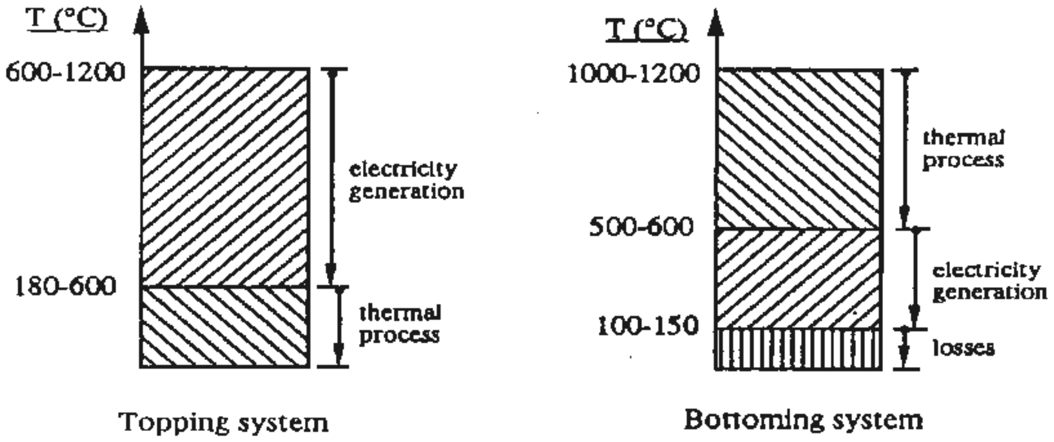

Figure 2.1Figurative temperature varieties for topping and bottoming cogeneration structures [1]

2.2 Performance Directories of Cogeneration Systems

This is important to characterize assured files, on which the thermodynamic execution of a cogeneration framework and encourage examination of option arrangements. Various records have showed up in writing. The peak vital of those are characterized in section[11][1]:

Following relation can be used to calculate the efficiency of any prime mover i.e Diesel Engine, Steam Turbine and Gas Engine;

$$\eta_m = \frac{W_s}{H_f} = \frac{W_s}{m_f H_u} \qquad (2.1)$$

Where.

$\dot{W}_s$ Power of the shaft,

$\dot{H}_f$ fuel. power (flux. of the fuel. energy) disbursed.

$$\dot{H}_f = \dot{m}_f H_u \qquad (2.2)$$

$\dot{m}_f$ Mass flow rate,

H_u Fuel's Cost for Heating purposes.

Electrical Efficiency:

$$\eta_e = \frac{\dot{W}_e}{\dot{H}_f} = \frac{\dot{W}_e}{\dot{m}_f H_u} \qquad (2.3)$$

$\dot{W}_e$ is the yielded net electric power of the framework, i.e. the electric power consumed by essential hardware has been expelled from the electric power of the generator [12].

Thermal efficiency:

$$\eta_{th} = \frac{\dot{Q}}{\dot{H}_f} = \frac{\dot{Q}}{\dot{m}_f H_u} \qquad (2.4)$$

where

$\dot{Q}$ is the helpful thermal power yield of the cogeneration framework.

Total efficiency of energy of cogeneration system:

$$\eta = \eta_e + \eta_{th} = \frac{\dot{W}_e + \dot{Q}}{\dot{H}_f} \qquad (2.5)$$

The nature of heat is lesser than the nature of power. It is diminishing with the temperature of fuel at which it is accessible. Case in point the nature of heat as boiling point water is lower than the nature of heat as steam. Therefore, it might not be exceptionally fitting to include power and also heat as it is shown in Equation. (2.5).

Relation mentioned below can be helpful to calculate following:

Power to heat ratio:

$$PHR = \frac{\dot{W}_e}{\dot{Q}} \qquad (2.6)$$

Fuel energy savings ratio:

$$FESR = \frac{\dot{H}_{fS} - \dot{H}_{fC}}{\dot{H}_{fS}} \qquad (2.7)$$

where

$\dot{H}_{fS}$ Entire power for discrete production of $\dot{W}_e$ and $\dot{Q}$,

$\dot{H}_{fC}$ fuel power of the cogeneration structure generating the similar quanti$\dot{W}_e$ of $\dot{Q}$ and If the sole purpose is to save energy using cogeneration system then FESR should be greater than zero.

Using Expressions (2.3)-(2.6):

$$\eta = \eta_e \left(1 + \frac{1}{PHR} \right) \quad (2.8)$$

$$PHR = \frac{\eta_e}{\eta_{th}} = \frac{\eta_e}{\eta - \eta_e} \quad (2.9)$$

It ought to be worth specifying that the power-heat proportion is the principle variable for choosing a cogeneration framework for a specific problem.

3 Cogeneration Technologies

3.1 Gas Turbine and Cogeneration Systems

In medium to high power cogeneration systems gas turbines are widely use and these turbines can be based upon either simple cycle or can be combined cycle turbines and they can generate energy ranging from few kilowatts to megawatts.

Gas turbines has large variety depending upon their applications, ranging from heavy duty industrial application to compact and small for jets and aircrafts. In these applications engines are robustly design for immovable applications, in which case they are known as "aero derivative turbines". Usually they can start quickly and response abruptly to any change in load. Both gas turbine plants have been productively utilized for cogeneration having as primary points of interest little capital contribute at first, easy and maintenance is cheap, any fuel can be used, which can easily be recovered with high calorific value, and high efficiencies in larger turbines.

3.2 Gas Turbines Cycles

Brayton Cycle or Constant Pressure Cycle has known ideal for the operation of the gas turbines. There are two reversible adiabatic cycles (isentropic) and two processes of constant pressures[13].

The main application of the gas turbine cycle nowadays is in the aviation industry, although gas turbine units usage for power generation is increasing tremendously, usually using natural gas as fuel. Marine propulsion is also carried out through gas turbines[11].

3.3 Gas turbine Cycles on Cogeneration

3.3.1 Open Cycle Gas turbine using Cogeneration System

Wildly available gas turbines in any field of gas turbine application is worked on the principle of the Brayton Open Cycle (also called Joule Cycle if irreversibility are not considered) as shown in Figure 3.1, air is taken from ambient and compressed in compressor to drive the turbine[1] .Due to operation of compressor pressure of combustor increases. Pressure ratio of 15:1 is achieved in older or smaller units. Better compression ratio i.e. 30:1 is achieved in new or large units.

Diffuser supply compressed air charge at fix pressure in combustion chamber. And fuel is pumped in to the combustor to combust. The diffuser retards the speed of air to values where combustion happened in the combustor. 1.0-2.0% pressure is dropped in combustor. Combustion takes place lean air fuel mixture. The exhaust gases leave the combustion chamber or combustor at high temperature. At exhaust we obtain the highest temperature, the difference between the inlet and exhaust will be higher, the higher would be the efficiency[14].

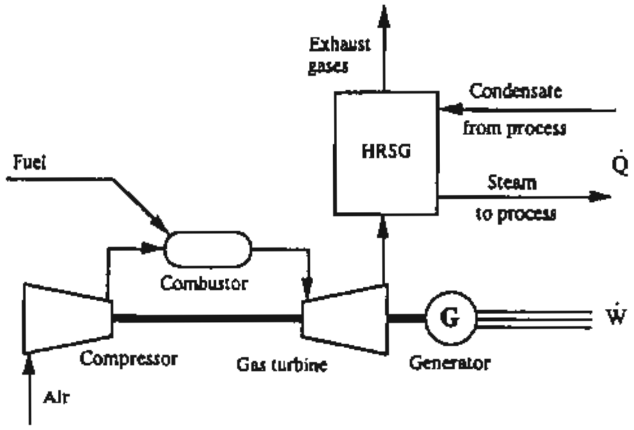

Figure 3.1 open cycle gas turbine with Cogeneration System [3]

Mechanical work to energize the compressor and break-load e.g. electrical compressor is produced by the exhaust gases or flue gases that enter in gas turbine at very high temperature and pressure. From the gas turbines, exhaust gases leave at very high temperature ranging from 450 to 600°C which is very suitable to utilize for heat recovery system or cogeneration system. It is influenced by the heat recuperation boiler of single-pressure or twofold pressure for additional effective recuperation of heat. Triple-pressure is additionally conceivable however not extremely common, on the grounds that it makes the framework more unpredictable and costly, which is not generally defended and also cost for developing the pressure[15].

Quality of steam depends upon the high pressure and high heat content and high temperature. Gas leaving the turbine has all these qualities and thus makes it suitable to not only use for some thermal processes but also to run a steam turbine which provide surplus mechanical work without any cost.

These gases can be used directly after leaving the turbine in some thermal process instead of using in the steam turbine for example drying where high temperature heating is required or wood seasoning.

Along above mentioned applications of heat recovery and cogeneration process, it also worth considering that heat content may increase of flue exhaust gases by additional combustion of fuel.

Electrical power ranging from10-100 MW can be generate with open cycle gas turbine. Various fuels are available and can be used such as natural gas, fuel obtained by the distillation of petroleum or gasification of mineral coal. Hydrocarbons obtained during catalytically cracking of hydrocarbons can be used as fuel and run the turbines [16].While use such non commercially fuels care must be taken because these fuels may contains element of halogen group such as potassium , calcium or even Sulphur and these halogen or halogenate atoms may erode the turbine blades[8]. Fuel treatment or exhaust gas filtration is a remedy of these issues and these issues must be addressed before the flue gases enter in turbine.

Frameworks smoldering fluid fuels or vaporous by-results of synthetic procedures may oblige more regular check and support, which brings about lower accessibility due to condensation on turbine blades and chocking of diffusers. The life of the system is around fifteen to twenty years and it is critically exaggerated by low quality fuels or deprived maintenance.

3.3.2 Closed cycle gas turbine for cogeneration systems

Working fluid is usually circulated in closed circuit in closed cycle gas turbines. Working fluid is normally heated before entering in the turbine and heat is removed or recovered after it has been exhausted from the turbine and heat exchanger are used for this purpose [17].

After addition experience, the dependability of close systems is required to be at any rate equivalent of open-cycle whereas the accessibility relied to be higher, because of the fluid is not contaminated.

A close cycle gas turbine block diagram is shown in Figure 3.2, source of heat can be anything, and it may be internal or external combustion of fuel

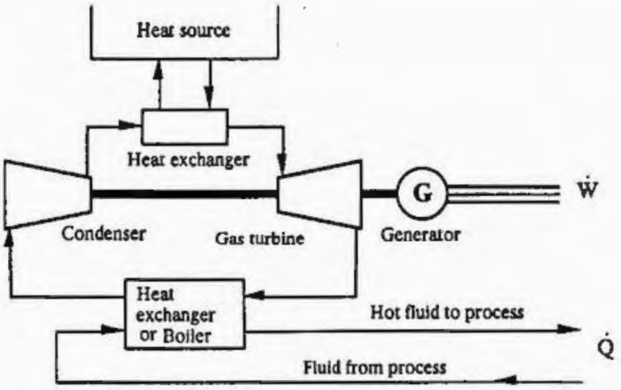

Figure 3.2 Cogeneration system with close cycle [4]

3.4 Gas Turbine Cogeneration Thermo-dynamics

3.4.1 Efficiency and power to heat ratio (rated power)

Small to medium gas turbine frameworks are typically insignificant for electrical effectiveness in the scope of 25.0–35.0%. Bigger frameworks constructed as of late have come to electric efficiencies of 41–42.3% by method for high temperature of fumes gasses at the turbine bay (1200.0-1400.0C). The general unwavering quality is traditionally up to 61–81%. The power to heat proportion (PHR) is in the reach Substantial amount of the turbine power rating is even up to 50.0%, is utilized to run the compressor, so provides relatively low electric efficiency. To enhance the compression ratio the intercooler, turbo chargers or similar utilities can be used.

Pre heating of air charge can be opted as a solution to enhance the electrical energy production efficiency by using regeneration methods.

In such a case, the recuperated heat from the fumes gasses after the regenerative heat exchanger abatements. On account of cogeneration, and for joined gas-steam cycles, the expansion of a regeneration for the air preheating is not necessary[4].

The ideal recoverable heat relies on upon the base heat content satisfactory in the fumes gasses. Fuel having Sulfur exacerbates, the fumes gas temperature can't be diminished than 140.0-165.2 C, keeping in mind the end goal to sidestep the sulphuric corrosive dew point. On the off chance that the fuel is for all intents and purposes free of Sulfur, similar to the case with common gas, the fumes gas temperature can be as diminished as 90-100deg. C for reutilization in cogenerate.

3.4.2 Surrounding conditions and partial load effect

Air entering in the compressor has ambient conditions. This amount of work required for compression depends upon initial temperature and density of air, and fuel being combust, and the fuel required to attain an indicated turbine inlet temperature. As per consequences output parameters such as output efficiency, gas flow rate, and gas temperature are dependent on input conditions which are based on the ambient [18].

The performance of turbine decreases with increase of altitude as the pressure drop or decrease in the ambient temperature. The capacity reduces up to 2–4% for each 300 m change in altitude from sea level.

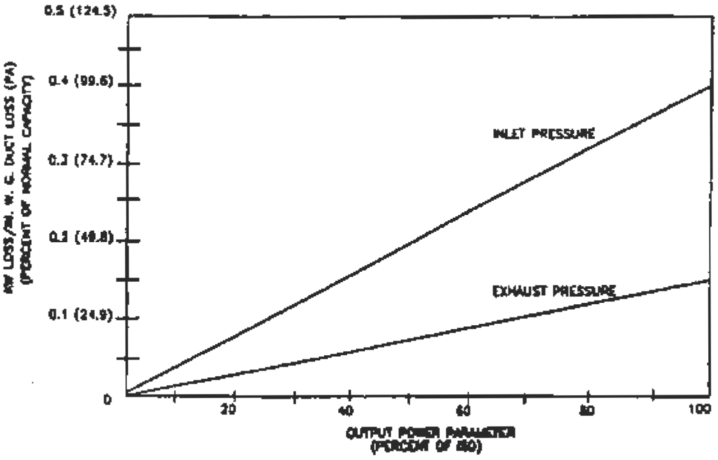

Figure 3.3 Output power parameter vs. percent of normal capacity of inlet and outlet [3]

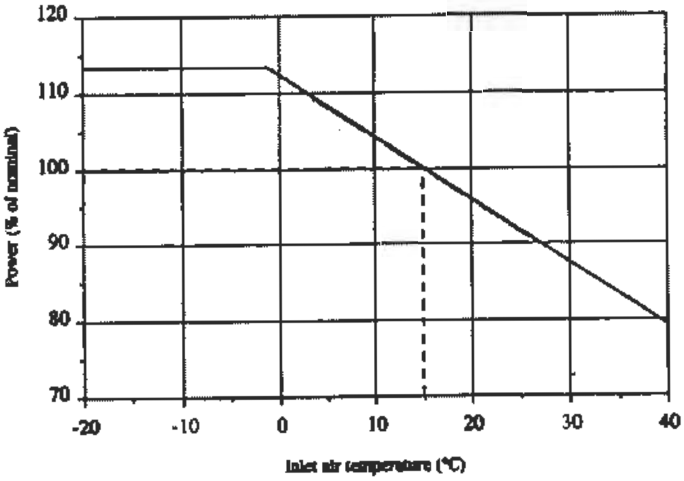

Figure 3.4 Effect of temperature on power generation [3]

3.5 Power Generation through steam

Steam turbine system is comprises of three main components:

1) heat source
2) steam turbine
3) Heat sink.

The operation is based on the Rankine cycle, either it may be original Rankine cycle or it may improve cycle with steam reheating or may be regenerative using water preheating.

Usualy boilers are the common heat source, which may run on any kind of fuel or different combinations of fuels. Boiler provides super-heated steam. Nuclear reactor may also be used in the replacement of boilers or any other source of heat can be used such as renewable energy sources. Indeed, even waste by-items can be smoldered, given the heater is outfitted with legitimate contamination diminishment units [19].

3.5.1 Fundamental structure of Co-Generation system using turbines

Different types of configurations can be used for the steam turbine which are elaborated in this chapter. Flow diagrams are used to explain the simple configurations lacking of indulging. So steam reheating, if any or regenerative water preheating and assistant gear are not demonstrated here.

Steam turbines with Back-pressure

The configuration of steam turbine with Back-pressure is the simplest configuration as shown in figure 3.5

Steam leaving the turbine must be equal or near having greater pressure as compared to ambient or atmospheric pressure[7]. It is also feasible to collect the stream from any stage of gas turbine matching to our thermal design requirements in term of temperature and pressure. After the release from the turbine charge of steam is feed to heat recovery system or load, here it discharges heat and is condensed [19].

The back-pressure system has the following advantages:

- Having simplicity in information with least possible components.
- Minimum investment cost.
- Feed water requirement is nil or minimum.
- High efficiency, net heat rejection is minimum.

This system has few disadvantages which are discussed below:

- Size of steam turbine is increased for the same output conditions, due to its operation under low enthalpy.
- Steam flow rate is dependent to the thermal load, so the electric power generation is dependent on thermal load.
- Two way power supply is required due to dependency on thermal load[19].
- Thermal load is dependent on the heat extraction through condensation.

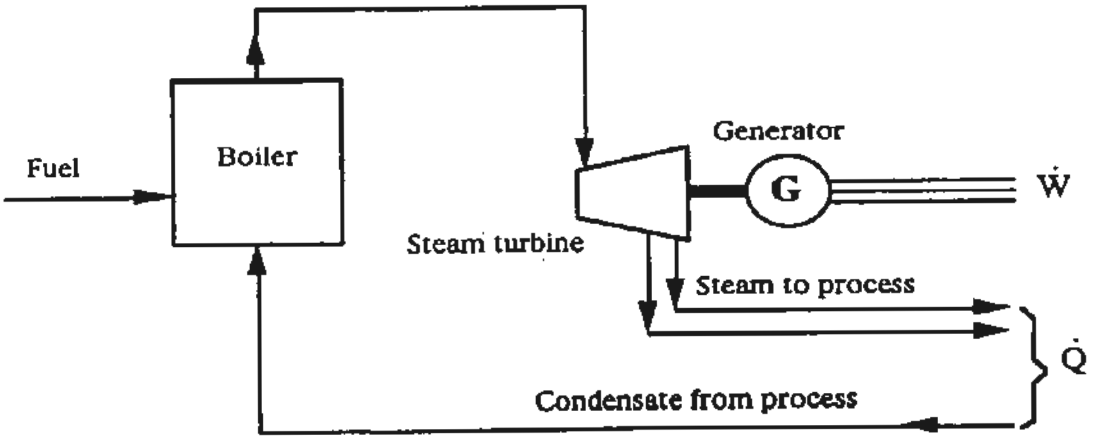

Figure 3.5 Power generation system with steam turbine [6]

Condensing Steam turbine systems

Such type of systems involved removal of thermal energy at least from one intermediate stage Figure 3.6 whenever its meet with required designed thermal load. The leftover steam is depleted to the weight of the condenser, which can be as low as 0.051 bar with coordinating consolidating temperature of about 33°C[19]. Usually the heat extracted from intermediate stage has very low in calorific value and hence use less and usually wasted in ambient.

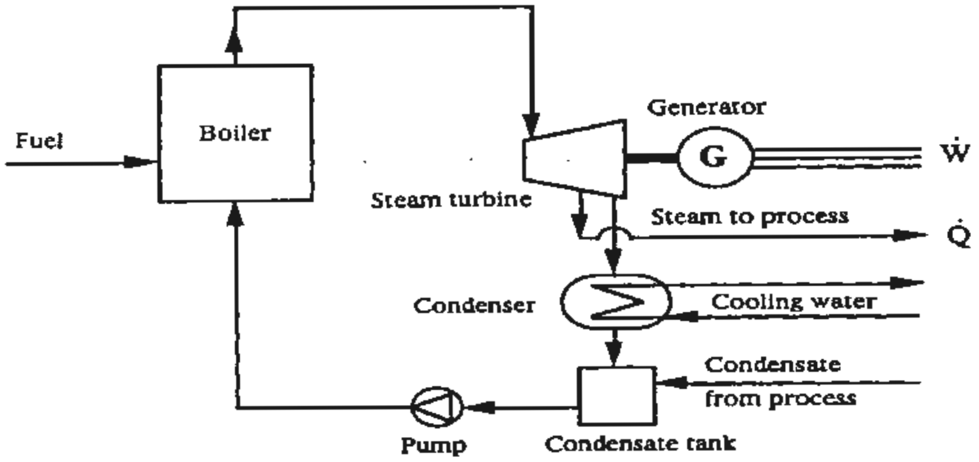

Figure 3.6 Power generation system with condensation turbine [6]

Extricated steam can likewise be utilized for regenerative food water heating, which enhances the Rankine cycle proficiency, and for driving supplementary gear [12].

As compared to back-pressure system, it required higher capital investment and has very poor efficiency. Though, it can regulate the electrical power self-sufficiently, to a definite extent, of the thermal load by good parameter of the steam flow rate through the turbine[20].

Bottoming Cycle Steam Turbine System

Many industrial processes (e.g. in steel mills, glass-works, ceramic factories, cement mills, oil refineries) various operations has been carried out at high temperature exhaust gases (1000.0-1200.0C). At the end of the process, these gases contain high temperature (500-600.0C).Despite wasting these high temperature flue gases into the atmosphere and disturbing ecology of the region, these gases can be used in a heat recovery system like Heat Recovery Steam Generator (HRSG) to drive a steam turbine [21].

Using this scheme, first hand fuel can be used to produce thermal energy and can generate electricity from byproducts (bottoming Cycle) as shown in Figure 3.7.

In Figure 3.7, a condensing steam turbine is shown, however, a back-pressure turbine can also be used[21].

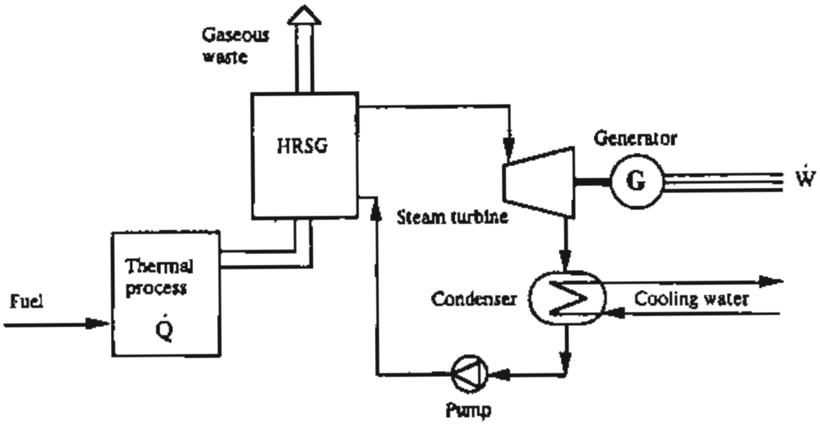

Figure 3.7 Steam Turbine with bottoming cycle cogeneration [6]

3.6 Combined Cycle Cogeneration Systems

Combined cycle means coupling of two system of thermodynamics which have relation with working fluid and having different temperature gradient. Topping cycle is higher in temperature and rejects the heat, which may be recovered and can be utilized by the botomm cycle or low temperature cycle to produce energy which may be electrical or mechanical which improves the overall efficiency[7].

3.6.1 Rankine Cycle System

A simple explanation of components in the diagram is representation of Combined Joule – Rankine Cycle Systems more elaboration of system with a double-pressure boiler and gives its enactment features[12]. Double- or triple-pressure steam boilers improves the heat regaining and improves the efficacy. Disadvantage of this is that system becomes complex so they are only viable in the bigger systems. This is not the final arrangements of components, other options should also be considered.

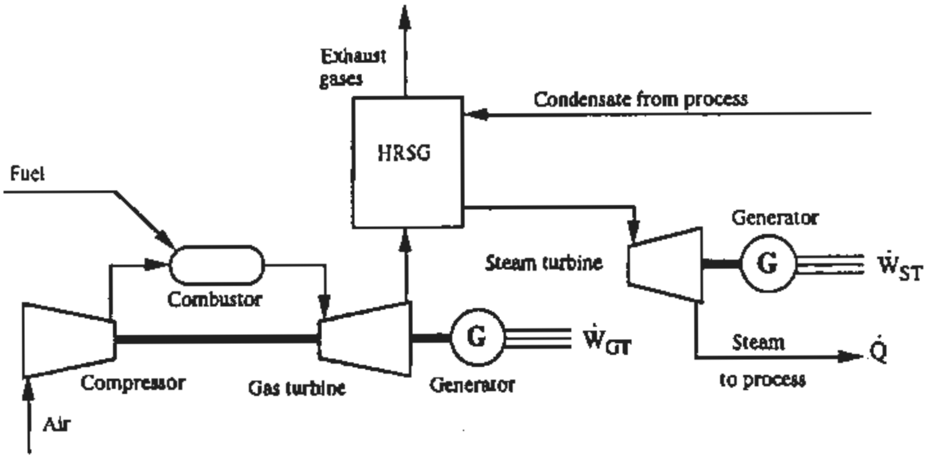

Figure 3.8Reverse pressure turbine with combined cycle generation system [3]

The most extreme conceivable steam temperature with no supplementary terminating is by 25-40.0C .which is lesser than the fumes gas temperature at the way out of the gas turbine. While the steam weight can be achieved at 80 bar.

Additional heat is supplied by using the burners in the boiler if temperature and pressure are required with higher values. This cost of the combustion of additional fuel[19].

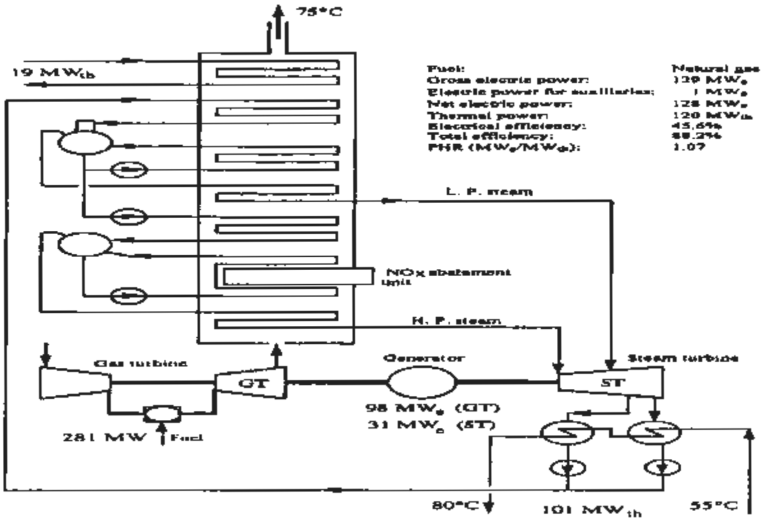

Figure 3.9 Extraction Turbine with cogeneration system [3]

Joule – Rankine /combined cycle systems very much reliable, its reliability is so high that it is 81 to 85.1%, the annual average availability is 77.0–85.0% and the economic life cycle is 14–25.0 years.

Other salient features are electric efficiency which is up to 34-45% and net efficiency is ranging from 70 to 80 % while it gives power to heat ratio which is 0.61 to 2. Electrical efficiency can be further enhanced. The electric efficiency can be increased further. It can be increased up to 60% by using additional heating or improving the heat extraction.

3.6.2 Combined Diesel – Rankine Cycle Systems

Coupling of diesel cycle with Rankine cycle is also possible. Arrangements for such coupling of cycles is very similar to the Joule – Rankine/combined cycle systems also shown in the diagram, main change is the gas turbine unit (compressor – combustor – gas turbine) is replaced by a Diesel engine. Medium to high power engines may make the addition of the Rankine cycle economically achievable [8]

4 Thermodynamic Performance

4.1 Reciprocating IC Engine Cogeneration Systems

I.C engines (Reciprocating) are highly efficient and are available in many sizes starting from 75 kW to 50 MW. They have ability to operate on different liquid and gaseous fuels, and are also easily available (80–90%). Due to these characteristics I.C engines are first choice in industrial, residential and commercial sector, not only this but also in the academia where load is not as high as industrial setup.

4.1.1 Taxonomy of Reciprocating IC Engine Cogeneration Systems

The IC engine systems are classified on two characteristics;

Their classification is based on the operating cycles which is Otto and diesel cycle. In Otto cycle spark plugs are used for the combustion of fuel and usually natural gas or gasoline is used as fuel while in diesel cycle combustion take place due to the high compression of the fuel and diesel is used as fuel.

Cogeneration system can also be classified on basis of engine size:

- Small power systems installed with Diesel engine (75–1000.0 kW) or gas engine (15–1000.0 kW).
- Medium units (1.0–6.0 MW) with Diesel or gas engines.
- High power units (greater than 6.0 Mega Watt) installed with Diesel engines.

Following types of Gas-engines are commercially available.

- Small engines are light with high power to weight ratio (15–30kW) and usually used as gasoline engines in cars.

- Diesel engines presently used in cars are available in maximum power 200 kW rating. Since the excess air can be adjusted accurately. The conversion to gas engines most of the timedoes not reduce the power.
- Heavy duty engines (power output 3000 kW) work as stationary engines and manufactured for heavy industries or maritime applications.
- Dual-fuel engines are Diesel engines with maximum output power 6 MW.The whole sum of energy needed is 90% out of which 10% has generated by natural gas and furnace oil.

Knock resistance of fuel can be calculated by the methane number i.e Number of molecules can be produced by a single molecule of fuel or number of molecules of methane present in wt %age.

The methane number of High-knock-resistant methane is100 while the methane number of butane is 10 and hydrogen has methane number of 0 which lies at the bottom of the scale as shown in

Table 4.1.

Fuel		Methane number
Name	Composition	
Hydrogen	H_2	0
Methane	CH_4	100

Table 4.1 Methane number of gaseous fuels [4]

Diesel engines are delegated fast, medium-speed and low-speed engines. Table 4.2gives the speed and power ranges for each type

Type	Speed (RPM)	Power (kW)
High-speed	1200 – 3600	75 – 1500
Medium-speed	500 – 1200	500 – 15000
Low-speed	100 – 180	2000 – 50000

Table 4.2Speed-power range of Diesel engines [4]

4.1.2 Schematics of Reciprocating IC Engine Cogeneration Systems

Illustrates a comprehensive stream graph of such a framework, without being the main conceivable setup (specifically concerning the game plan of heat exchangers). The motor whimsies the generator. Four heat exchangers recoup heat from liquids mandatory for the procedure of the motor: greasing up oil cooler, coat water cooler (shut circuit of the motor), charge air cooler, and fumes gas heat exchanger (or heater). The recouped heat produces high temp water and steam, as in Figure3.5.1, or it can be used for comparable industrial uses[13]. In small engines, the existing heat might not be enough to generate steam generation economically viable; in such scenario hot water is supplied.

The water is heated to 75-80°C with heat recovered from the coolers. The pre-heated water is then enters in heat exchanger (exhaust gas) where its temperature is increased to 85-95°C and evaporation occur. Saturated steam of 180-200°C is usually produced by medium size engines, while large engines can provide superheated steam at 15.0–20.0 bar pressure with temperature 250.0-350.0°C. The base fumes gas temperature at the way out of the heat exchanger is 160-170C for fuels containing residuals of sulfur, similar to Diesel oil, or 90-100□C for without sulfur fuels like characteristic.

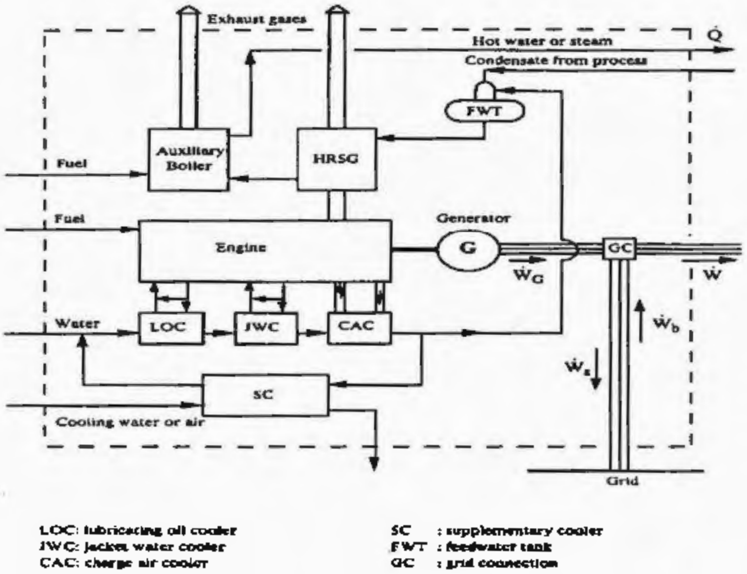

Figure 4.1 Cogeneration system flow with reciprocating I.C engine [19]

4.1.3 Thermo-dynamic Performance of Cogeneration Systems with I.C Engines (Reciprocating)

The electrical efficiency of small and medium size engines is 35.2–45.3% and efficiencies of modern large gas engines are around 50.0%. The total efficacy of the system is around 70–85%. The power to heat ratio is around 0.81–2.38, and highest of the above discussed three systems are examined to this level.

Reciprocating IC engines have the ability to maintain the efficiencies over a broad range of operations at different loads. Engine manufacturing Companies give partial load production by the usage of either tables, logs or graphs.

5 Design, Process and Selection of Cogeneration Systems

The selection best appropriate cogeneration system technology and system proposal for a specific scenario is the biggest challenge. This problem is briefly discussed in the following section.

5.1 Technique for System Selection and Design

The possible variations in energy requirements must be considered before any contemplation of cogeneration. Energy sparing measures, demand administration, changes in procedures can be financially effective in them as well as influence the sort, size and financial matters of the cogeneration framework.

The assortment of the optimal cogeneration system must be based uponstandardsindicated by the financier and end user of the system keeping in view the economic routine, energy efficiency, continuous operations and other various performance procedures. The inquiry postured, in the early, on passage can be expressed all the more unequivocally as an arrangement of choices that must be made with respect to set of choices.

The category of cogeneration framework (steam turbine, gas turbine, reciprocating engine, combined cycle, etc.),

- number and minimal power of prime movers
- equipment required for heat recovery
- thermal and electric storage requirements
- Operation modes i.e. electrical and thermal power can operate at any heat recovery time

The entire action from the starting origination to the last outline can be isolated in three steps:

- Initial assessment.
- Feasibility study and system selection.
- Comprehensive design.

The activities to be achieved in each step are defined briefly in the following sections.

5.1.1 Initial Assessment

An examination of the site is performed keeping in mind the end goal to achieve a first appraisal of the specialized conditions. Characteristics which are inspected include the following:

- Maximum Levels and period of electrical/thermal loads.
- Energy saving methods assessment before cogeneration.
- Process changing probability which can affect electrical and thermal loads.
- Handiness of space for placement of the cogeneration system.
- Cogeneration may have influence on generation and operation of the equipment used in the power generation such as chillers, heat exchangers, boilers etc.
- Pre-feasibility study is always desirable for an improved 0evaluation at this level.

5.1.2 System Selection and Feasibility Study

This is the most important stage since it will be concluded whether or not the cogeneration is feasible and which is the best design for the specific problem. It comprises the following whereabouts.

1) Accumulation of information and drawing of load profiles for the different vitality structures required: power, heat as steam at different pressure and temperature levels, heated at boiling point water at different temperatures, cooling necessities, etc.
2) Knowledge about tariffs of electricity and fuel, as well as local regulatory body and legislation.
3) Choice of cogeneration technology can deliver the eminence of heat required.
4) Choice of the quantity of units and of the limit of every unit. From the perspective of power effectiveness, the determination ought to be such that the cogenerated heat is utilized, maintaining a strategic distance from environmental issues.
5) Choice of the process mode and count of the energy and financial matters of execution. Calculations might be revised for different operation modes.
6) The best performing framework will be selected. Single- or multi-criteria methodology can be followed.

In case of an impulsive switching between the electrical/thermal loads, this is always beneficial to inspect the technical and financial viability of thermal storage or electrical storage to maximize the operation of cogenerated electricity and heat.

5.1.3 Comprehensive Design

For the framework chose in Stage II a point by point study takes after. There may be have to gather more precise and point by point data about load profiles and repeat activities 4 and 5 of Stage II at a higher profundity, with a specific end goal to either confirm or marginally change the primary attributes of the system. Detailed specialized particulars of the principle units are composed down, including limit, proficiency and controls, as well as outflows, commotion and vibration levels. Details for other real segments are likewise arranged.

At long last the site of the framework is chosen and the configuration study is actualized delivering the fundamental drawings for development or adjustment of the building (if necessary) and for the establishments of the framework.

Development drawings are readied for fuel supply (counting tanks, if vital), air gulf and fumes gas conduits, funneling, electric hardware and network interconnection.

5.2 Graph for Loads

5.2.1 Graph for loading profiles

Both electrical loads and thermal loads of a framework are function of time. Every specific type of energy required has its own specifications: power, nonstop utilization of fumes gasses, high-pressure-steam, low-temperature-steam, boiling hot water, chilly water, and so on. Besides, the tops of the different loads typically don't happen in the meantime. To choose a framework on the premise of normal load, most likely will bring about low yearly aggregate proficiency, low yearly fuel efficiency reserve funds proportion and poor financial execution. Preferably, the study should be in light of information of every specific load in each of the 8760.02 hours of the year, also variations of load from year to year. The trouble dependably is the manner by which to gather the appropriate information and to prepare those with a specific end goal to deliver pretty much precise profiles.

In case of newly designed system, helpful performance data is other comparable systems, for which information are accessible; nonetheless, changing outline practices, innovation and procedure changes and expanded sympathy toward energy reserve funds and ecological security may bring about huge decrease in energy necessities of new structures or commercial enterprises. Another source is the outline studies for procedures (in an industry) and for HVAC of structures. Estimation for structures can likewise be in view of parameters, for example, normal utilization per unit volume of possessed space, normal high temperature water utilization per unit, constantly joined with day by day circulation of material in the specific kind of building. More expand techniques utilization particular PC programming for capacity forecasts.

For current systems, electrical and regular gas practicalities may have the capacity to give heat energy utilization information. Optional foundations may be the fuel prices, location information administration frameworks, steam outlines and powerhouse logs. Data logs might likewise give information that are helpful in assessing energy prerequisites. Earlier investigations of energy utilization, energy sparing methods and interest side administration may give helpful data as well.

Many thermal loads are known elements of surrounding circumstances. Case in point, space heating loads are essentials of the surrounding temperature.

On the off chance that sophisticated information are not accessible, before continuing to the last determination and measuring of the cogeneration framework, there may be have to direct an observing program in co-operation with the utility and/or by interim establishment of metering equipments. The observing system might likewise serve in recognizing among the different employments of vitality structures.

Any arrangements for future augmentations, obliterations or changes to the office and its procedures ought to be contemplated for anticipating future burdens.

It is not rare that accessible information may contain mistakes because of a few reasons: erroneous meters, lapses in perusing, wrong procedure of crude information, and so forth. Along these lines, it is emphatically prescribed to cross-check the precision and consistency of information.

The point of all the exertion depicted in the past passages is to grow hourly load outlines for every day of a year. This is redundant, and may not be for all intents and purposes conceivable, to have 365 unique profiles. Contingent upon the accessible data, burden profiles are strained for gatherings of comparative (perspective of burden) days, as it is portrayed by the month or may be season, and also a day of the week. Illustrations are demonstrated in figures:

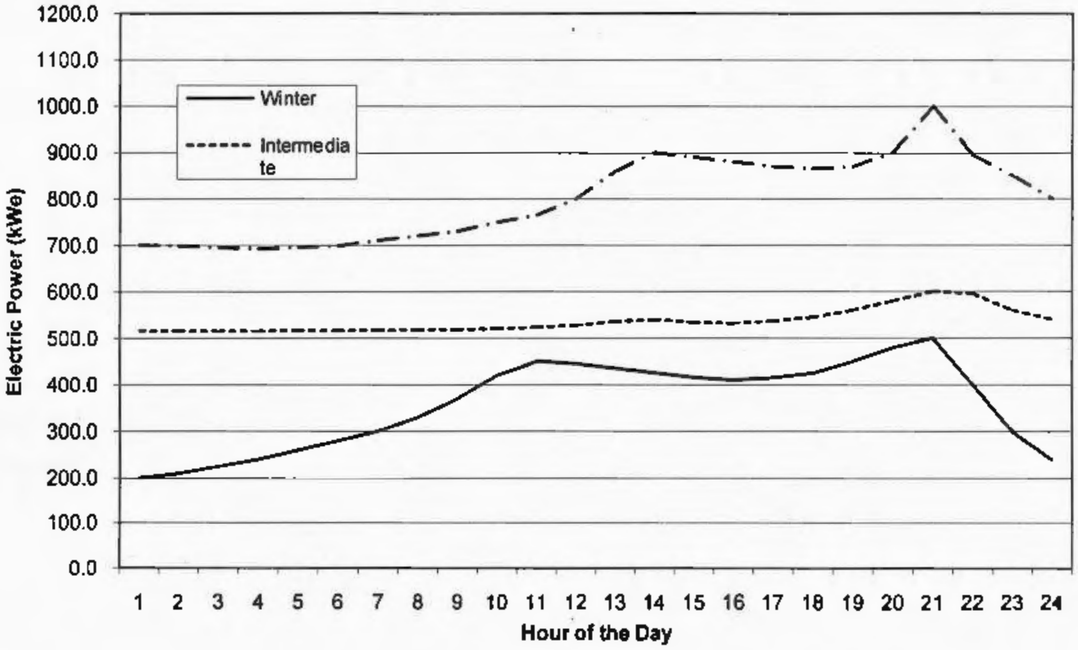

Figure 5.1 Hourly electric power profiles in a hotel [14]

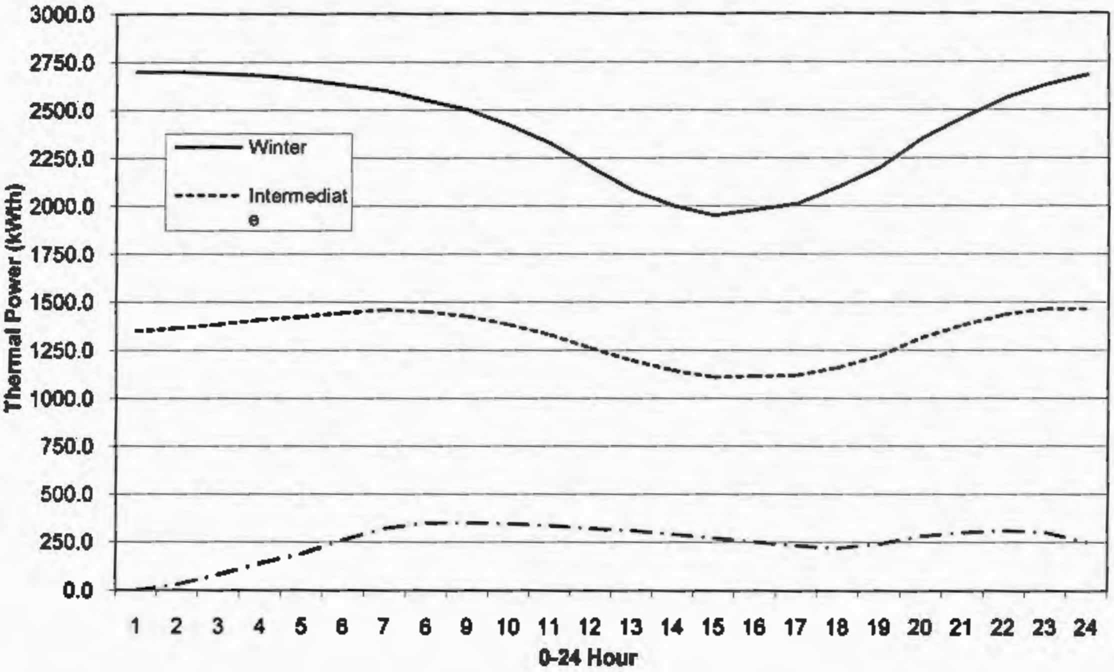

Figure 5.2 Hourly thermal power outlines in a hotel [14]

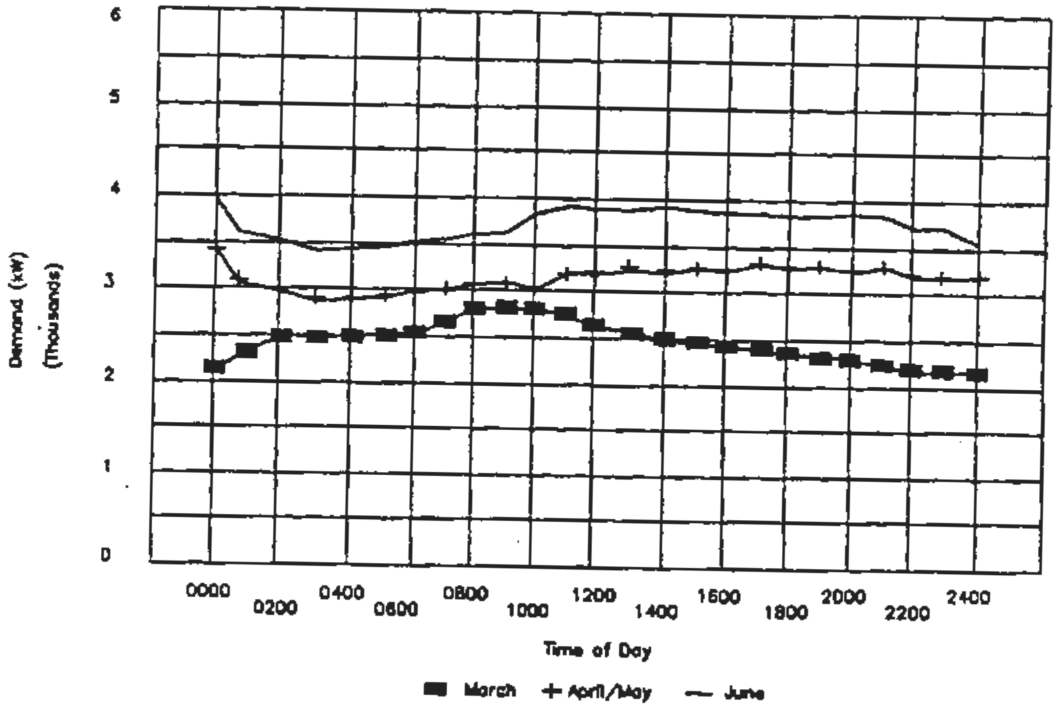

Figure 5.3 Monday to Friday profiles according to months (Hospital [14]

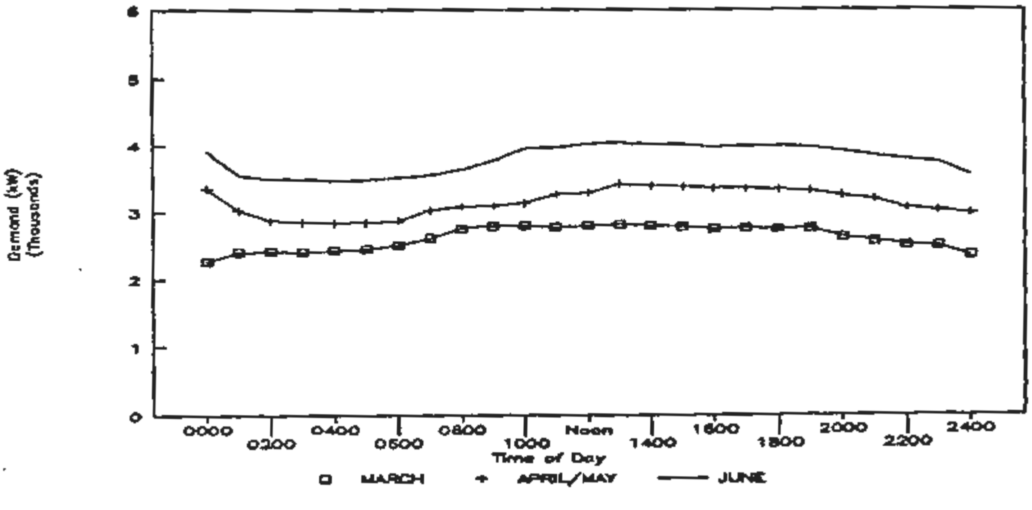

Figure 5.4 Saturday and Sunday profiles according to months (Hospital [14]

5.2.2 Recess in curves of load

After load summaries, it is valuable to sketch the load length of time curve for every type of energy that demonstrates the number of hours (in a year) that the obliged force surpasses a definite level. The coordinates of the chart can also be in outright values (kW. hours) or as rates (% of most extreme interest, % of time). A sample is delineated in Figure 5.5:

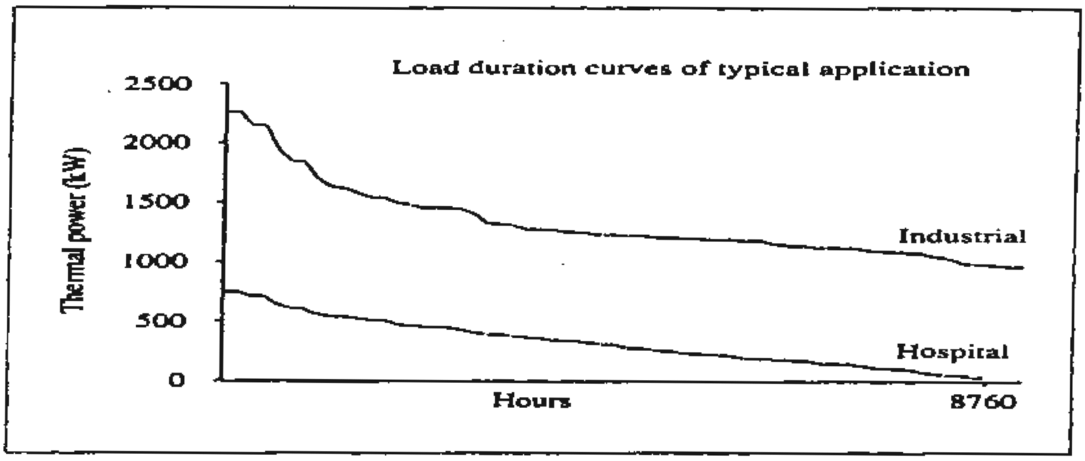

Figure 5.5 Load interval curves of the system [4]

5.2.3 Capacity or Load Curves

By incorporating focus to the area under the limit – load curves are generated, which narrates the force interest to aggregate site load (energy) that happens at particular force level. A practical illustration is given Figure 5.6.

According to Figure 5.6, specific office will utilize very nearly 90.2% of the vitality presupposed amid one month on force levels which are equivalent to 70.0% of the top or fewer. Therefore, if a motor generator system is introduced, measured at 70.0% of the top force, this will supply 90.0% of the energy presupposed during a month. With a specific end goal to build the energy supply from 90.0% to 100.0%, an increment of just 11.0%, the limit of the generator should be expanded from 70.0% to 100.0%, i.e. by 43.0%. Expanding the limits and hence the expenditure of a framework by more than 40.0% to build the energy utilized on location by just 11.0% may not be extremely financial understanding, except it is conceivable to offer overabundance power to the matrix under great monetary relations. Once more, it is important to consider regardless of whether the cogenerated-heat is utilized to a discriminating level.

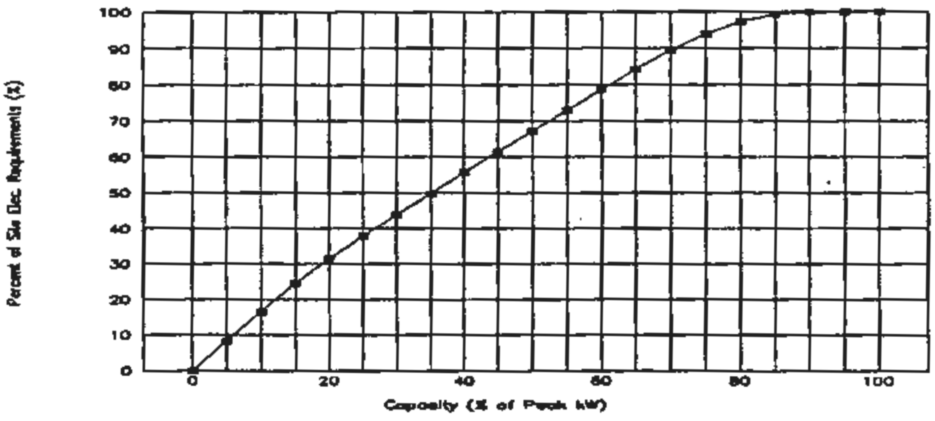

Figure 5.6 Sample capacity – load of a month [4]

6 Results and Recommendations

The selection of a cogeneration system is dependent on site thermal and electrical load, end user operational need, equipment and fuel availability and economics. A preliminary project evaluation requires a methodological approach. This chapter describes the methods for cogeneration project evaluation.

For Mathematical modelling of Cogeneration project evaluation, following formulas will be used.

6.1 MATHEMATICAL FORMULATION

Calculation of Steam Costs

To find Average cost of steam, following stepwise procedure is to be used:

1. For given steam pressure and temperature, read h_s, enthalpy of steam, from steam tables.
2. For given feed water temperature, read h_{fw}, enthalpy of feed water from steam table.
3. Determine boiler efficiency, consult boiler manual.
4. Calculate fuel requirement from the equation.

   $F = (h_s - h_{fw}) \times 100/E$

Where F= Fuel required, kJ/kg

E= Overall boiler efficiency,

h_s = Enthalpy of steam, kJ/kg

h_{fw} = Enthalpy of feed water, kJ/kg

5. Calculate cost of fuel/unit of steam from the equation;

   $C_F = F \times P/1000$

where C_F = Cost of fuel/ Tonne of steam

F= Fuel required, kJ/kg steam

P= Price of fuel, Rs/GJ

Assume other costs, such as feed water treatment and maintenance and operation of the boiler @ 3% of cost of fuel.

Calculation of unit cost of steam

Cost of fuel in Pakistan (Rs/GJ)

Fuel	Units	Energy Cost
Natural Gas	Rs/GJ	250

Boiler Operating Data

Overall Boiler efficiency		80%
Pressure of the steam	psig	200.00
Temperature of steam	Deg C	198.00
Enthalpy of steam	kJ/kg	2,791.00
Temperature of feed water	Deg C	70.00
Enthalpy of feed water	kJ/kg	289.00 (126 Btu/lb)
Change in Enthalpy	kJ/kg	2,502.00
Avg cost of fuel	Rs/GJ	250.00
Unit cost of fuel	Rs/Tonne	781.87

From the formulas given in 4 and 5.

$F = 2,502.00 \times 100 / 0.8 = 312,750$ kJ/kg

$C_F = 312,750 \times 250/(1000*10^3) = 781.87$ Rs/Tonne

Unit operating Cost	Rs/Tonne	23.45 (@ 3% of fuel)

Therefore

Unit cost of steam	Rs/Tonne	805.32

Calculation of Annual fuel requirement for cogen boiler

Annual fuel req = (Annual steam production x Energy req./tonne)/cogen boiler efficiency

Calculation of Fixed and Variable cost of power

For our base case, the following tariff will be used:

(All figures are in Rs/kWh)

Table: For Variable Costs

Tariff	Energy Charges	Additional Charges	FAC	TOTAL
B-3(up to 5000kW)	1.15	1.60	0.13	2.88

Table: For Fixed Costs:

Tariff	Fixed Charges
B-3(up to 5000kW)	290.00

For - base case:

Peak demand	kW	4,500
Operating hours/yr	hours/yr	8,760
Annual power demand	Mill.kWh	30.00
Avg demand	kW	3,425

Calculation for fixed cost of power:

Tariff classification	B-3	
Connected Load	kW	5,000
Peak demand (MDI)	kW	4,500
90% of MDI	kW	4,050
Fixed Charges/ month	Rs/kW	290.00
Total Fixed charges/ month	Rs/kW	11,745,00
Annual Fixed Charges	Rs.Mill	14.094
Fixed Charges/unit	Rs/kW	0.47

Calculation for Variable cost of power:

Energy charges	Rs/kWh	1.15
Fuel Adjustment	Rs/kWh	0.13
Additional charges	Rs/kWh	1.60
Variable cost / unit	Rs/kWh	2.88

Total Cost / unit	Rs/kWh	3.35

6.2 BASE CASE

Base Case Data

Number of working hours per year	hours/yr	8,760
Cost of fuel	Rs/GJ	250.00
Annual process steam requirement	Tonnes	131,400
Maximum steam demand	Tonnes/hr	20.00
Average steam demand	Tonnes/hr	15.00
Base steam load	Tonnes/hr	10.00
Cost of steam	Rs/Tonne	805.32
Annual process power requirement	Mill. kWh	30.00
Peak power demand	kW	4,500

Average Power demand	kW	3,425
Base Power Load	kW	3,300

6.2.1 COGENERATION WITH STEAM TURBINE

Calculation for separate production of process steam

Annual cost of steam = Avg cost of steam x Annual process steam requirement (i)

= 805.32 x 131,400 = 105.81 Rs Mill/yr

So

Annual cost of steam	Rs Mill/yr	105.81

Calculation for separate production of process power

Annual cost of power = Total unit cost x Annual process power requirement

= 3.35 x 30.00

= 100.5 Rs Mill/yr

So

Annual cost of steam	Rs Mill/yr	100.5

Calculation for Cogenerated steam and power

<u>Cogeneration Boiler:</u>

Steam Temperature	Deg C	400.00
Steam Pressure	Bar	41.37
Steam Enthalpy	kJ/kg	3,225.00
Feed water Enthalpy	kJ/kg	209.00(@50 Deg C)
Energy required/tonne steam	GJ/Tonne	3.016
Annual steam Production	Tonnes	131,400(Base Case)
Cogen boiler efficiency	%	90.00%

Annual Fuel Requirement	GJ	440,336
Price of fuel	Rs/GJ	250.00
Annual cost of fuel	Rs.Mill	110.084
<u>Turbo-Generator:</u>		
Theoretical Steam Rate (TSR)	kg/kW	8.52
Turbo-Generator Efficiency	%	75.00
Actual steam rate	kg/kW	11.36
Maximum steam demand	kg/hr	20,000(Base Case)
Peak power generation	kW	1,761
Avg steam demand	Tonnes/hr	15.00
Avg power generation	kW	1,320
Number of working hours/ yr	hours	8,760
System availability factor	%	95.00%
Total power generated	Mill. kWh/yr	10.99
Power required for auxiliaries	Mill. kWh/yr	0.44
Useful power generated	Mill. kWh/yr	10.55
Annual process power req.	Mill. kWh	30.00
Power to be purchased	Mill. kWh	19.45

Since Power produced by turbo-generator is lesser than the annual process power requirement, so we have to buy remaining energy from grid station.

Total Fixed cost of power	Rs Mill/yr	14.094
Variable cost of purchased power	Rs/kWh	2.88

Total Variable cost of purchased power	Rs Mill/yr	56.016
Annual cost of purchased power	Rs Mill/yr	70.10
Annual cost of fuel	Rs Mill	110.084

Annual Cost of energy	Rs Mill/yr	180.184
Annual cost of maintenance and operation	Rs Mill/yr	9.00(@5% of Capital)

Total annual operating cost of cogen system	Rs Mill/yr	189.184
Base Case power cost	Rs Mill/yr	100.5
Base Case steam cost	Rs Mill/yr	105.81
Total Base Case Operation cost	Rs Mill/yr	206.31

Net Savings	Rs Mill/yr	17.12

6.2.2 COGENERATION WITH GAS TURBINE

Base Case annual cost of steam	Rs Mill/yr	105.81
Base Case annual cost of power	Rs Mill/yr	100.5

Calculation for Cogenerated steam and power

Gas Turbine:

Efficiency of Gas turbine	%	25.00
Base power load	kW	3,300
Number of working hours / yr	hours/yr	8,760
System availability factor	%	95.00%
Number of operating hours	hours/yr	8,322
Total power generated	Mill. kWh/yr	27.46 (3300x8322)
Fuel required	GJ/yr	395,461
Power required for auxiliaries	Mill. kWh/yr	0.82
Useful power generated	Mill. kWh/yr	26.64
Annual process power req.	Mill. kWh	30.00
Power to be purchased	Mill. kWh	3.36

Since Power produced by Gas turbine is lesser than the annual process power requirement, so we have to buy remaining energy from grid station.

Total Fixed cost of power	Rs Mill/yr	14.094
Variable cost of purchased power	Rs/kWh	2.88

Total Variable cost of purchased power	Rs Mill/yr	9.676
Annual cost of purchased power	Rs Mill/yr	23.77

Waste Heat Boiler:

Feed water Enthalpy	kJ/kg	289.00
Steam temperature	Deg C	198.00
Steam pressure	psig	200.00(sat.)
Steam Enthalpy	kJ/kg	2,791.00
Energy req./Tonne steam	GJ/Tonne	2.502
Heat recovered as % of fuel input	%	45%
Energy input into turbine	GJ/yr	395,461
Total heat recovered	GJ/yr	177,958
Steam generated	Tonnes/yr	71,126(177958/2.502)
Number of operating hours	hours/yr	8,322
Steam Rate	Tonnes/hr	8.55(71,126/8,322)
Base load steam demand	Tonnes/hr	10.00

Note: Steam produced by waste heat boiler is less than base steam load.

Cost of fuel for gas turbine:

Annual fuel req. of cogen system	GJ	395,461
Price of fuel	Rs/GJ	250.00
Annual cost of fuel for cogen system	Rs.Mill	98.86

Output	Small Units	Medium Size Unit
Electricity	21%	29%
Exhaust heat(Theoretically recoverable)	53%	46%
Exhaust heat(not recoverable)	21%	20%

Generator, Oil cooler and radiation losses	5%	5%
Total	100%	100%

Cost of steam for existing low pressure boiler:

Annual process steam req.	Tonnes/yr	131,400
Steam generated by cogen system	Tonnes/yr	71,126
Steam req. by low pressure boiler	Tonnes/yr	60,274
Cost of steam from low pressure boilers	Rs/Tonne	805.32
Annual Steam cost from low pressure boilers	Rs Mill/yr	48.53

Annual cost of purchased power	Rs Mill/yr	23.77
Annual cost of fuel	Rs Mill	98.86
Annual steam cost from low pressure boiler	Rs Mill/yr	48.53
Annual Cost of energy	Rs Mill/yr	171.16
Annual cost of maintenance and operation	Rs Mill/yr	8.558
Total annual operating cost of cogen system	Rs Mill/yr	179.72
Base Case cost for purchased power	Rs Mill/yr	100.5
Base Case cost for steam	Rs Mill/yr	105.81 Rs Mill/yr
Base Case operating cost	Rs Mill/yr	205.86

Net Savings	**Rs Mill/yr**	**26.14**

6.2.3 COGENERATION WITH RECIPROCATING ENGINES

Base Case annual cost of steam	Rs Mill/yr	105.81
Base Case annual cost of power	Rs Mill/yr	100.5

Calculation for Cogenerated steam and power

Generator Sets:

Number of sets		8
Capacity per set	kW	600.00
Total generating capacity	kW	4,500
Annual power generation	Mill kWh	30.00
Generator Efficiency	%	31.00%
Annual fuel use	GJ	348,387
Cost of fuel	Rs/GJ	250.00
Annual fuel cost	Rs Mill/yr	87.10

Waste Heat Boiler:

Annual fuel use	GJ/yr	348,387
Percent heat recovery	%	15.00%
Heat recovered	GJ/yr	52,258
Stem temperature	Deg C	147.00
Steam pressure	psig	50.00
Steam enthalpy	kJ/kg	2,742
Feed water Enthalpy	kJ/Kg	289.00(@70 Deg C)
Energy req./Tonne steam	GJ/Tonne	2.453
Steam generated	Tonnes/yr	21,304
Number of working hours/yr	hours/yr	8,760.

Avg steam production	Tonnes/hr	2.43
Cost of steam from existing low pressure boiler:		
Annual process steam req.	Tonnes/yr	131,400
Steam generated by cogen system	Tonnes/yr	21,304
Steam req. from low pressure boilers	Tonnes/yr	110,096
Cost of steam from low pressure boilers	Rs/Tonne	805.32
Annual steam cost from low pressure boiler	Rs Mill/yr	88.66

Annual cost of fuel	Rs Mill	87.10
Annual steam cost from LP boilers	Rs Mill/yr	88.66
Annual cost of energy	Rs Mill/yr	175.76
Annual cost of maintenance and operation of cogen system	Rs Mill/yr	8.79(@5% of capital)
Total annual operating cost for cogen system	Rs mill/yr	184.54
Base Case cost of steam	Rs mill/yr	105.81
Base Case cost of power	Rs mill/yr	100.5
Base Case operating cost	Rs mill/yr	260.31
Net Savings	**Rs Mill/yr**	**21.77**

Set of Generators are installed at a unit whose exhaust is taken common and is used as inlet to the furnace, which will preheat the steel bars in the furnace to reduce the amount of primary fuel used for heating purposes.

Before moving to simulation results and discussion it is necessary to have understanding about the boundary conditions given to this specific scenario;

Given conditions are as under;

Input Temperature (Temp of generator's exhaust gas) = 485 ^{0}C

Mass Flow rate (of exhaust gas from generator) = 4473 Kg/hr

6.3 Simulation Results

The simulation to verify the temperature gradients has been done in ANSYS 15.0. In the FE analysis transient flow has been observed in the furnace with the time. It is to note that no external force or agent has been used in to propagate the temperature. Only the mass flow rate from the exhaust of the generators has been used for this purpose which has virtually no operating cost.

We have used following parameters to achieve desired results for existing problem

1- Static pressure across the outlet.
2- Static temperature across the outlet.
3- Magnitude of velocity across the outlet.

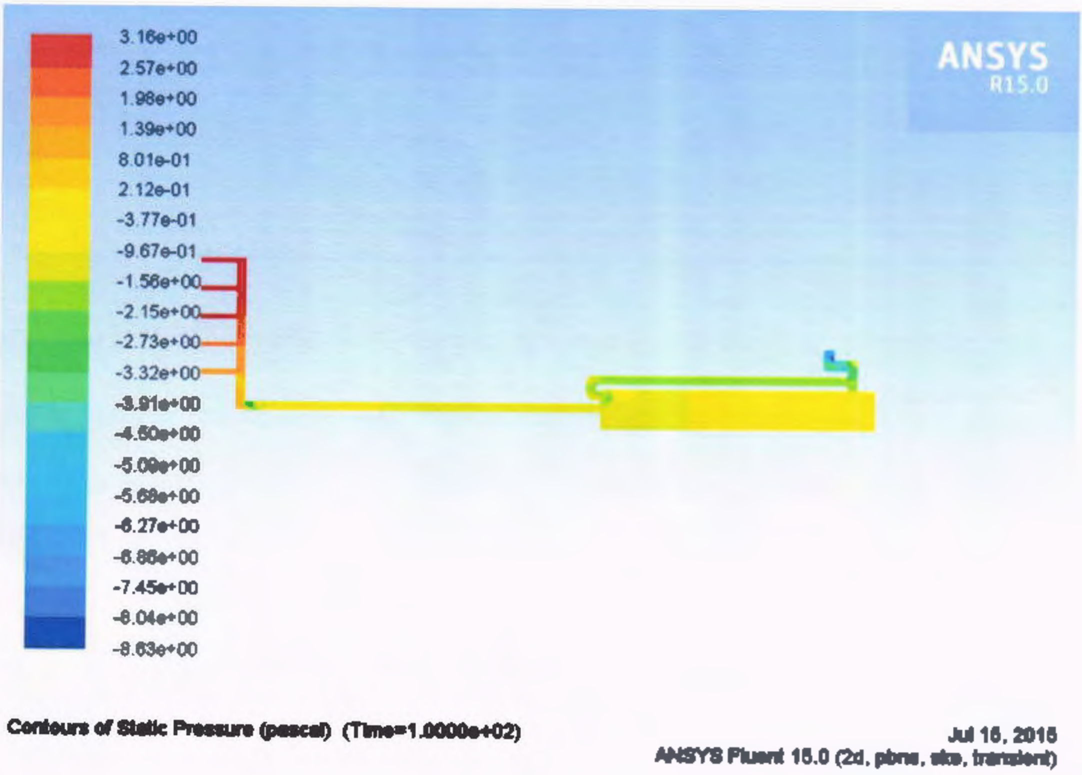

Figure 6.1 Gas Pressure at t=100 sec

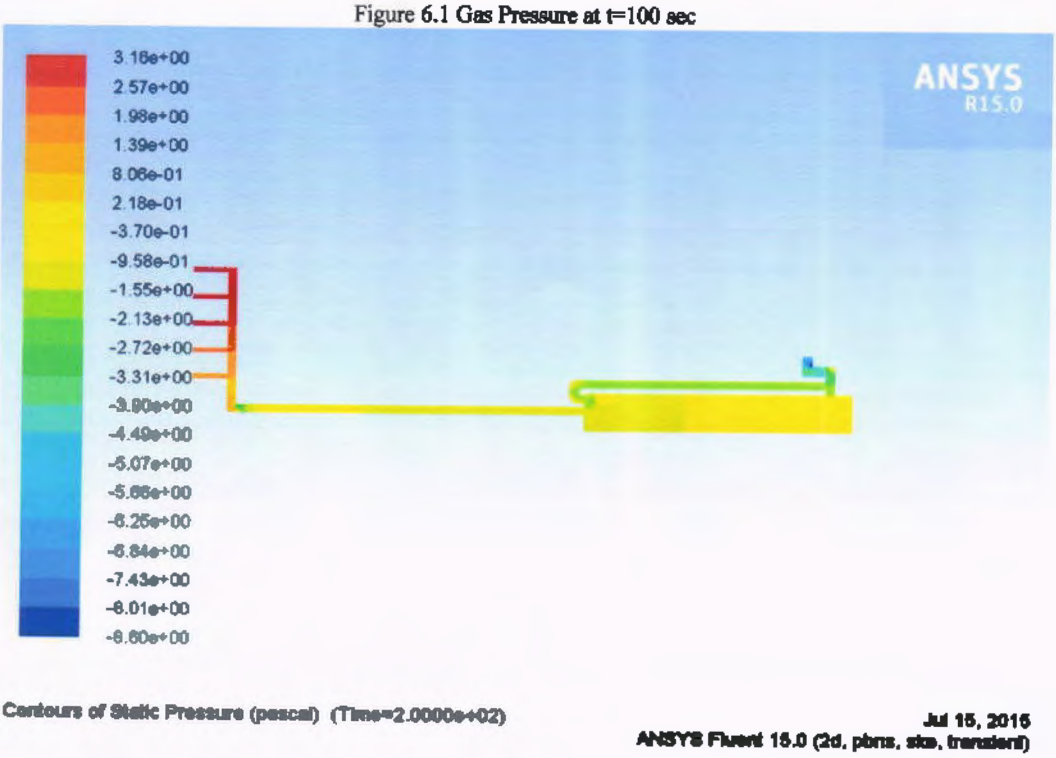

Figure 6.2 Gas Pressure at t=200 sec

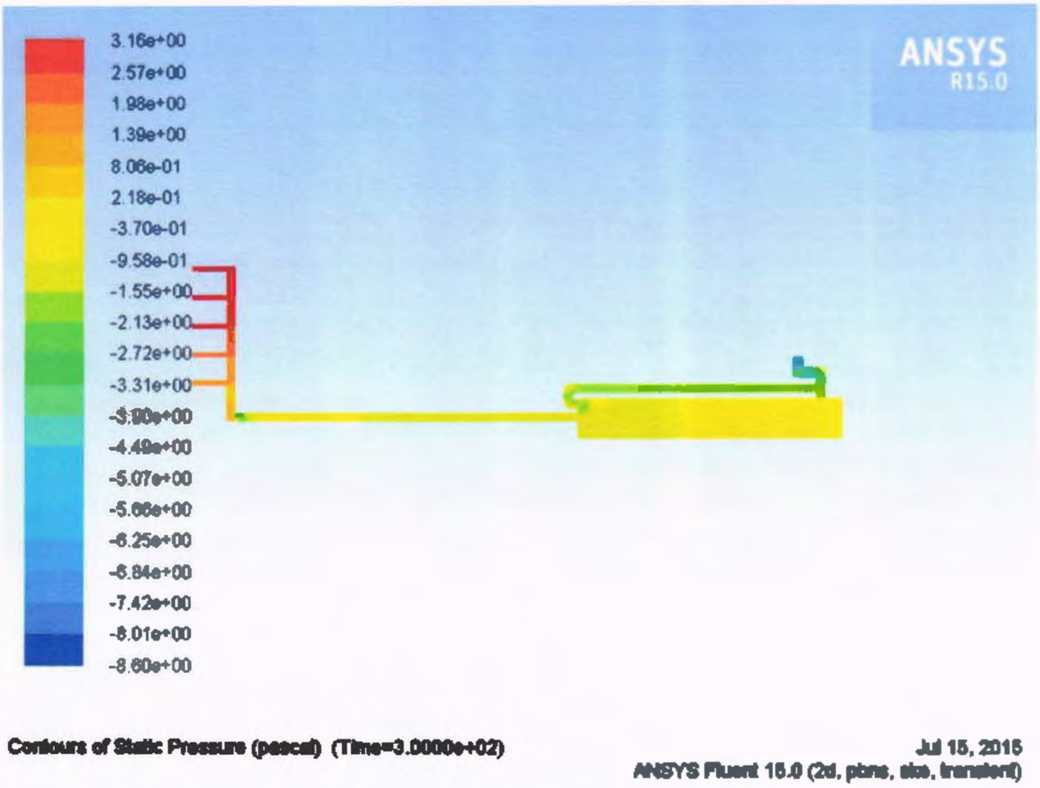

Figure 6.3 Gas Pressure at t=300 sec

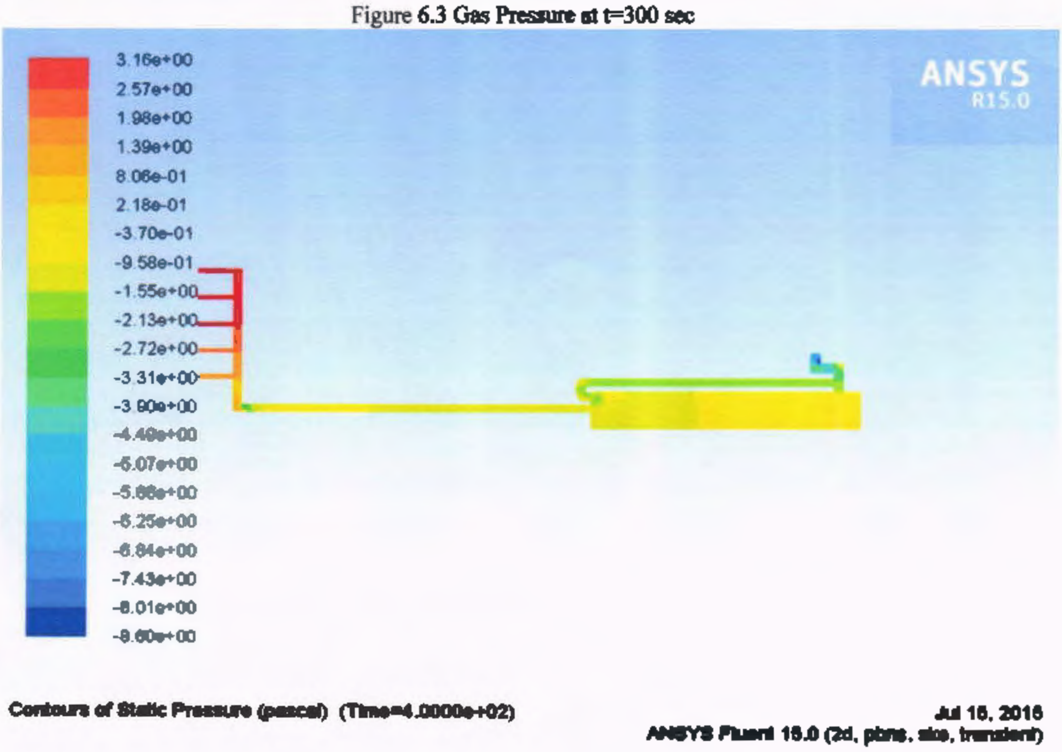

Figure 6.4 Gas Pressure at t=400 sec

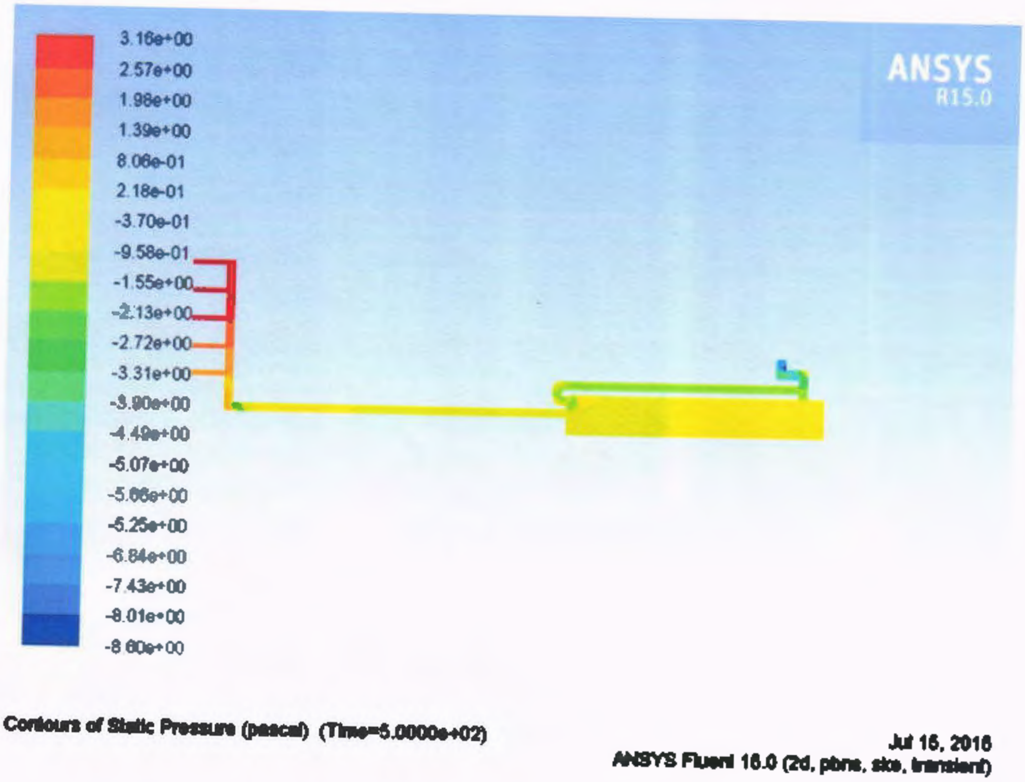

Figure 6.5 Gas Pressure at t=500 sec

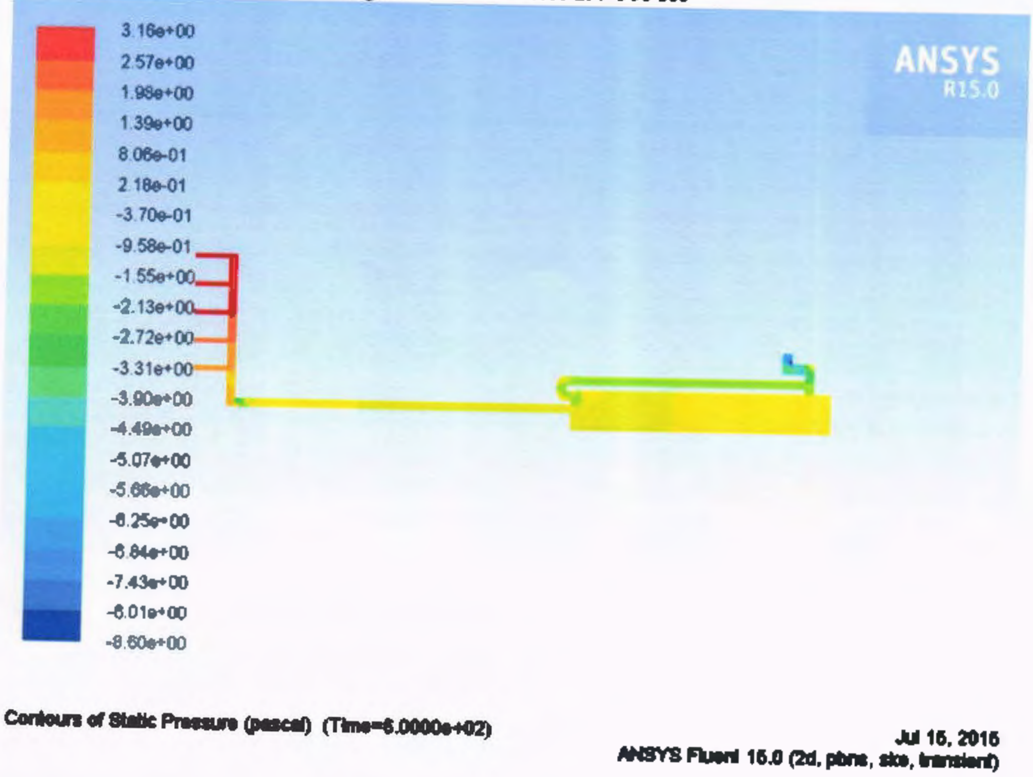

Figure 6.6 Gas Pressure at t=600 sec

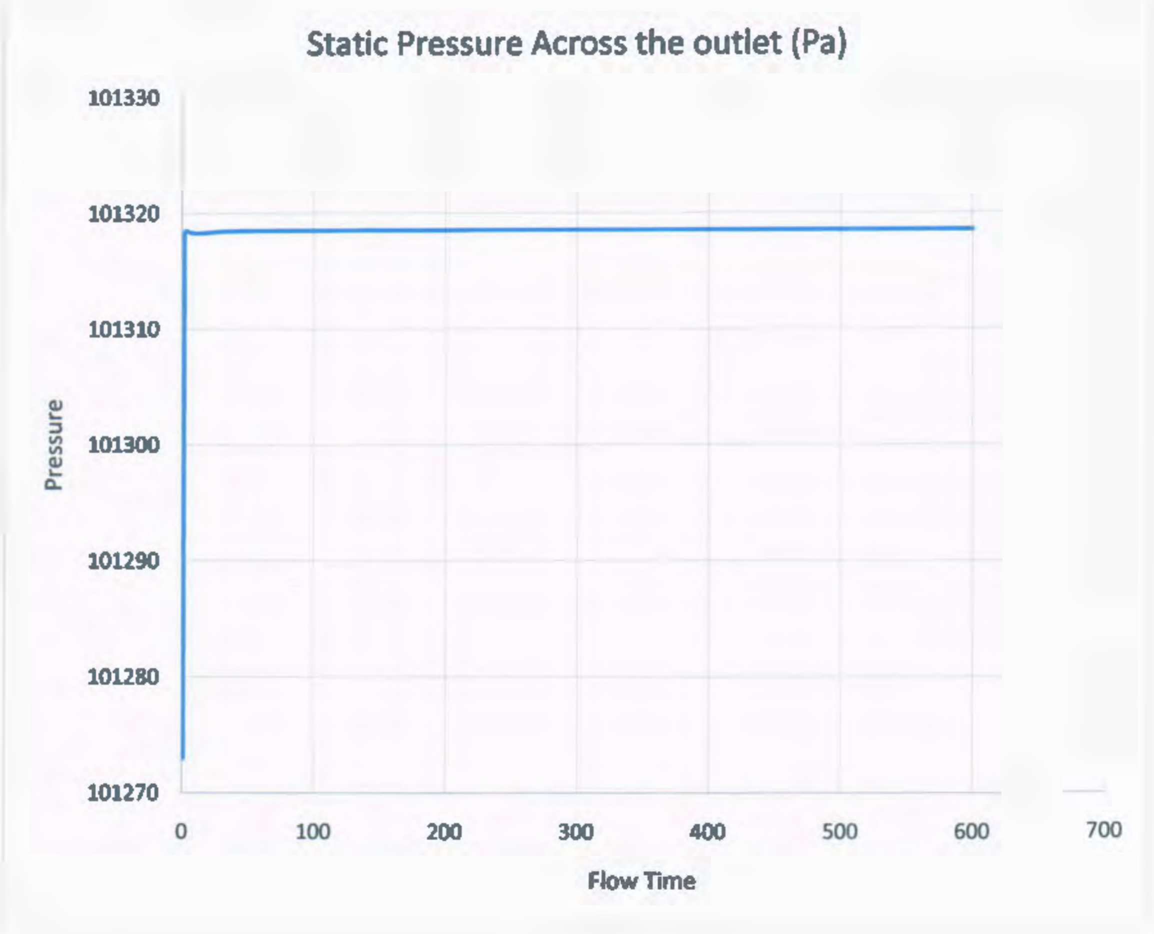

Figure 6.7 Static Pressure Across the outlet

STATIC PRESSURE ACROSS THE OUTLET.

We have considered static pressure across the outlet of generator i.e. inlet to furnace, at time from 0 to 600 seconds. Graph shows that the static pressure remains constant throughout the flow time which represents that flow of gases will not be disturbed during the process.

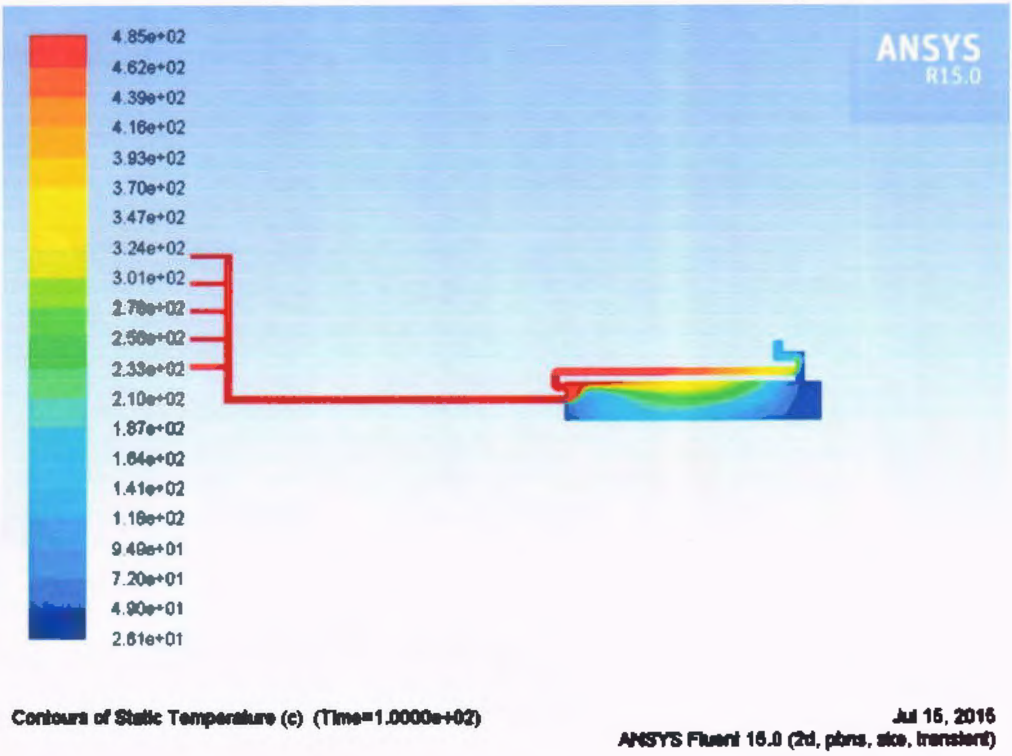

Figure 6.8 Temperature at t=100 sec

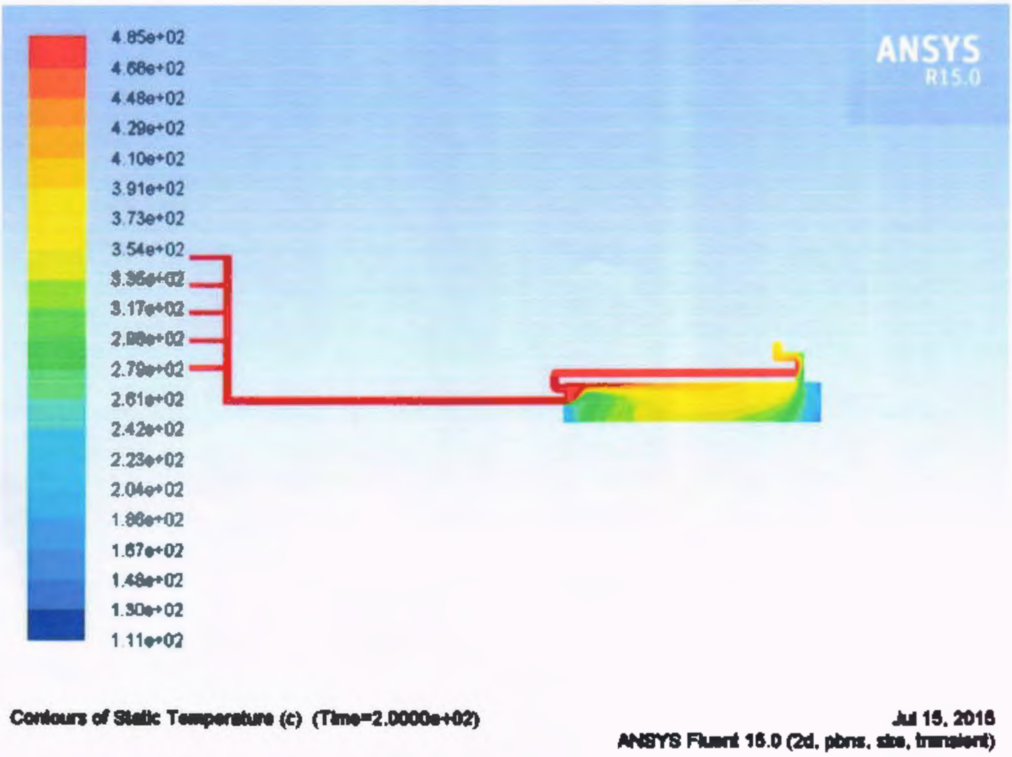

Figure 6.9 Temperature at t=200 sec

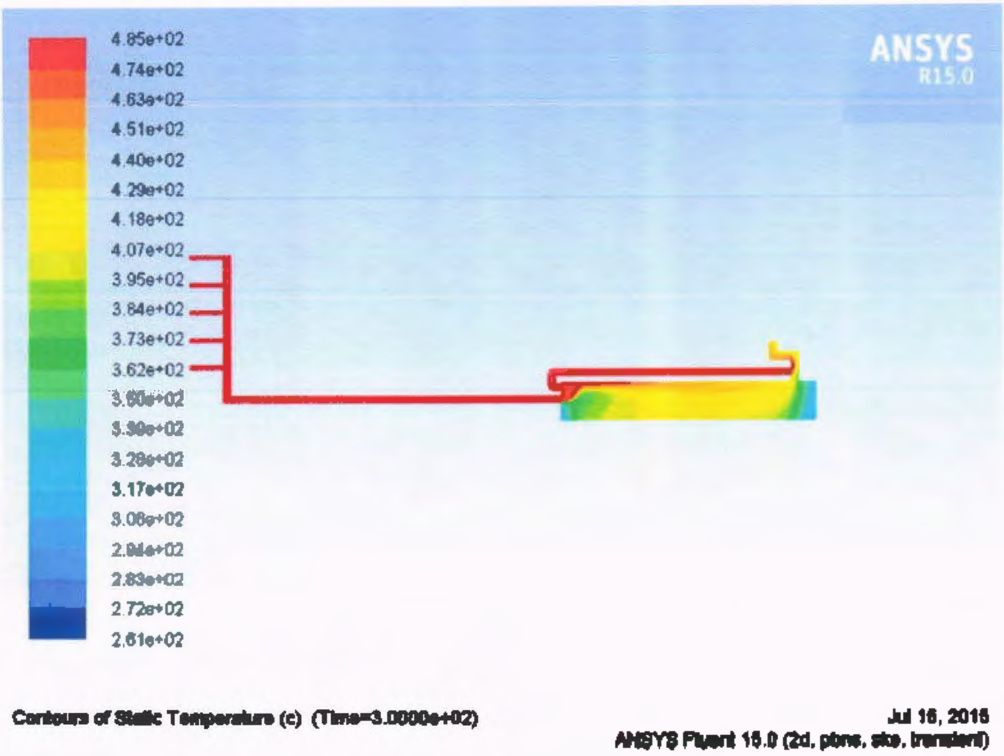

Figure 6.10 Temperature at t=300 sec

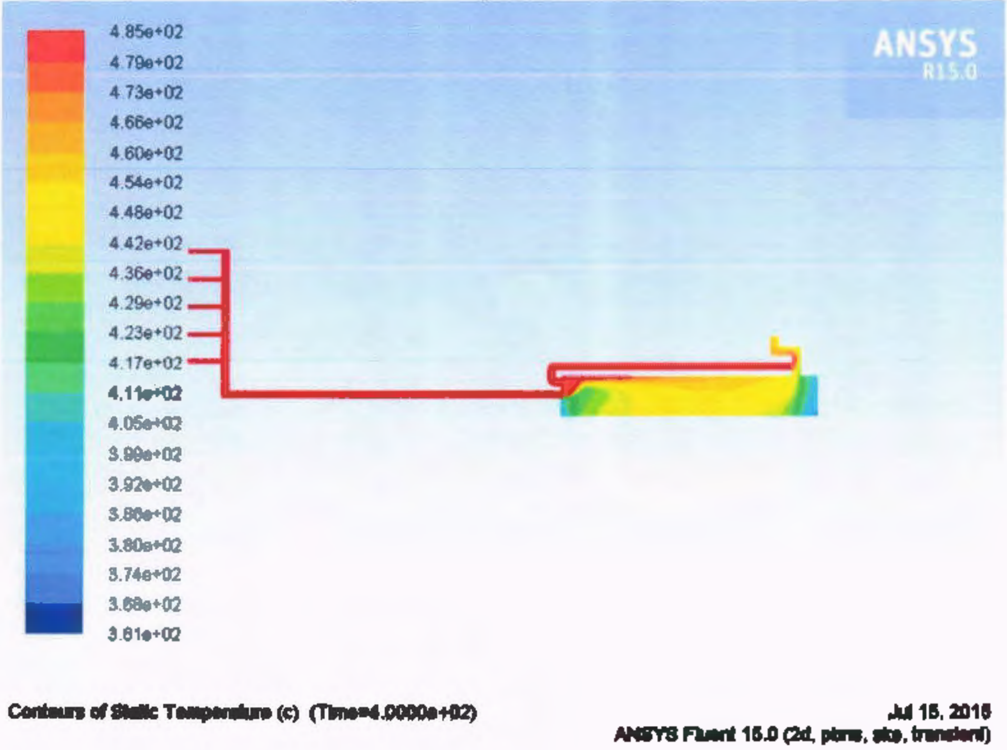

Figure 6.11 Temperature at t=400 sec

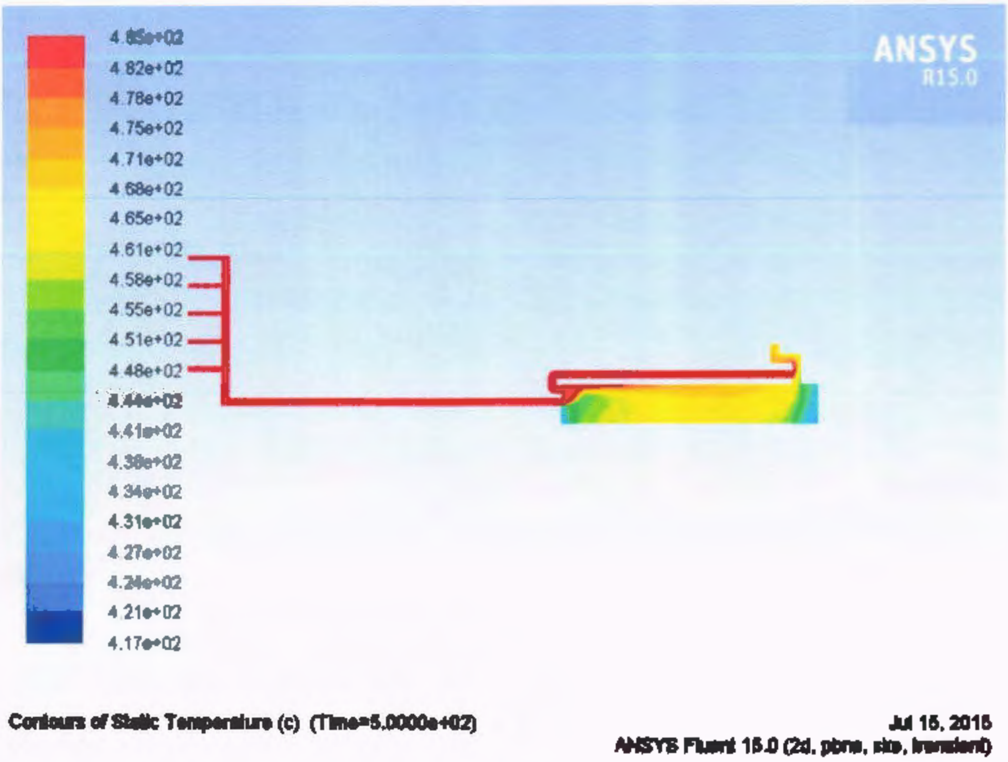

Figure 6.12 Temperature at t=500 sec

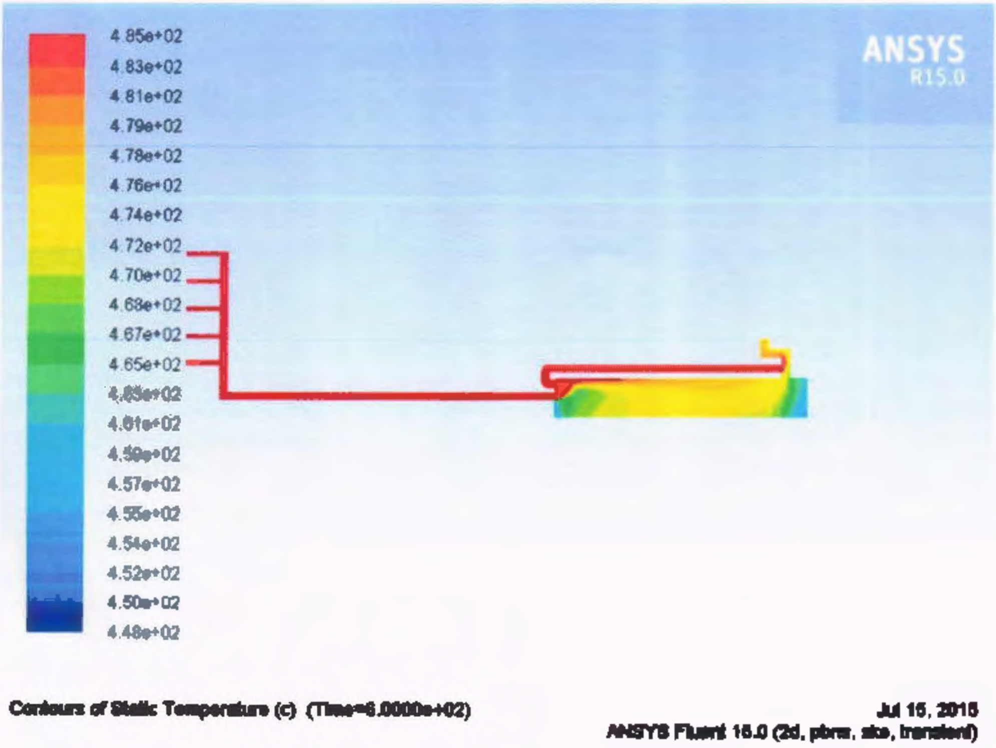

Figure 6.13 Temperature at t=600 sec

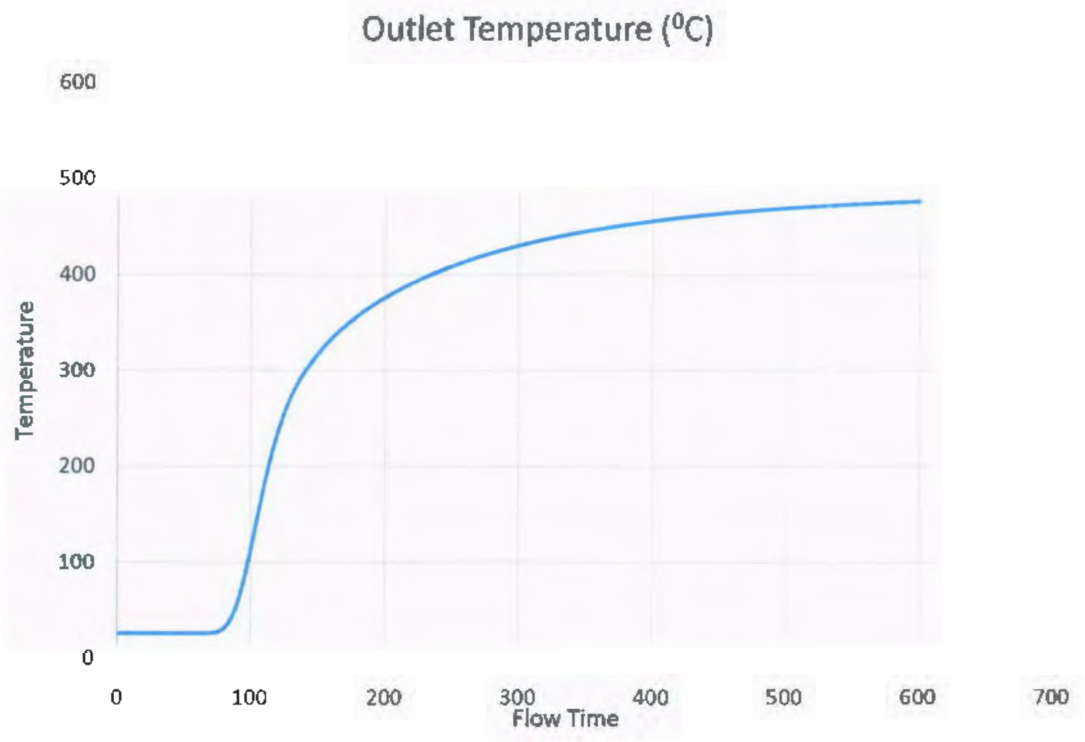

Figure 6.14 Outlet Temperature

STATIC TEMPERATURE ACROSS THE OUTLET.

We have considered static temperature across the outlet of generator i.e. inlet to furnace, at time from 0 to 600 seconds. Graph shows that the static temperature increases throughout the flow time. At time t=100 temperature of gases at outlet of generator is almost in the range of 100 degree centigrade and as flow time increases the temperature entering the furnace will also increase and this can be clearly seen from red color in the Ansys simulation results noted at various time intervals in the range of t=100sec to t=600sec. These things clearly represents that flow of gases will not be disturbed during the process and temperature entering the furnace will increase and help in preheating of steel bars in the furnace, Preheating of steels bars will increase the production capacity of the unit resulting in more production in lesser time.

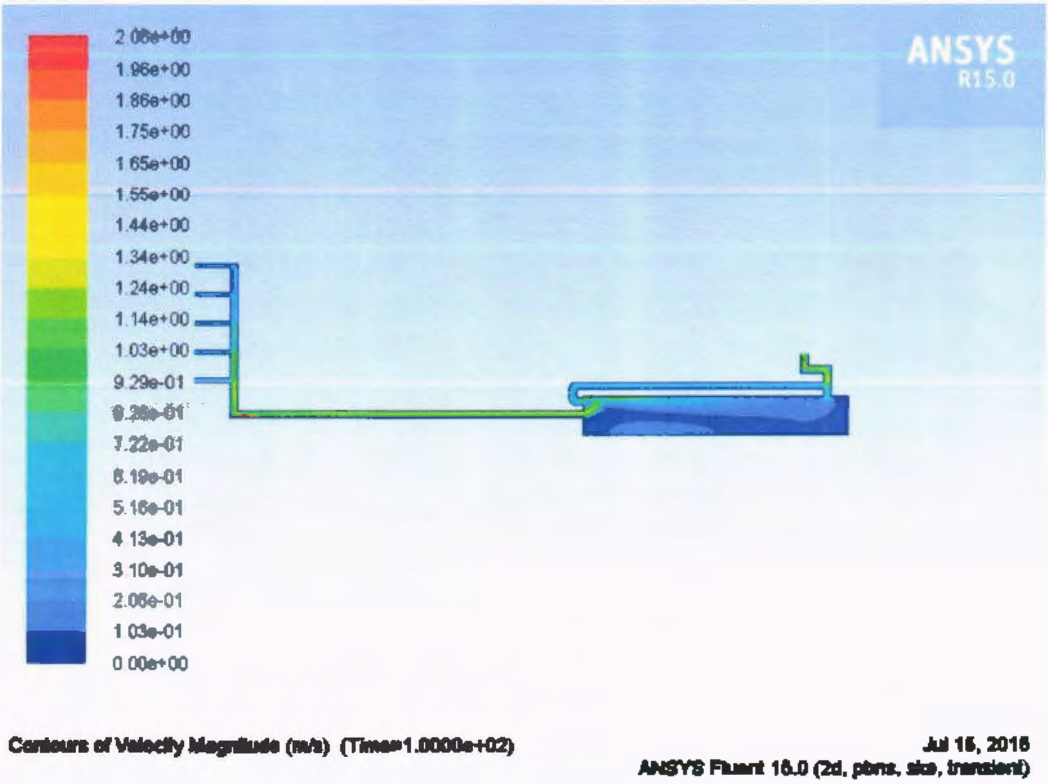

Figure 6.15 Magnitude of velocity at t= 100sec

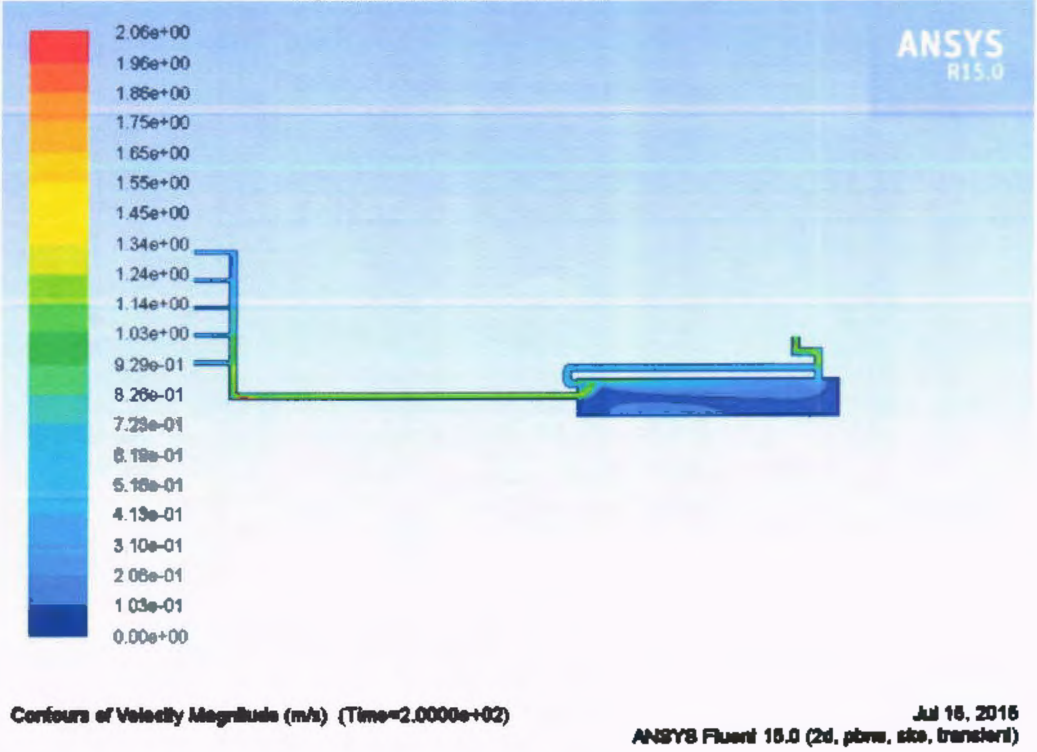

Figure 6.16 Magnitude of velocity at t= 200sec

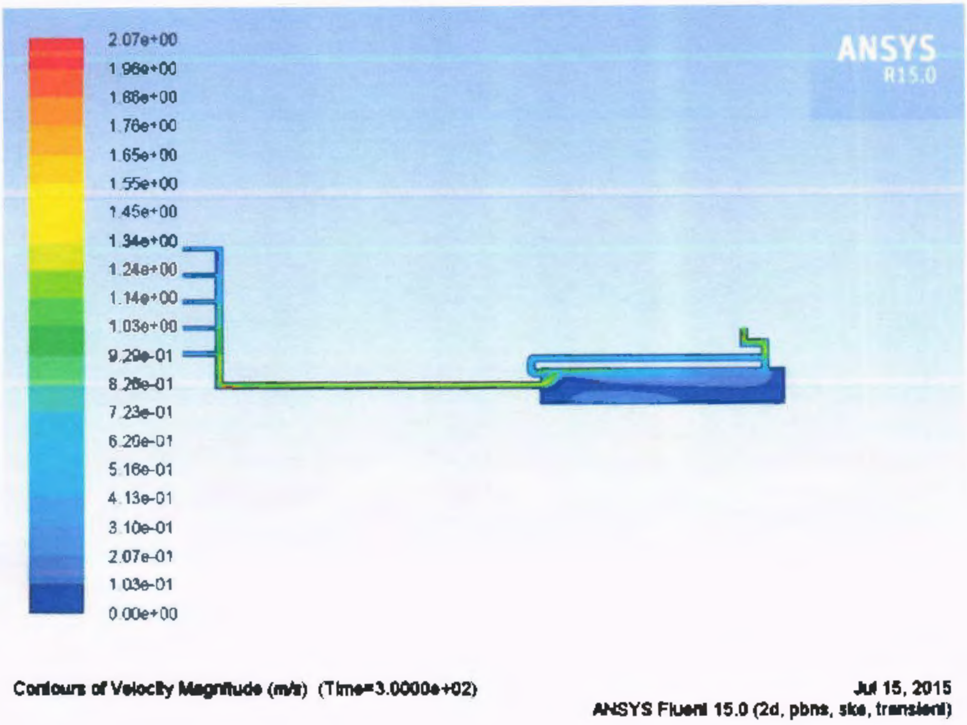

Figure 6.17 Magnitude of velocity at t= 300sec

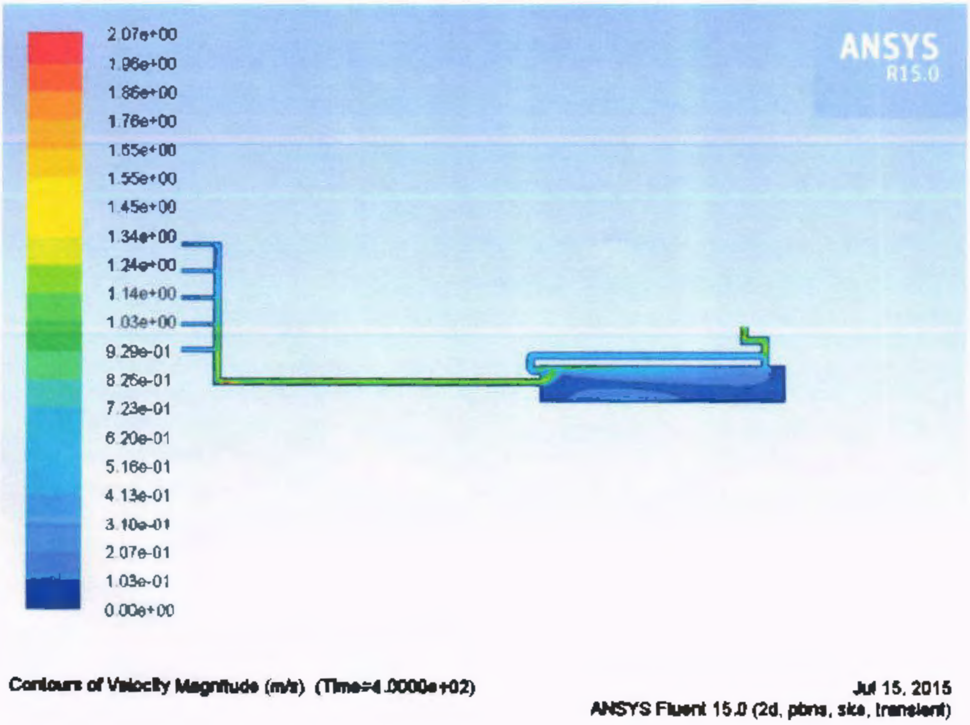

Figure 6.18 Magnitude of velocity at t= 400sec

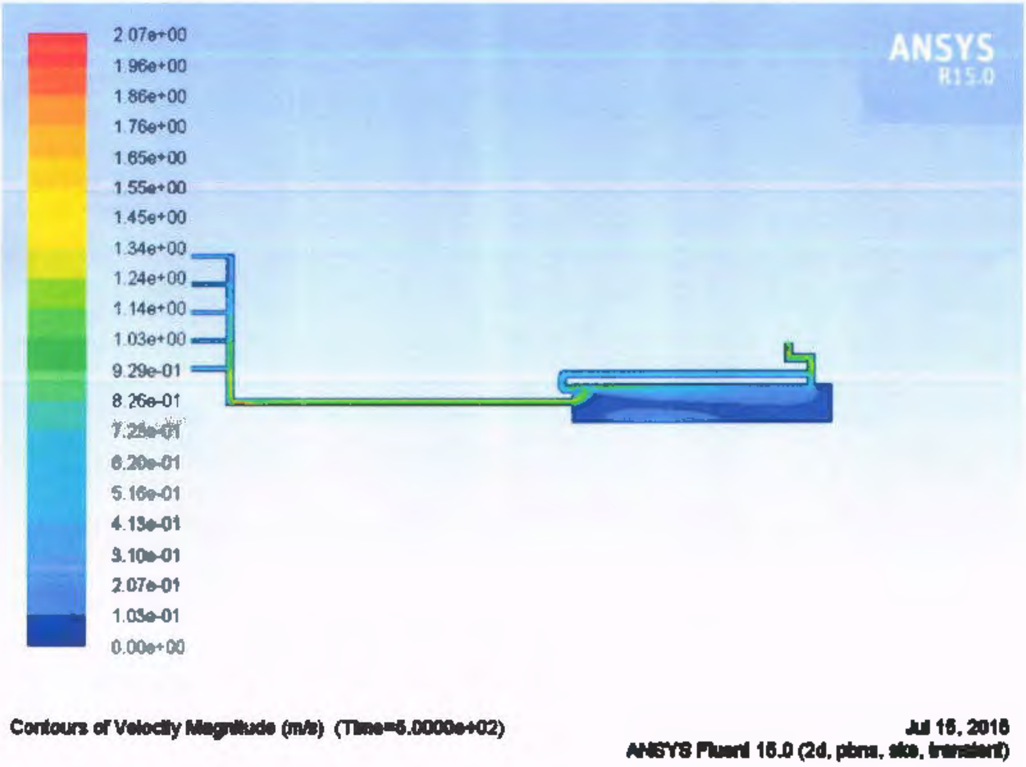

Figure 6.19 Magnitude of velocity at t= 500sec

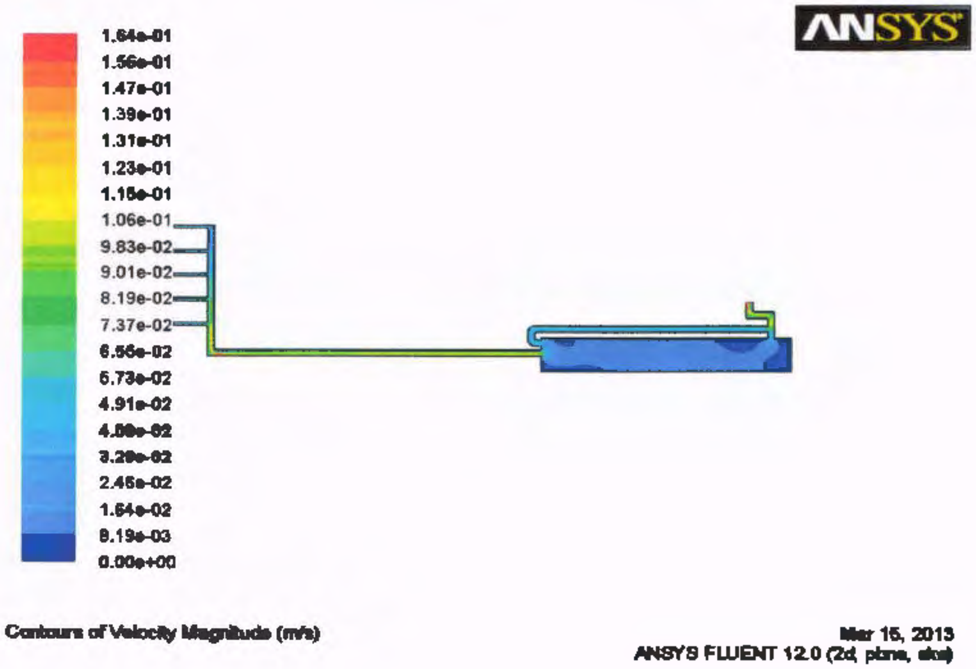

Figure 6.20 Magnitude of velocity at t= 600sec

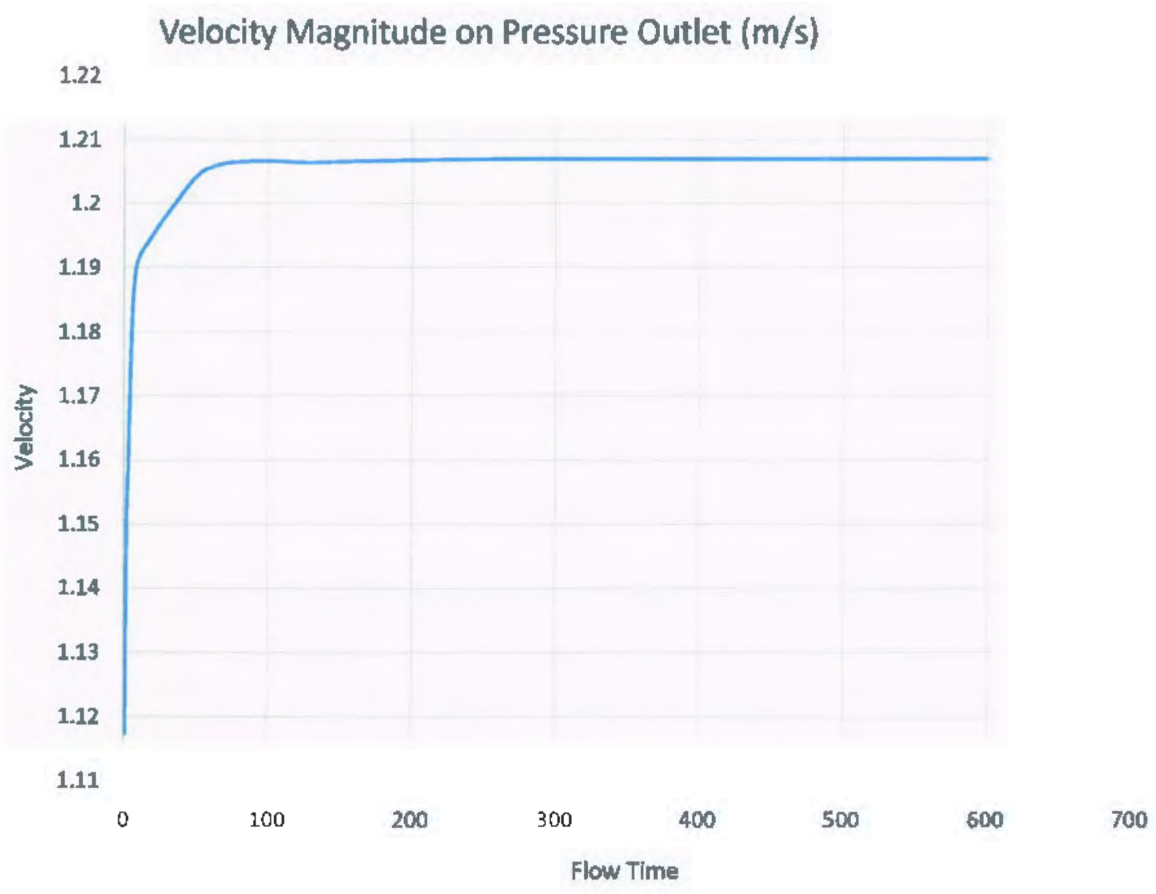

Figure 6.21 Velocity Magnitude

MAGNITUDE OF VELOCITY ACROSS THE OUTLET.

We have considered magnitude of velocity across the outlet of generator i.e. inlet to furnace, at time from 0 to 600 seconds. Graph shows that the magnitude of velocity increases initially then remains constant throughout the flow time from t=100sec to t=600sec which represents that flow of gases will not be disturbed during the process.

6.4 Cost Analysis

Amount of Gas Consumed	5900 mmbtu
Price Per mmbtu	Rs. 488.23
Amount of Gas Consumed per day	196.6667 mmbtu
Monthly Cost of Gas	Rs. 2880557
Daily Cost of Gas	Rs. 96018.57
Required Temperature of Furnace	1600 ^{0}C
Amount of Gas Per ^{0}C rise in Temperature	0.122917 mmbtu
Cost of Gas Per ^{0}C rise in Temperature	60.0116
Temperature elevation through cogeneration	470 ^{0}C
Amount of Gas Saved per day	57.77083 mmbtu
Cost of gas saved per day	**Rs. 28205.45**
Cost of Gas saved per month	**Rs. 846163.6**

6.5 Conclusion and Discussion

Literature review indicates that combined heat and Power (CHP) generation or Cogeneration has now been widely used over the globe for its better efficiency, efficient use of natural and monetary resources and very less environment hazard. Priory CHP has been used in power generation, steam generation in gas and steam turbines. Basic Principle of cogeneration is to utilize high temperatures effluents (gases, steam and water) in waste heat recovery mechanism to recover heat energy from the waste. Mainly CHP has been used in electrical power generation.

This study identifies the novel idea of the usage of cogeneration system. This research depicts the scenario of five electric generators working on natural gas exhaust CO_2 at the ambient temperature of 485 ^{0}C with the mass flow rate of 4473 Kg/hr. In this study, this effluent gas has been introduced to a reheating steel furnace which raises the temperature of the furnace up to 470 ^{0}C. These results have been verified using Ansys simulations.

Using the results obtained from the simulation and the actual consumption of gas of a local reheating furnace of the capacity 80 ton per day brings very useful results. From the financial standpoint using this study, a solid 29 % of fuel cost can be saved.

Not only this, if the country's depleted natural gas resources taken into account, around 58 mmbtu of natural gas can be saved daily and approximately 1700 mmbtu monthly. But it can also contribute to lessen the emission of carbon dioxide and carbon monoxide from both sides the emission from furnace and generators.

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