Process Design and Simulation of Coal Gasification

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Dedication

This thesis is dedicated abridgedly to my parents and siblings for their unlimited support, moral encouragement, and incalculable love

Acknowledgement

I am thankful to my Creator, **Allah Subhana-Watala** to have guided me throughout this work at every step and for every new perception which ALLAH setup in my mind to improve it. Indeed, I could have done nothing without ALLAH’s guidance. Whosoever helped me throughout the course of my thesis, whether my parents or any other individual was His will, so indeed none be worthy of praise but ALLAH. Peace and blessings of Allah be upon last Prophet Muhammad (Peace Be upon Him).

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Muhammad Shoaib Zafar

Abstract

Energy in demand today at both national and international level. Most of the resources of energy have been used. It is challenge of the day to cope with the energy problem. To overcome this problem, production of SYNGAS (CO+H2) using natural resources like coal is recommended which produces cost effective SYNGAS using coal gasification process which is environment friendly process. SYNGAS is used as fuel for internal combustion engines and used for production of Hydrogen which further is processed to produce Ammonia and Methanol. It is used as intermediate to produce synthetic petrochemicals via Fischer-Tropsch process. Our objective in this study is Modeling and Simulation of Coal gasification process to produce SYNGAS using Aspen Plus software and energy optimization of the whole process using Pinch technology. Capital cost of plant and utility cost of the process is calculated before and after energy optimization and then compared both costs. There are three types of gasifiers that are used for Coal gasification Process. First is Fluidized bed gasifiers here feed raw materials suspended the feed stock in an Oxygen rich gas which makes a bed in gasifier which act as fluid, efficiency of these gasifiers depends upon the reaction between feed stock and materials already going gasification process. Second is Moving bed gasifiers which are mainly used for gasification of biomass due to their lower operating temperature and flexibility in raw materials dimension. The last one is Entrained flow gasifiers, in this type of gasifiers feed stock, air or Oxygen and steam are fed at same time into the gasifiers. This study focused the process of Coal gasification using Entrained flow gasifiers is modelled and simulated in Aspen Plus ®. Nonconventional type of coal is defined and “enthalpy model” is “HCOALGEN,” which calculates the enthalpy of streams comprising coal. By simulated research, we calculate the behaviour of the actual process. After process simulation, it has been concluded that process can be controlled by controlling concentration of Oxygen and reactor temperature. When oxygen concentration increases in the reactor, Carbon is oxidized completely and produces useless by- products such as carbon dioxide, water and products of sulphur to enhance production. To produce SYNGAS, it is necessary that Carbon must partially be oxidized that is generating our desired product SYNGAS. Energy optimization of SYNGAS production process is done using Pinch analysis technique and using Pinch Technology recovered process energy which were wasted before and save 20.7 million $ per year which were consumed before for cooling and heating of streams.

Key Words: Coal gasification, Syngas, Process simulation, Optimization, Cost analysis

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Chapter 1

Introduction

The energy demand is increasing every day at both the national and international level. The energy system of the country did not yield to technology that control demand and supply of equity. At present, the biggest challenge is that petroleum and natural gas are used at a much faster pace and the demand for emerging technologies from developing countries increases, petroleum price is also rising since very long affecting the global economic conditions. Use of Coal is currently a major source of energy, in terms of contributing to the world's energy systems [1]. Coal can be very harmful to the environment due to the products while producing gas [2]. Coal reduction and elimination has received attention to promote clean and environment friendly fuels.

The world's oil resources, on which the rest of the world depends, are vast, so it's time to investigate substituting them. There were home-grown solutions available and coal over all other resources offered a natural option, but the organizers had been ignoring this for more than thirty years now. Pakistan is facing a serious energy crisis and is lagging in adopting state-of- the-art energy production technology. Therefore, the rise in oil prices and the depletion of natural gas reserves are forced to focus on coal-fired power plants to obtain the rise of coal- fired or solid waste into useful explosive products for hot applications and oil or chemical production, as well as lowering emissions [3] .

1.1 Background

The process to convert Coal to combustible gases by any process, it is called coal gasification even if there are several reactions are taking place other than gasification [4]. The product gases of coal gasification process include a range of combustible chemicals, the purpose of which is to make gas not limited to producing gasoline gas, because the gasification of the product can be easier processed to produce other important chemical and fuel feeds. Commercial gasification disruption usually involves a partially controlled oxidation to convert it into the gas products you want. Coal either can be heated directly by heat or indirectly by another source. Manufacturing method in general transfer (or pass) hot coals to provide close molecular links chemical reactions [5]. Gaseous reactants react with carbonaceous carbon problems (e.g., coal (hydrocarbons) or other major decay products of coal production gas products. Few gas products by such process are desirable from fuel quality conditions, performance, and environmental concerns [6].

As a result, coal gasification process is always accomplished in accordance with the following procedures this is not only for final product quality or quantity, but also for environmental issue. The key Stress on coal extraction may have been produced by integrated gas production integrated circuit types (IGCC), in the production of syngas for pipeline applications [3], in the production of hydrogen, or in the combination of liquid fuels and petroleum chemicals among other resources [6]. After the emerging of Hydrogen market, the role of coal gas production in hydrogen production may be very significant.

In this study, the modelling and simulation of coal gasification is done using steam as medium rather than its mixture with oxygen as it is practiced today in industry [2]. The purpose of this study is to make process more cost efficient. Gasification process has two parts one is gasifier and other is furnace. SYNGAS produces in gasifier is heated in furnace to provide more heat for endothermic reaction [6]. The flue gases produced in the gasifiers passes through the dagger tubes to change the temperature of cool bed gasifiers. The model is created for the assessment of heat transfer between different regions of bayonets and gasifier atmosphere. Gasification product, called Syngas achieved by gasification is a source of oil itself, and it is usually more efficient fuel than the first gasifier supplied [7]. This Syngas produced by Coal gasification process can now be burned in Internal Combustion Engines (producing hydrogen and methanol) or can be used as raw material for the Fisher-Tropsch process to produce synthetic fuel.

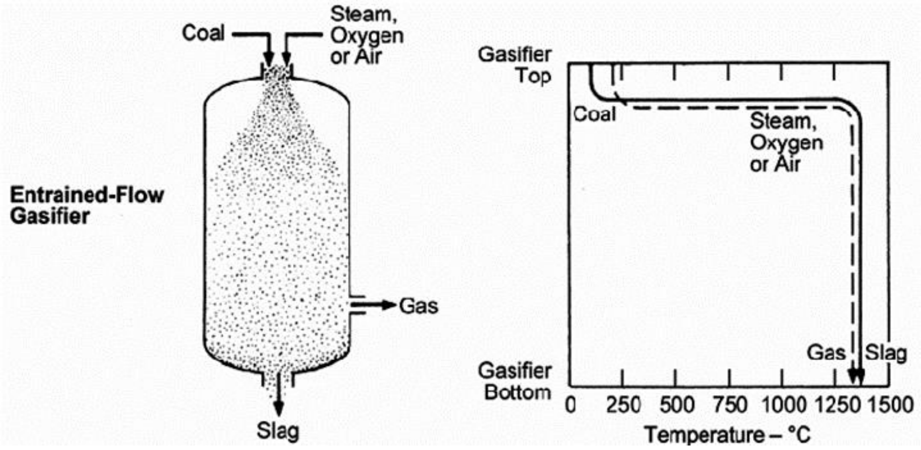


Figure 1 Entrained flow gasifier

Coal is one of the world's largest energy sources, accounting for 28.2% of the world's leading energy use particularly red coal-fired power systems which account for approximately 40% of global energy production and their responsibilities as energy loading systems are the most important. However, coal produces a great amount of sulphur and nitrogen oxides (SOx and NOx, respectively), CO2, and emits more combustion than other mineral oils [8]. Therefore, for the environment issue, clean coal technology (CCT) has been widely established to reduce environmental problems by increasing thermal energy and decreasing air pollution.

Integrated power generation systems (IGCC) are designed to improve thermal energy (up to 48% by high temperature (HHV)) and to reduce environmental effects related to conventional red power generation systems as summarized. Giuffrida studied the development of an IGCC system with oxygen-blown air, a bed-fed Shell-type dry food with 78.1% cold gas, and a 1335° C gas turbine [9]. They evaluated cold production (CGDU) with units of hot desulfurization (HGDU) in IGCC systems, using methyl diethanolamine (MDEA) in CGDU and zinc-based sorbent in HGDU [10]. They stated that the thermal net performance improved by 2.5% with HGDU and that the earth's temperature and O2 concentration in the sorbent re-distribution of HGDU did not distinguish the thermal performance of IGCC systems. In a consecutive study, they studied the IGCC's effect on the MHI-type air-conditioned air in a bedroom with 77% cold gas (i.e., the average thermal conductivity of the coal in the HHV Foundation). They reported that thermal efficiency reached 51.7% and 53.0% based on LHV without recording CO2 using 1335 and 1500 ° C of class turbine and HGDU, respectively. Sudiro calculated the heating performance of the IGCC systems at 1300

° C which is gasoline-powered and a two- bed reactor where the coal is emitted at 850 °C, and the insensitive char is heated by 980 ° C on the ignition [6]. They reported a greenhouse gas efficiency of up to 80.1% and that the efficiency of global plants reached 43.1% (LHV base) without CO2 emissions [11].

Various studies have been performed on testing the thermal performance of IGCC systems with CO_2 capture. Carbo examined the mixing of WGS reactors by combining CGDU and post- combustion CO_2 scanning unit at IGCC. They reported the efficiency of the temperature outside of CO_2 was 47.4% (LHV base) and that efficient [12].

1.2 Nomenclature

[CO]=Mean concentration of CO [C]=Mean concentration of C

After all this, Coal is dangerous to environment because it adds gasses to environment that are dangerous. For environmentally friendly fuel liquefication and gasification processes are under considerations. In coal gasification process coal is burnt and then Carbon is partially oxidized to produce mixture of combustible gasses like CO, H2 and CH_4. The non-combustible products like carbon dioxide, water and Ammonia are also produced. In 1940's, natural gas is a cheaper substitute to gases obtained from coal gasification. However, importance of coal gasification has been reviewed due to reduction of natural gas reservoir. Gasification is an important route for alternate energy production.

1.3 Process Model

Vertical reactor is used in this gasifier for gasification here coal is heated by very hot steam and the heat of the endothermic gasification reaction is provided by vertical bayonet tube heat exchangers installed by the defendant. Product of the gasifier is CO_2, H2, CH_4 and NH_3.The ashes and CO_2 produced during gasification and is removed from bottom of gasifiers. The ashes are heated first with air in the furnace to produce superheated smoke and hot gases used to provide the heating process using bayonets [1].

The heat which is needed for the reaction to be completed is taken from the hot gases from furnaces and from various utility streams therefore reducing the amount of fuel needed [13]. Production of SYNGAS is divided into two-part; one part is product stream that is sent for further development and other by-product is mixed with heated gas in furnace. A mixture of hot gases and SYNGAS is sent to furnace. The exhaust fumes produced are also used to produce very hot smoke using heat from a high-temperature furnace from a furnace [14] . High temperature fumes which are produced are used in gasification process. Flue gases from gasifier bayons are used to heat the air that needs to be heated in a furnace. Continuous heating occurs to produce full smoke of the process utility [15].

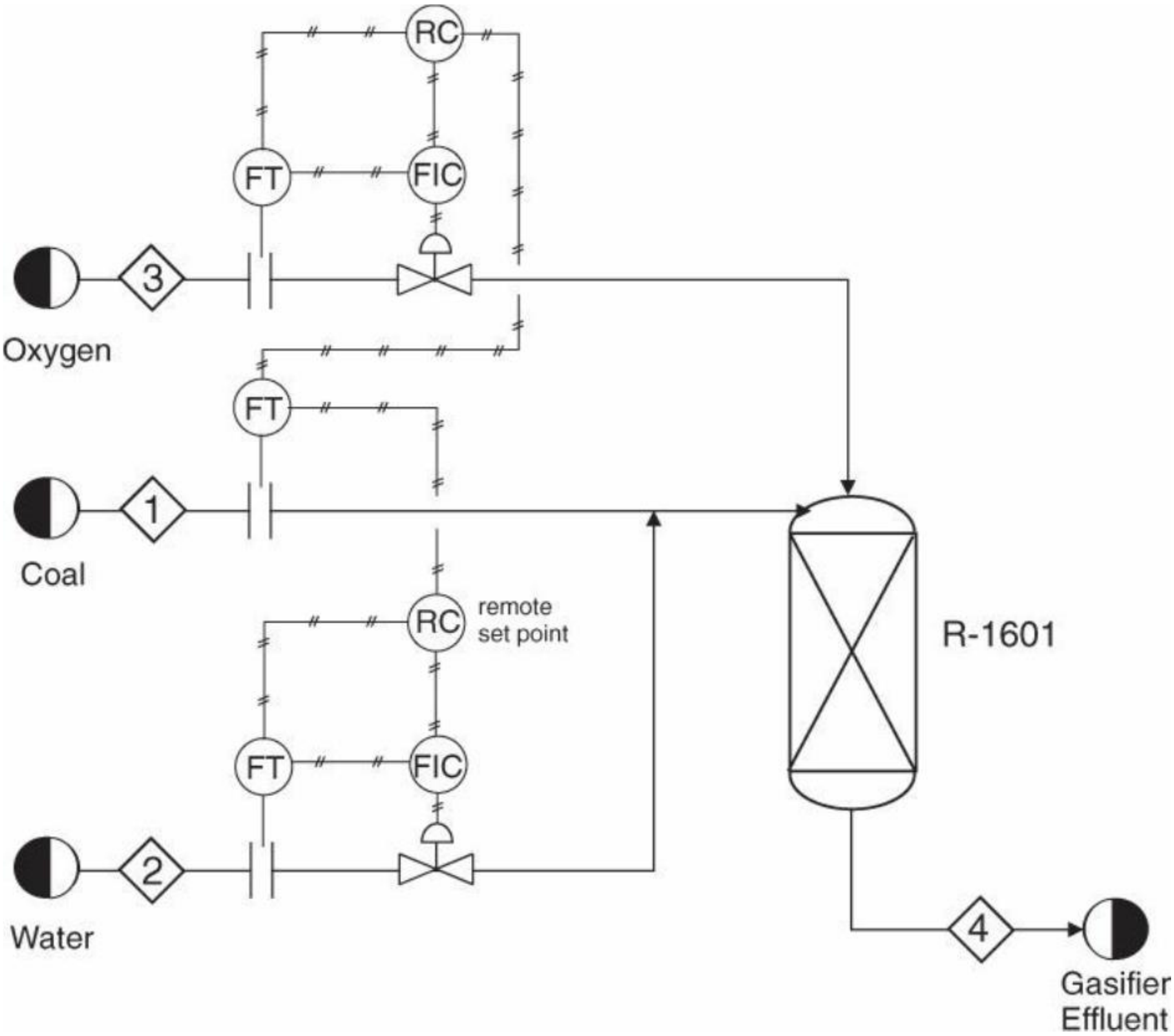


Figure 2 Process flow diagram of Coal gasification

1.4 Chemical kinetics

In gasifier countless reactions took place other than gasification. Such as, hydrogen gasification of char products produces methane. Methane also helps to generate processes like methane-steam reforming and methane-CO2 reforming. There are others many reactions which involves NH3 produced in reaction, these reactions are not counted here for simplicity. It is very challenging to calculate Carbon transfer accurately in a gasifier using blocks available in industrial process simulator. In Coal gasification, it is assumed that all sulphur present in process will be converted to H2S, and all Nitrogen converted to NH3. Furthermore, higher hydrocarbons which produced are neglected. Both reactions devolatization and tar cracking reactions are very fast and sometime combine. The heat required for the process is taken from hot gases passes through. In the bottom part of the gasifier, gaseous and solid reactors pass through the coastline of bayonet tubes, providing the heat until the required change is attained [5]. A hot heat bayonet has two fixed tubes, where the liquid can flow in two different directions. The channel can be the centre tube and the outlet in the outer annulated part, or vice versa. Assumed choice depends on the type of process and operating environments [16].

1) Pre-combustion CO2 imaging with WGS membrane reactor and CO2 direct condensation (IGCC-MR)

2) Post-burning CO2 imaging with calcination-carbonation loops (IGCC-CL) and

3) Oxy-fuel combustion (IGCC-Oxy) uses pure oxygen, to test the potential for improved thermal performance of IGCC systems [3]. They reported that the efficiency of the temperature range could increase to 45.1%, 45.9% and 45.8% (LHV base) in the model of IGCC-MR, IGCC-CL and IGCC-Oxy, individually when using HGDU [17].

In the IGCC system, it provides heat to the endothermal gas-cation by incomplete oxidation in a normal purified area causing substantial loss of exergy, resulting in 12-18% of the total system loss. Advanced integrated gas cycle systems (A-IGCC) have been planned to address this shortfall. In A-IGCC systems, the heat radiations from a wind turbine are also used in the gas as a coal-fired heat source. By recapturing the exhaust heat using the power of endothermic gas, the performance of the cold gas boiler is believed to be Kawabata et al. A review into the operation of the A-IGCC system also discovered that the heat emitted from a 1500°C gas turbine was not appropriate for use as a gas heat source [18]. They also reported the high thermal conductivity of A-IGCC systems that directly restores the emission temperature from 1700 ° C-class gas turbine gas up to 51.0% (HHV base) except for CO_2 imaging or desulfurization units and that installation liquid gas switches (WGS) and pre-coil or

CO_2 imaging units lead to loss of thermal energy by cooling and reheating of liquid sorbents [19]. However, few studies have examined the thermal performance of A-IGCC systems that are complete with gases, particle gas refining units, Sulphur compounds and other harmful ingredients in syngas, and CO_2 capture units.

In this study, we analyse the significance of thermal development of A-IGCC systems containing low-temperature bed gases based on the Sadiron et al model. It has two beds with 80.1% cold gas cleaner and CO_2 recording units. The 1650 ° C high power plant was supposed to be used as it is projected to be sold by 2020 by Mitsubishi Heavy Industries, Japan. At HGDU, we adopt a method that uses iron-based solvents because these animals have advances, including high temperature resistance, high resilience, and good permanence in damage and restoration. The most commonly available technology has been applied to other units and heat redevelopment has been upgraded with the integration of units.

The advantage of this type of structure lies in the probability of using high-temperature streams if the bayonets are made of proper materials that can withstand high temperatures. Another feature of this type of exchange is the capability of the two interconnecting tubes to grow separately of each other, thus enabling them to acclimate to high temperature environments. This type of heat exchanger has already been used in "Topsoe Bayonet Reformer" to produce syngas by shifting natural gas vapor.

The objective of this study is to calculate the possibility of using this switch with an indirect gasification process. It is possible to test the use of post-burning flue gases as a thermal reactor, which is installed in the central part of the bayonet tubes [19].

In reactor, coal fed to the upper part while steam is used as a rowing point that enters the lower part. This creates an opposing current flow between the solid reactant and the gases. A moving bed type is tested, in which the coal particles have a certain width. Hot flue gases pouring inside the bayonets formed by the burning of half of the green syngas produced in the gas furnace [18].

1.5 Research Goals

The study focused to develop a model of Coal gasification to produce SYNGAS in Aspen Plus ® software to improve design and optimization of chemical process. In addition, a research thesis also targets modelling and simulation of Coal gasification process, optimization, and cost analysis of the whole coal gasification process before optimization and after optimization. The primary research goals of this research work are:

1. Design process model and simulation in Aspen Plus® software and make a mathematical model for solving the equation.
2. Apply the pinch analysis on Coal gasification process and find the optimum value from the pinch analysis study.
3. Study the cost analysis of Coal gasification process using CAPCOS software. Cost analysis is done twice. One before optimization of the process and other after the optimization and then both costs are compared.

Chapter 2

Literature Review

2.1 Process description

Gasification, which is the process of converting waste, biomass and fossil fuels addicted to synthesis gas for future use, provides ability to produce clean energy and chemicals [20]. Synthesis gas produced using gasifier from coal, pet coke and biomass. In gasifier, sub stoichiometric oxygen(O_2) given to construct synthesis gas among a high concentration of CO/CO_2 [21]. The gasification reaction ultimately leads to a significant carbon conversion. The different types of gasifiers are used for this work, downhill pour, oxygen(O2) blow entrain flow gasifier is used [22].

- Units Gasification unit can be burnt with coal, biomass, waste, refineries, and with natural gas.
- Electricity generation both the production of electricity and the linked creation of petrol and chemicals, is emphasized in the issues of disruption of coal to improve electricity.
- R, D&D requires the production of pure coal based on gas expertise.

2.2. Process options

Another 20% of the world's gas-fired plants use coal as the thumb generates electricity [1] .Some manufacture products such as ammonia, methanol, ox chemical and synthesis gas. Biomass-generating plants are relatively small compare to the performance of energy, generate electrical energy and synthesis gas [23]. Weighty fuel goods along with plant waste residue are widely used to manufacture gases and chemicals, even if energy manufacture is combined through additional new units.

2.3. Technical options

Three types of expertise separated by a gasifier configuration relatively to flow geometry.

- Entrained flow gasifier, where compressed coal particles and gases flow simultaneously at high speed. They are the most widely used gas-fired coal.

- Fluidised bed gasifier, where coal particles hang where gas flows; coal-fed particles are mixed with gasification particles.
- Moving bed gasifier (also called a fixed bed) that generates electricity when the gases slowly flow up to the coal bed. Both concurrent and counter-current technology available but the former is more common.

2.4. Entrained flow gasifiers

The most widely used indoor flow gases with seven different types of technology (BBP, Hitachi, MHI, PRENFLO, SCGP, E-Gas and Texaco) are available in these gases, coal and other solid fuel particles simultaneously reacting with steam. and the spirit. -healthy or dry. air (e.g., temperatures 1200-1600 ℃ and pressure at 2-8 MPa in very large plants operating at about 2.5 MPa such high temperatures affect stoves and resistance health and require the use of expensive structures and the use of heat-resistant chemicals in SYNGAS under the inclusion of ash-reducing ash to prevent pollution and control rust problems. is widely used in commercial gases; slag can penetrate deeply into the opposing file before solidification [24].

There are two main methods of gas cooling, using high temperatures. When gasifier operating conditions are maintained, an increase in ash content will lead to a decrease in gas efficiency and an increase in the production and disposal of slag [25]. These three factors contribute to the increase in the total cost of the process [10]. The decrease in gas efficiency is mainly due to the additional oxygen consumption needed to dissolve the mineral and thermodynamic particles from the heat released by the irreversible printer. However, some technologies have requirements for charcoal ash that vary slightly depending on their construction [19]. Refractors are an expensive part of gas-fired equipment and to be economically viable they must last at least 2-3 years [22].

For both economic and technological reasons, low-ash coal is favoured [21]. An increase in ash content will result in a loss in gas efficiency and an increase in the generation and disposal of slag if gasifier operating parameters are maintained. These three elements all add to the process's overall cost increase. The higher oxygen consumption required to dissolve the mineral and thermodynamic particles from the heat emitted by the irreversible printer is mostly responsible for the fall in gas efficiency. However, some technologies have requirements for charcoal ash that vary slightly depending on their construction. At least one ash is required for SCGP (O 8 wt%), BBP (O1 wt.%) And Hitachi gasifiers for coagulation of slag gases to be mixed with slag to work and reduce heat loss in the wall types of sulphur flow and Halogen types also vary with each process. It is determined by the design and resistance of the materials used in the cooling, cleaning, and handling systems, as well as the working conditions of the gas system (particularly gas heating) and the processing power of substandard equipment, such as in the sulphur injection sector.

2.5. Moving bed gasifier

There are only three types of gas installation procedures using portable bed presses (BGL, BHEL, Dry Laundry Lurg) that are manufactured at the industrial level although they are the most mature of the three most common types of gas [17,19]. Carrying gasifiers in bed can be slagging (BGL) or gas ash (Lurgi, BHEL). They are only suitable for solid fuel and can process coal with biomass and / or waste. The main difference between the two types of gases is that ash-filled dryers use a much higher amount of moisture in oxygen than gasifying slagging, resulting in much lower temperatures in the furnace (1000 8C) and a dry ash system. What should be the coals that act as lignite? Moving bedding can process coals with ashes. It is estimated that 35% of the coal-fired ash can be processed in dry gas in the Sasol Liga and at the BHEL washing machine. A coal cylinder (5-80 mm) is placed over the gas with a hopper key. Processing may be necessary to determine this size as the best coal feed will usually have an electric explosion. A mixture of steam and oxygen is introduced into the bottom of the reactor and improve the flow of coal. The lifespan of a coal bed is 15-60 minutes of pressure / oxygen pipes and can be a few hours of ventilation. Bed pressure is typically 3 MPa for gas suppliers with up to 10 MPa testing. Charcoal enters the top of the gas filter and is burned, dried, energized, refuelled, and exhausted as the gas evaporates. Moisture is first transported to a dry place and then the coals are heated and energized by the hot product gas while descending to the garage where the steam and carbon dioxide reaction is cancelled. The remaining sheet is finally completely heated in the oven when the bed reaches a very high temperature. High temperatures in the furnace are usually found in 1500-1800 °C of crushed presses and 1300 °C of dry ash pipes. As the flow varies, the gas leaving the air printer cools against the inlet feed and temperatures ranging from 400-5500 8C. Therefore, the use of more expensive syngas is not necessary to transmit bugs. However, temperatures above the gasifier are generally insufficient to break the bitumen, phenols, oils, and boiling hydrocarbons produced in the pyrolysis area as well as the gas-fired product [21]. Changes in recent construction include the heat of the cake and the ashes of the ashes. Depending on the gas composition and other aspects of coal, such as large size, the tolerance of various coal gas varies from 5% of the Dakota Gasification industry to 50% of fines (30-40% solid fines and slurry of up to 30% fines) in the BGL gas station. The following include precautionary measures before gas extraction and fines. Coal-fired coal should be covered with low-grade coal to be processed into Lurgi's dry electricity at Sasol. The BGL gasifier can allow solid coals if the trigger is connected to a coal distributor. Coal ash (AFT) is also a parameter to be considered for dry ash and gas leaks. Low ash temperatures can lead to the formation of ash in a dry ash bed, which is why the ash temperature is higher than the effective working temperature of dry gas ash.

2.6. Fluidized bed gasifier

There are six types of ventilation systems (BHEL, HTW, IDGCC, KRW, transport reactor, Mitsui Babcock ABGC) using compressed bed presses although most will still be developed with solid grinding oil (0.5-5 mm), except for the switch that holds between the drinking bed and the gas that enters and operates in the form of fuel spray (i.e., 50 mm coal) [17]. Coal is placed in a large flow of gas (either air or oxygen / smoke) that strengthens the oil bed as it happens. The bed is made of sand / coke / char / sorbent or ash. The duration of the gasifier is usually set to 10-100 s but can also be very long, when the feed is exposed to high temperatures at the gas door. The high degree of back mixing ensures uniform distribution of heat in the gases, which usually works at temperatures below the ash (900-1050 8C) to prevent the melting of the ash, therefore, to avoid reduction and loss of bed temperature. There are both dry ash and combined ash systems [23]. One of the main advantages of these types of gases is that they can work with flexible loads that give them high turndown flexibility. The effect of low temperatures is that incomplete carbon dioxide changes in one phase, leading to a reduction in the efficiency of cold gas than in other species [13]. To avoid the production of high-carbon fly ash, many bed systems are now equipped with a recycling station unit. However, depending on the coal used, this can lead to an increase in the ash content in the bed. Hybrid systems, where coal is first extracted from a liquid bed followed by a fire extinguisher in a cool bed, can solve this problem and improve carbon transfer which has resulted in higher gas cooling efficiency [26]. Due to the low operating temperatures of the printers in the liquid bed, active lignite such as coal and coal-fired coal is popular [27]. Liquid bed gases that work with composite ash can process very high coal because they have a higher temperature of cold gas than dry ash systems. The sulphur found in electrical gases such as H2S and COS can be kept slightly in bed (up to 90%) and magical properties such as limestone. This leads to a significant reduction in H2S exposure to substandard equipment and thereby reduces corrosion of the material. The result of the use of magic is to keep sulphur compounds in beds, as well as low operating temperatures in waterless bed gasifiers, allowing the use of cheap materials for building heaters and cleaning devices. Waterless sleeping systems are more tolerant of sulphur than indoor water systems.

However, coal with a high sulphur content is not recommended because it may require additional addition of sorbent which has resulted in an increase in the mixing volume emitted by this process and is therefore more expensive [28].

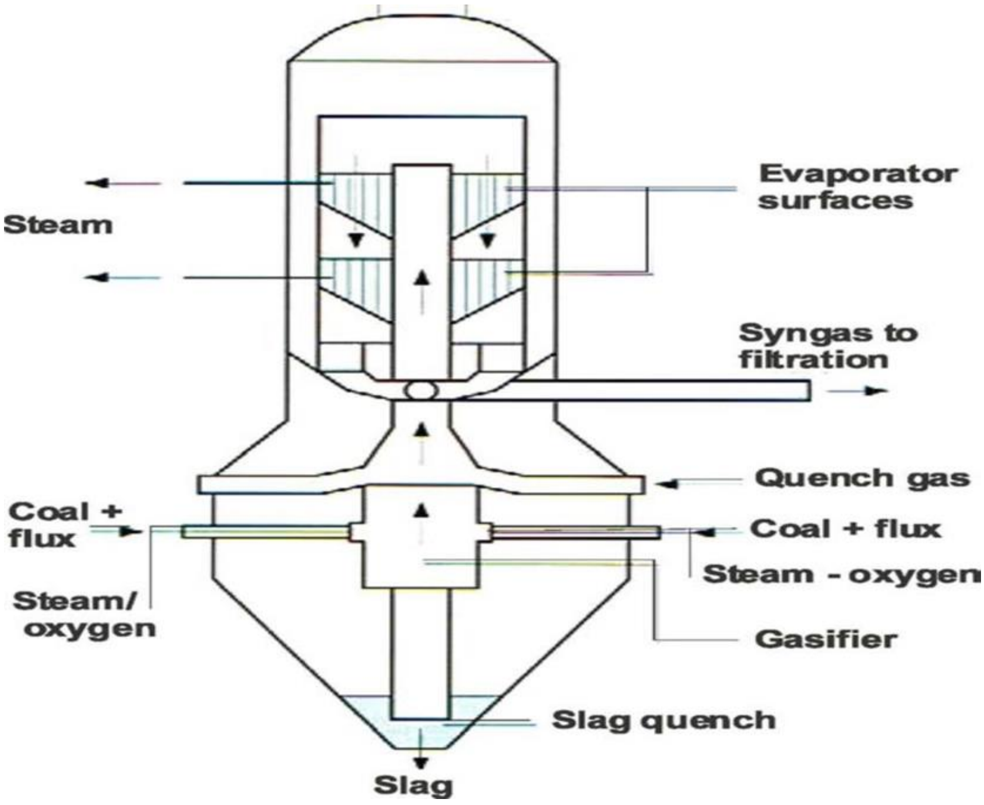


Figure 3 Fluidized bed gasifier

2.7. Oxygen blown entrained flow gasifier

It has been concluded that pressure, oxygen-induced penetration into gasification is a popular technology to meet these needs [29]. There are already large numbers (> 80 plants, 2010) of coal-fired fossil fuels to produce ammonia, energy production, petroleum chemicals, or petroleum products [8]. Biomass installation, however, is still under construction under a solid provider. One explanation for this is because solid biomass has a more difficult supply than coal. With gas technology's independence, it's critical to comprehend the impact of varied gas operating conditions on process productivity, syngas creation, and plant efficiency to investigate the solid properties of biomass gasification of flammable metal embedded in a gas station (5 kW). They concluded that free high-quality free syngas would be available when the gas temperature exceeded 1350 C for a few seconds. The driver's largest gasifier, designed for a high thermal input of 1 MW at high pressures of 10 bar, was used to investigate autothermal gasification of powdered wood. Furthermore, the gasifier was built to work with clean air to create gases with high quantities of CO, CO_2, H2, and H2O while emitting minimal N2. As N2 works as a synthetic ballast, making the process less efficient and more expensive to utilize, the syngas is designed and ready to continue operating.

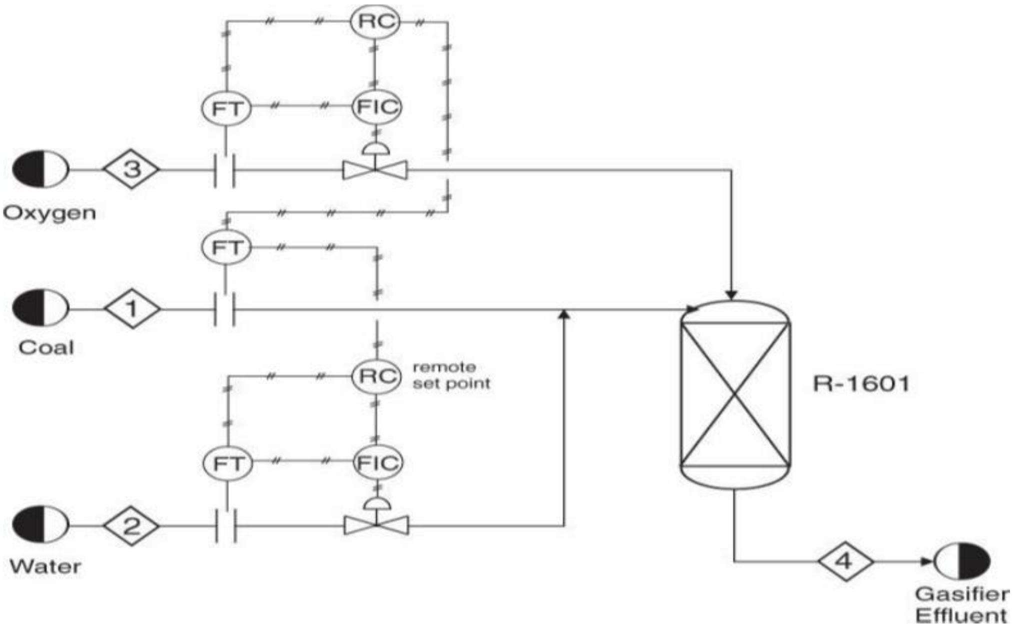


Figure 4 Process diagram of Coal gasification

A diagram of the internal oxygen flow system is shown in Figure B.15.1. Illinois no. 6 Coal, spread 1, mixed with water, spread to form a slurry. Typically, a slurry is produced in a tank by mixing charcoal with the right amount of water and stirring for hours. For simplicity, the same combination can be considered. The slurry and oxygen (95% pure by weight), Stream 3, are sent to the gasifier. In normal gas operation, an oxygen-to-coal ratio is used to maintain the temperature of the gas release so that the ash remains melted and lowers the gas wall. However, it is difficult to measure the output rate reliably and directly because of difficult conditions. Therefore, only the measurement controls are shown in figure. A measure of water and coal is used to maintain the viscosity of the slurry. Many reactions occur in the gasifier, for Subsequently following reactions take place.

$$CO + 0.5\ O_2 \rightarrow CO_2 \qquad \text{B.15.1}$$

$$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O \qquad B.\ 15.2$$

$$H_2 + 0.5O_2 \rightarrow H_2O \qquad B.\ 15.3$$

$$C + 0.5\ O_2 \rightarrow CO \qquad B.\ 15.4$$

$$C + CO_2 \rightarrow 2CO \qquad \text{B.15.5}$$

$$C + H_2O \rightarrow CO + H_2 \qquad \text{B.15.6}$$

In the electric filling machine, several additional reactions take place. Methane is produced through hydrogen gasification of mash, for example. Methane aids in the conversion of methane to steam and methane to CO2. There are other NH3 reactions that can also be classified as simple. Using the blocks provided in commercial process simulators, it is extremely difficult, if not impossible, to precisely compute the conversion of carbon to a gas filling machine. Complex hydrodynamics, solid fidelity, diversity, coal, char, tar, and ash are only a few of the major factors in the simulation process that are difficult to follow.

Chapter 3

3.1 Modelling and simulation of Coal gasification

For Coal gasification, the significant reactant are Coal, Oxygen, Nitrogen and Biomass materials. Oxygen comes from air or use Oxygen cylinders. A worked-on coal gasification is carried out using Coal and Oxygen as raw material. Oxygen is separated from air. The modelling and simulation of Coal gasification is done in Aspen Plus ®. Figure 5 is the process flow diagram of the process is:

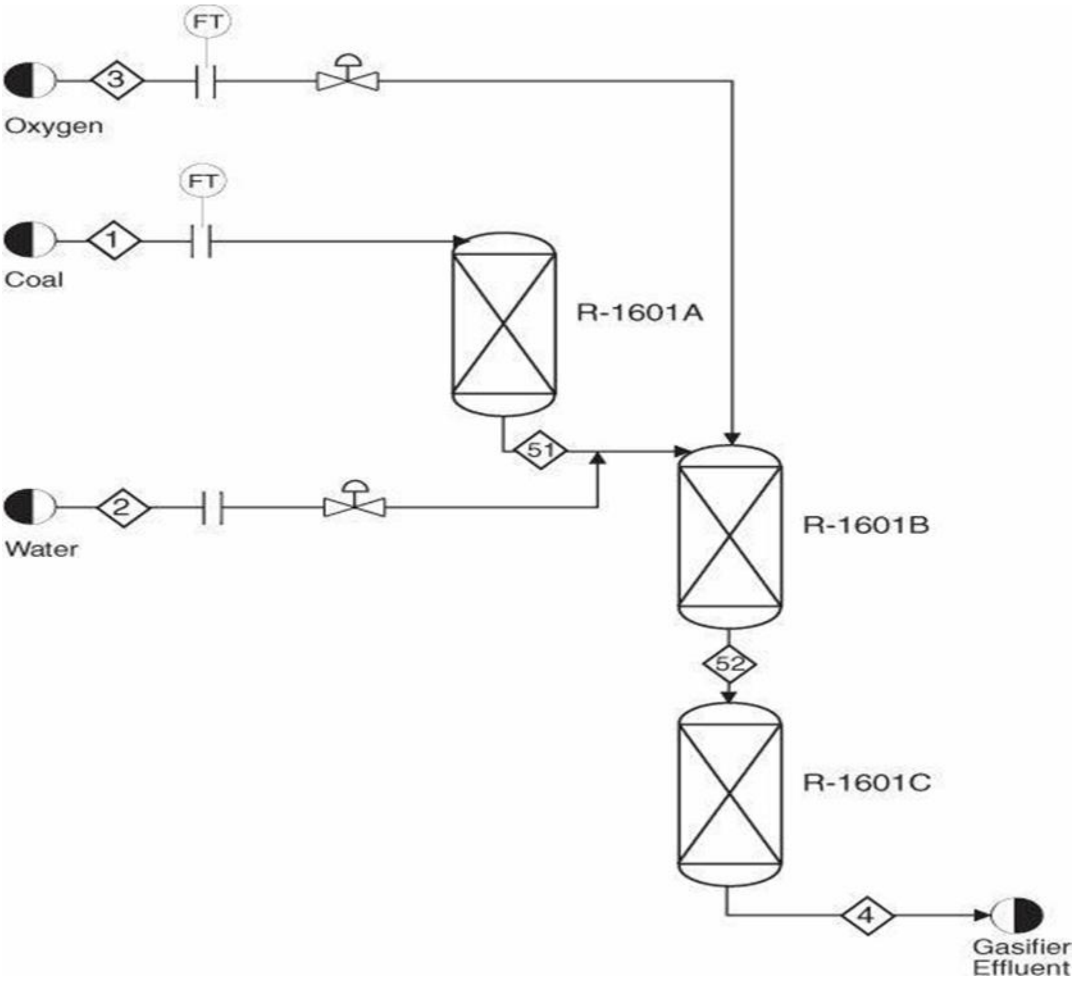


Figure 5 Process flow diagram

It is clear from process flow diagram, stream number 1 which is coal enters the reactor, where the pyrolysis of coal take place. Aspen plus modelling of solid is different from liquids and gaseous form. Because coal is a heterogeneous mixture of various complicated components, calculating its physical properties is extremely challenging. However, under the working parameters of the gasifier, its enthalpy and density can be determined using proper correlation or experimental data. Coal is designated as 'NC' (non-conventional) in Aspen Plus, and the enthalpy model for coal is HCOALGEN, which is unique to coal materials. Heat of combustion, heat of formation, and heat capacity have few empirical relationships. Coal entering before reactor is heated to 40℃ by heat exchanger and furnace and pressure is kept to 25.3bar. After passing through reactor R1 temperature of product rises to 500℃ and pressure drop to 23.5 bar. Now here temperature is raised to 1050℃ using heat exchanger and furnace. Before entering to R2 we mixed water and oxygen to product. Oxygen enters at temperature of 50℃ and pressure of 26.3 bar. Water is mixed with coal to make slurry, temperature and pressure of water is kept 40℃ and 26.3 bar. After mixing water to coal slurry, whole raw material is then heated to 500℃ and pressure is kept constant to 25bar. After heating raw material is sent to reactor R2 which is RGIBBS reactor where coal is burnt to Carbon and other materials. After reactor R2 due to exothermic reaction temperature of product rises to 1050℃ and pressure is 25bar and then enters to the reactor R3 which is RGIBBS too here more component reactions take place and final product which is SYNGAS (CO+H2) along with other products like Carbon dioxide, Ammonia, Hydrogen sulphide and Methane is formed. After this further burning temperature of product raises to 1153 ℃ which is then cooled to 30℃ by series of heat exchanger. Our desired product which is SYNGAS is separated by a separator S1 and give product at temperature of 30℃ and pressure of 25 bar. On the other hand, remaining by products Carbon dioxide, Ammonia, Hydrogen sulphide and Methane are collected at stream number 9. We can use these compounds to make useful other products.

3.2 Reaction Kinetics

Several reactions take place in the gasifier other than gasification. Coal drying, coal pyrolysis, and gasification in part char

Finally following reactions take place,

$$CO + 0.5\ O_2 \rightarrow CO_2 \qquad \text{B.15.1}$$

$$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O \qquad B.15.2$$

$$H_2 + 0.5O_2 \rightarrow H_2O \qquad B.15.3$$

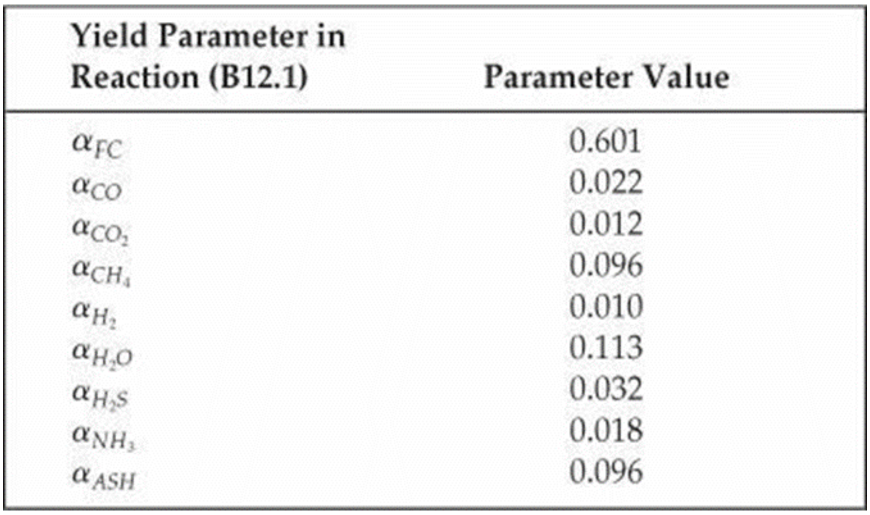
$$C + 0.5\,O_2 \rightarrow CO \qquad B.15.4$$

$$C + CO_2 \rightarrow 2CO \qquad \text{B.15.5}$$

$$C + H_2O \rightarrow CO + H_2 \qquad \text{B.15.6}$$

The product yield (on a mass basis) due to devolatilization and tar cracking (Reaction [B.15.1]) for Illinois no. 6 coal is calculated from Syamlal and Bissett and reported in table 1.

Table 1 Parametric Values



Yield Parameter in Reaction (B12.1)	Parameter Value
α_{FC}	0.601
α_{CO}	0.022
α_{CO_2}	0.012
α_{CH_4}	0.096
α_{H_2}	0.010
α_{H_2O}	0.113
α_{H_2S}	0.032
α_{NH_3}	0.018
α_{ASH}	0.096

The reaction kinetics for Reaction (B.15.3) is given by Westbrook and Dryer [5]:

$$-r_{CH_4} = 8.47 \times 10^{10} \exp\left(-\frac{202{,}680}{RT}\right) C_{O_2}^{1.3} C_{CH_4}^{0.2} \frac{\text{kmol}}{\text{m}^3\text{s}} \qquad \text{(B.15.10)}$$

The reaction kinetics for Reaction (B.15.4) is given by Jones and Lindstedt [4]:

$$-r_{H_2} = 2.72 \times 10^{15} T^{-1} \exp\left(-\frac{167{,}504}{RT}\right) C_{H_2}^{0.25} C_{O_2}^{1.5} \frac{\text{kmol}}{\text{m}^3\text{s}} \qquad \text{(B.15.11)}$$

The kinetics of the surface reactions described in the open literature for a shrinking-core model are employed in Equation (B.15.5) for the char burning reaction [4]. The rate statement has been simplified for use in a process simulator by assuming that the diffusive resistance in the ash layer is the leading resistance to mass transfer. Furthermore, the char particles are estimated to have a diameter of 400 m, and the gasifier's average working pressure is 24.5 atm. As a result, the reaction kinetics for this equation can be stated as follows:

$$-r_C = 1.63 \times 10^9 \exp\left(-\frac{113{,}070}{RT}\right) y_C^{2/3} y_{O_2} \frac{\text{kmol}}{\text{m}^3\text{s}} \tag{B.15.12}$$

The kinetics for Equation (B.15.6) is given by Wen et al. [6]

$$-r_C = 42{,}090 \exp\left(-\frac{175{,}880}{RT}\right) y_C y_{CO_2} \frac{\text{kmol}}{\text{m}^3\text{s}} \tag{B.15.13}$$

The kinetics for Equation (B.15.7) is given by Wen and Onozaki [6]

$$-r_C = 42{,}090 \exp\left(-\frac{175{,}880}{RT}\right) y_C y_{H_2O} \frac{\text{kmol}}{\text{m}^3\text{s}} \tag{B.15.14}$$

The kinetics for Equation (B.15.8) is given by Wen and Onozaki [6]

$$-r_{CO} = 52.3 \exp\left(-\frac{70{,}071}{RT}\right)\left(y_{CO} y_{H_2O} - \frac{y_{CO_2} y_{H_2}}{K_{eq}}\right) \frac{\text{kmol}}{\text{m}^3\text{s}} \tag{B.15.15}$$

In Equation (B.15.15),

$$K_{eq} = \exp\left[-3.689 + \frac{4019}{T}\right] \tag{B.15.16}$$

In the equations provided before, the activation energy is given in kJ/kmol, the units of concentration are kmol/m3[[FR 3]] (gas), and T is in K whenever a specific unit is needed.

Figure below shows the Coal first entered to heat exchanger and then to furnace to heat the coal after heating coal enters to reactor R1 which is RYIELD reactor here decomposition of coal take place

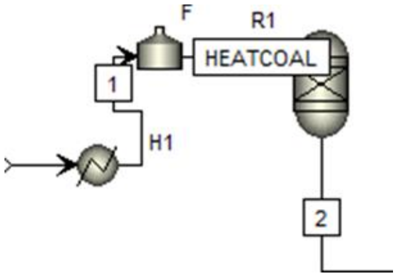


Figure 6 Feed stream heated and entered reactor R1

Result after passing through reactor R1 is shown in table 2.

Table 2 Result after passing through reactor R1

Temperature℃	500
Pressure-bar	23.5
Vapor Frac	1
Mole Flow kmol/hr	6770.68
Volume Flow cum/hr	7272
Mass Flow tn/hr	100
Enthalpy flow	20.942
Mass density lb/cuft	30.32
CO	4499.30
NH_3	135.25
H_2	76.91
CH_4	716.63
CO_2	89.56
H_2O	849.93
H_2S	2241.224
O_2	3281.4

Figure below shows that feed from reactor R1 to heat exchanger H2 and furnace F1where it is heated to temperature 1050℃ and 25 bar pressure and results are given below in table 3.

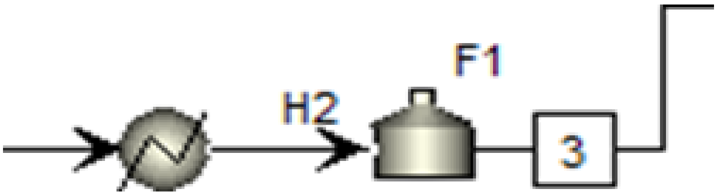


Figure 7 Feed heated in H2 and F1

Table 3 Results available after heating.

Temperature°C	1050
Pressure-bar	25
Vapor Frac	1
Mole Flow kmol/hr	6770
Volume Flow cum/hr	10017.7
Mass Flow kg/hr	100000
Mass density cuft/hr	0.623
Mole Flow kmol/hr	6770
C	54044.75
CO	4524.80
CO_2	3941.94
H_2O	15311.88
CH_4	11496.76
NH_3	2303.438
CH_4	11496.76

After passing through heat exchanger and here we mix water and Oxygen and mix it in mixer M1 and then feed is heated before entering to reactor R2.

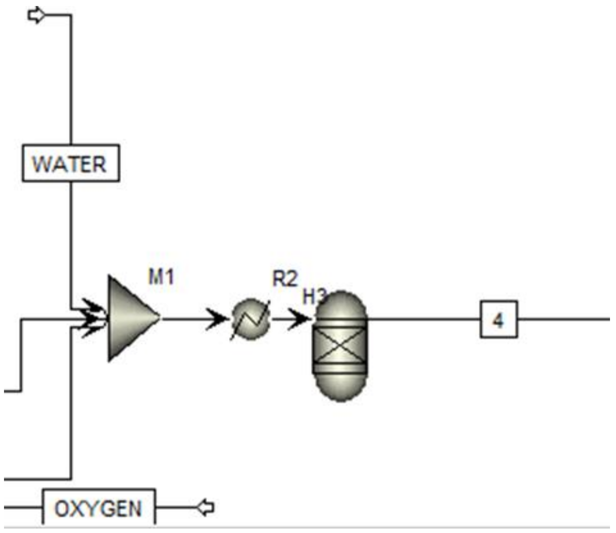


Figure 8 Feed water and Oxygen mixed, and feed enters to R2

Results available after passing reactor R2 in Aspen Plus ® given in table 4

Table 4 Results after passing reactor R2

Temperature℃	1050
Pressure-bar	25
Vapor Frac	1
Mole Flow kmol/hr	6770
Volume Flow cum/hr	44605.73
Mass Flow kg/hr	233000
Mass density cuft/hr	0.3260952000
Mole Flow kmol/hr	10258.2869
C	3042.0679
CO	0
CO_2	2425.28
H_2O	4082.479
CH_4	0
NH_3	467.236

Feed after passing through reactor R2 enters to reactor R3 where more decomposition of Coal takes place and final product which is SYNGAS (CO+H2) which is then taken to a separator where SYNGAS is separated from other product.

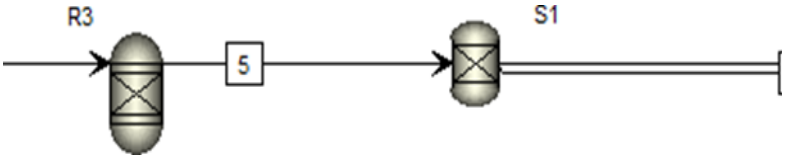


Figure 9 Feed enters the reactor R3 and separator S1.

Results available after passing reactor R3 and separator S1 in ASPEN PLUS® in table 5

Table 5 Results available after passing reactor R3 and separator S1

Temperature ℃	1143
Pressure-bar	25
Vapor Frac	1
Mole Flow kmol/hr	6770
Volume Flow cum/hr	32823.86
Mass Flow kg/hr	119291.15
Mass density cuft/hr	
Mole Flow kmol/hr	10258.2869
C	0
CO	4063.75
CO_2	0
H_2	2710.477
CH_4	0
NH_3	0

After passing through separator our product divided into two streams SYNGAS and stream number 9 which is by product of the process and can be further processed to produce useful product. After separating the SYNGAS and by products, the products are cooled using series of heat exchanger. here we use series of heat exchanger instead of one, the reason behind this is we cannot increase or decrease temperature from a specific temperature. Using series of heat exchanger lesser area is required and probability of explosion decreases.

Here SYNGAS is cooled from 1143℃ to 30℃, for this we used heat exchanger H4 and H5 which gradually decreases the temperature to 30℃.

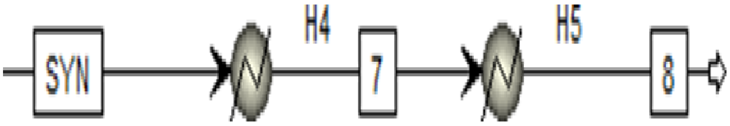


Figure 10 SYNGAS is cooled using H4 and H5

Here in the table below given below the final product of stream 8 which is SYNGAS.

Table 6 Results of SYNGAS production

Temperature℃	30
Pressure-bar	25
Vapor Frac	1
Mole Flow kmol/hr	6770
Volume Flow cum/hr	6829.745
Mass Flow kg/hr	119291.15
Mass density cuft/hr	1.090
Mole Flow kmol/hr	6774.22
C	0
CO	4063.746
CO_2	0
H_2	2710.477
CH_4	0
NH_3	0

This is final stream 9 which comprises of by-product of process here temperature of product is reduced to 30℃ by using series of heat exchanger.

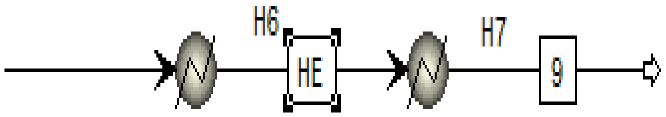


Figure 11 by products cooled using H6 and H7

Here is the table which shows the result of process. Here temperature of by product stream is decreased to 30°C.

Table 7 Results of by products

Temperature °C	30
Pressure-bar	25
Vapor Frac	1
Mole Flow kmol/hr	6770
Volume Flow cum/hr	6829.745
Mass Flow kg/hr	113708.85
Mass density cuft/hr	6.983
Mole Flow kmol/hr	3945.82
C	0
O2	1.904E-10
CO	0
CO_2	3088.8072
H_2S	531.8081
H_2O	4557.3356
H_2	0
N_2	514.5980
CH_4	5.60288
NH_3	0.88317

3.3. Process Flow Diagram in ASPEN PLUS ®

Process flow diagram of Coal gasification in ASPEN PLUS ®

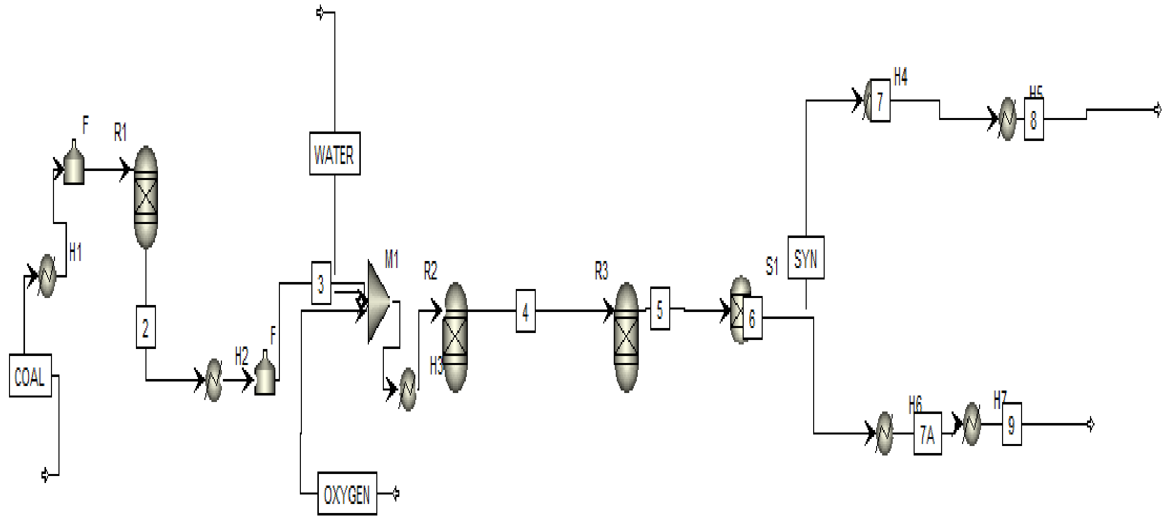


Figure 12 Process flow diagram of Coal gasification in Aspen Plus

Chapter 4

4.1 Optimization of a Chemical Process

Process intensification is a novel solution to meet the existing challenge in chemical progression industries. It is vital to the fast growth of the chemical industry. There are many types of approaches to intensify the process. In the industries, numerous challenges are facing such as minimum the usage of energy and disposal of waste and generation of electricity or improving the cost factor in addition to the ecological policy. Chemical industries are continuously worked to find the latest solution to complete the hassle. Process Intensification is used to find the solution to challenges like optimum energy usages. A significant example of the process intensification is reactive distillation, microreactor and rotating packed bed. Reactive distillation is a combination of reactor and separation of distillation column and addition of catalyst. There is simultaneous removal of vapor product from boiling systems. The equilibrium has moved to the product at higher conversion, and it generally enhances the reaction rate and selectivity of the product.

On the other hand, it reduced energy efficiency by 80% and the cost investment is 20%. Rotary packed bed is an excellent software that overcomes mass transfer limited and it utilized centrifugal acceleration to create turbulence. The Microreactor is a small dimension reactor, and they have a low reactor-volume ratio to surface-area ratio. Therefore, they have a high rate of heat transfer and reasonable temperature control in the process.

Process Intensification and Process Optimization have had a significant effect on the interest in the research community. The process Optimization is caused by a significant increase or advances in the speed and robustness of the equipment. Process Intensification is used for process improvement to decline the size of equipment. Process Intensification are included process, business & environmental aspects. Process Intensification is a method of reducing the size of equipment, energy reduction or waste production to achieve an aim.

4.2 Method for Process Optimization

4.2.1 Process Optimization

Process optimization is mathematical optimization that employs objective functions to maximize and minimize. The objective function is constraint through a given realistic section of the system improvements. Some physical relations and process specifications define process optimization for another variable. Process Optimization is based on mathematical programming for overall process analysis. The process Optimization is classified into mathematical optimization, hybrid method and heuristic methods. Heuristic approaches are based on a set of laws that gain by practice with unit operation scales and they are verified by simulation and experimentation. There are three categories of heuristics method, i.e., mining model data, data model and application model. The heuristic method is used to improving the existing process.

4.2.2 Mathematical Optimization

Optimization is established on the creation of a superstructure, and it bring together all possible flow sheets. By simulation, optimizations the flowsheet structure and enhances design that can be generated associated to a sequential approach, Table 8 shows the optimization methods are:

Table 8 Methods of optimization

	Heuristic	**Mathematical Modelling**	**Hybrid**
Methodology	Heuristic-based method	Optimization problems areused on the based superstructure	Heuristic structure method butthere are replacing of fixed rule
Scale	Task and Unit operationscale	Unit operation & task scale	Unit operation, task & Phenomena scale
Advantage	Improvement of theprevious process	Simulation and optimization for betterresult	There is simple structure, narrowspace by thermodynamic, Less complex MINIP/NLP

Limitation	Lack of knowledge &require an expert man	An optimal path is impliedin the superstructure	The heuristic has eliminated non-optimal solutions.

4.3 Retrofit

The industrial motivation toward the retrofit is increasing capacity, increasing productivity and safety, and decreased energy, waste, and operational cost. Process intensification has estimate 70-80% of a process design project that contends with a retrofit. Process Systems Engineering and Process Intensification have decreased energy consumption and help to increase and improve quality, safety, and conversion.

There are four-step heuristic methodologies, including base case analysis, general improvement without analysis, optimization, and solution. Process Optimization is used to resolve the current challenges in the chemical industry. Both process intensification and process intensification are a powerful mathematical tool.

4.4 Technique and Process of Reaction Optimization

- Raw material and selection of reagent.
- The scale-up technique.
- Increase quality controller aspects.
- Safety Material Data Sheet
- Focus on environmental aspects.
- Control hazard of the chemical process.

4.5 Pinch Analysis of Coal gasification

4.5.1 Methodology of Pinch Analysis

The collection of Pinch Analysis Technique

The first point is data withdrawal. We take the process sheet from the dependable energy and mass balance and remove the stream data needed for a pinch analysis.

There are understood placement principles on studying cold and hot utilities and estrangement systems and other process systems related to GCC and the pinch analysis.

There are multiple levels of hot and cold value levels. Therefore, the mixing of cooling and heating systems optimally with this process.

- The Network optimization and relaxation modify a network to reduce and eliminate a small heat exchanger that is less cost-effective.
- The retrofit of presence chemical plants adapts a technique to dealing with an existing plant layout and exchanger.
- There is systems analysis of power and heat systems and refrigeration and heat pumps systems.
- There are causes of process change that alter the operating condition of different unit operations and stream to maximize heat integration.

There is a systematic study of the method; in this stage, there is process analysis of the real process.

- First, get or construct and copy the plant flow sheet with the flow, temperature, and heat capacity data and create reliable energy and mass balance.
- Secondly, remove the stream data from different energy and mass balance.
- Select the minor heat transfer temperature $\Delta Tmin$ and calculate pinch temperature and energy target.
- Now examine the openings for process change and transformation of stream data according to target.
- Now consider and include different possibilities for integration with the plant site and restricting the heat exchanger to the subset of these streams.
- Analysis of the power requirements and then recognize chances for combined power and heat and heat pumping.
- The second last has definite whether the instrument process change and what other efficiency level will be used and the heat exchanger design to regain heat within the process.
- Finally, outline the utility methods to supply the cooling and heating requirements and alter the heat exchanger network.

4.5.2 Multiple Utilities

Types of Utility

There are hot utilities are supping heat to a process

- Furnace
- Stream Heater
- Flue gas of furnace
- Hot heat is rejected from a thermodynamic heat engine
- Thermal liquid
- Thermal fluid and hot engine
- The used heat that comes from refrigeration & heat pump condenser
- Electrical heater Cold Utility

The cooling water system

- Air cooler
- Stream raising and the heating feedwater system
- Chilled water systems
- Refrigeration systems
- The heat engine below the pinch point

4.5.3 Critical Steps of Pinch Technology

There are four steps for pinch analysis in heat regaining for both existing and new heat exchanger designs.

- First, Data extraction is involved in the collection of data for the utility and process.
- They are targeting the temperature which is best for various respects.
- In the design of heat exchangers, an initial warmth exchanger network is established.

Last is optimization wherever the initial design is essential and enhanced economically.

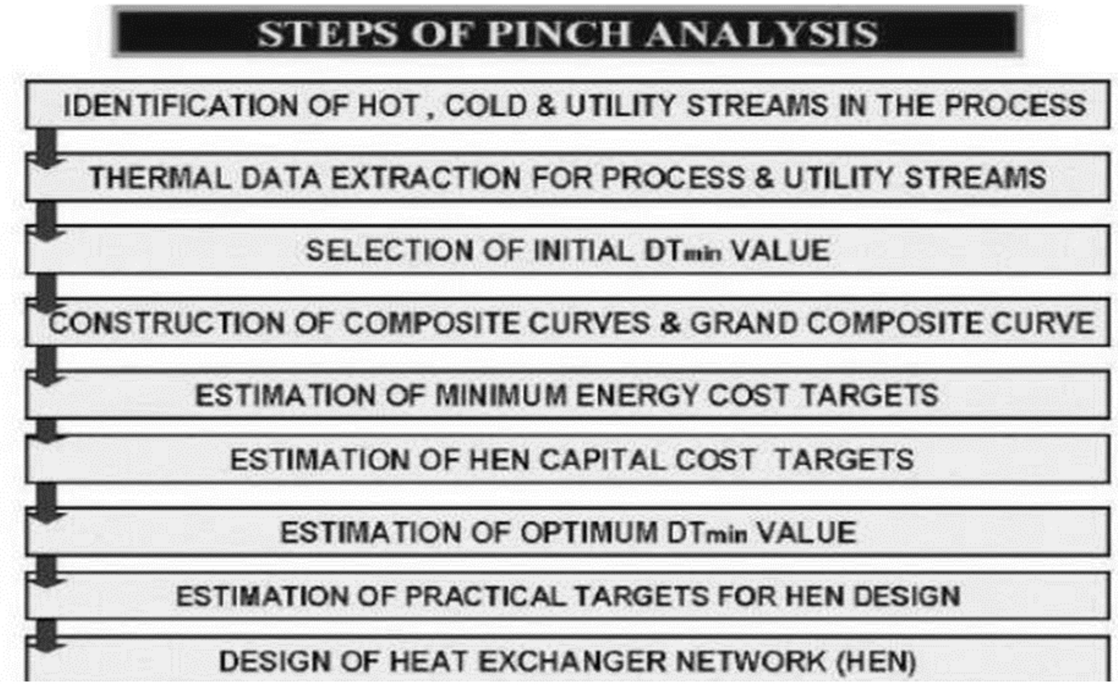


Figure 13 Steps of Pinch Analysis

Targeting

The importance of Process Integration is to the ability to classify the target performance before the designing step is starting. The maximum heat recovery system with the specified value for the smallest allowable temperature and the target can be formed for smallest energy usage, a smaller number of the heat exchanger and minimum process to process total heat transfer area. In addition, the calculation will identify the heat recapture pinch and act as a bottleneck for heating recovery.

Designing

Many productions are conducted out using the pinch design method in the heat exchanger network design in 1983 Linnhoff and Hindmarsh. The unique method focuses on the smallest energy recovery consumption and installation of a few units, and graphical and numerical calculations are regarded as heat transmission area and full yearly price throughout the design. Pinch analysis methods are used to decay at utility pinch points and identical process systems to enable the engineer to get a preliminary network and achieve a minimum energy target. The pinch design method is also given a situation where stream split is necessary to get minimum energy. The stream splitting is also used in area consideration and minimum and optimal temperature use for driving forces. The design policy is mentioned above to start strategy at the pinch point. At a pinch point, energetic forces are restricted and a critical match for most regaining of heat.

Optimization

The optimization was implemented by the heat exchanger network design to recover maximum energy by designing a pinch analysis method. Therefore, it should be regarded as first and initial design and final optimization are required. The heat exchanger's initial location depends upon a pinch location and the pinch point depends upon a ΔTmin. This is the first key parameter of the pinch design method. It is now repeating all calculations for the synthesis of Heat Exchanger Network for different values of ΔTmin. Using different ΔTmin values is possible to get a good starting value for heat recovery in an exchanger.

4.5.4 Basic Element of Pinch Technology

Grid Representation

The grid has represented a heat exchanger network. The grid representation is:

- Hot Streams that required cooling medium. It is moving in the right direction.
- Cold Streams that are required a heating medium. It is moving in the left direction.
- A heat exchanger is characterized by vertical lining joining the two open circles on the separate streams being matched.
- Cooler and heater are represented in an open circle on the streamline being cooled and heated. Figure 14 represented the grid diagram of the heat recovery problem.

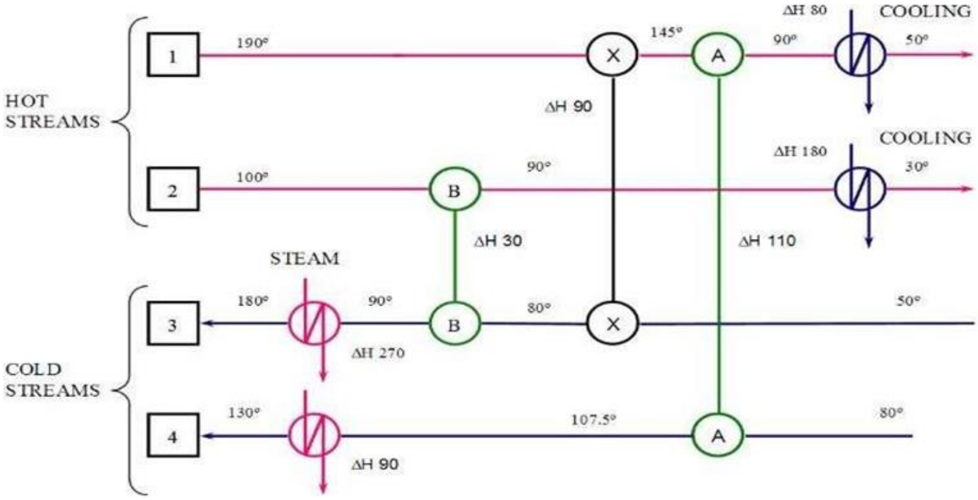


Figure 14 Heat recovery grid diagram

4.5.5 Composite Curve

The composite curve consists of different stream data that are representation a material balance and process heat. The composite curve allows a designer to predict the cold and hot utility aims of design and dynamic forces for the heat transfer and locate the heat recovery. In composite curve consists of temperature-enthalpy profile of the heat process, and heat demand of the process together get a graphical representation. Composite curves are also provided the minimum requirement of cold utilities and cold utilities in the process. The hot composite curve structure simply involves adding enthalpy that is changing streams in relevant temperature interludes. Figure 15 shows the composite curve of the heat recovery problem.

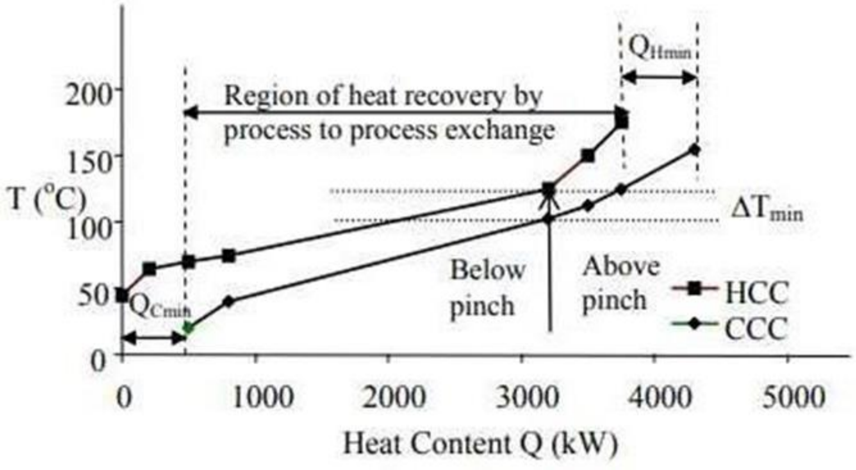


Figure 15 Heat recovery composite curve

4.5.6 Problem Table Algorithm

A graphical representation of composite curve for generation of minimum energy target is a clumsy and consuming.

The procedure of the problem table is broken into three stages.

- First, we set up the shifted temperature from the stream source and then the target temperature is subtracting by ΔT min/2 and from the hot stream and addition ΔT min / 2 to the cool streams.
- We can calculate energy balance from each shifted temperature

$\Delta H = [\sum Cp\ cold - \sum Cp\ hot]\ \Delta Ti$

Δ H = Heat balance from the shifted temperature and temperature interlude i an Δ H is a temperature difference.

CPc = Cold stream Specific heat capacity CPh = Hot stream Specific heat capacity

In the cascade, the surplus heat is reduced the temperature point from intermission to intermission. It is also feasible that any surplus of heat presented from the hot stream in the interval is as hot as necessary to supply shortage in the cold stream move toward the next interval. Heat cannot be travelled up to the temperature balance. Figure 16 is the composite curve diagram.

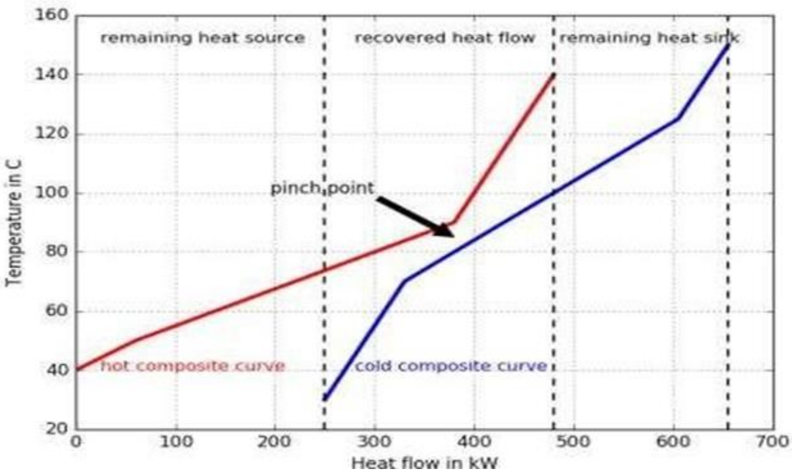


Figure 16 Composite curve

4.5.7 Grand Composite Curve

The Grand composite curve represents a graphical demonstration of a heat cascade. The Grand composite curve is based on process stream data.

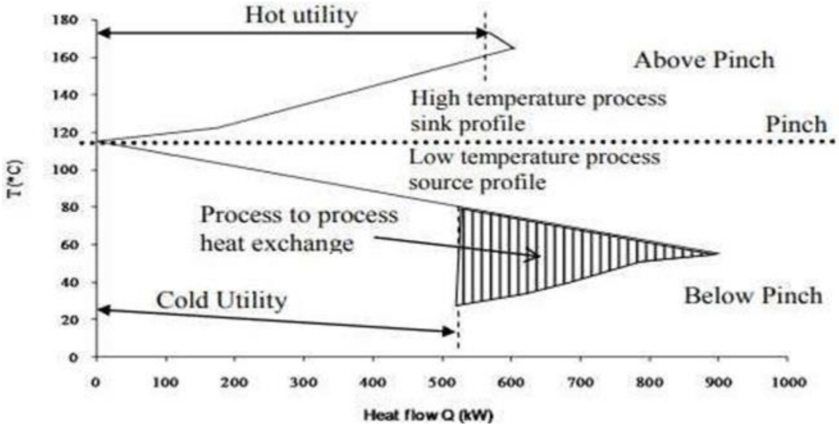


Figure 17 Grand composite curve

The Grand composite curve is showing the process/utility interface. Figure 17 shows the Grand Composite Curve is shown to visualize cold and hot utility and provides multiples utilities in the process stream.

4.5.8 Maximum Energy Recovery

In the composite curve diagram, the intersection between cold and hot composite curves shows extreme heat revival in the process. The sink/source of the process exchanger is given five concepts.

- Target: The composite curve is telling us how much exterior cooling/heating is required. The optimum process is confirmed as while non-optimal processes are recognized with confidence and great speed.
- The Pinch: The pinch tells us we need external reheating above the pinch and external chilling below the pinch point. It tells us the place of the heat exchanger, furnace, and cooler ECT.
- More in more out: The inefficient process efficiency required more minimum outside heating and the lowest external cooling. The excess of external heating has provided the heat transfer equipment twice.
- Freedom choice: The heat source and heat sink are separate. This constrainer is helping the designer to choose the control arrangement and plant layout. If the designer violates the Law, he will calculate the pinch heat flow and predict the overall penalty involved. Figure 18 shows the maximum energy recovery diagram.

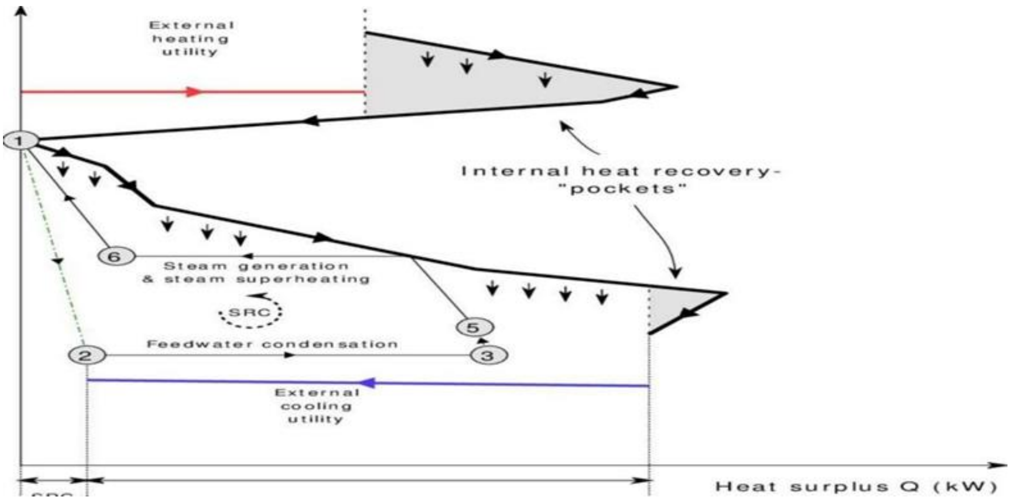


Figure 18 Maximum energy recovery

One of the most important tools in process intensification is Pinch analysis for the efficient use of energy, water and hydrogen in the process, which is used to improve the efficient use of energy, water and hydrogen in process chemical industries. The pinch analysis is well recognized method in chemical industry to improve the efficiency.

- Chemical
- Petrochemical
- Oil Refinery
- Paper and pulp
- Steel and Metallurgy

Pinch analysis is the tool that allows us to examine the energy flow contained by the flow and discover the inexpensive way to maximize heat recovery and minimize the use of external utilities. This method is used to identify energy-saving processes with the processor utility systems. Pinch analysis process utilities to find the optimum way to use them and save the financial saving. With this method, both capital investment and operating costs can be decreased.

4.6 The Pinch Concept

Pinch analysis is a structured approach that can be used to improve related to process and external utility. Pinch analysis gives us opportunities such as improving efficiency, reducing operating costs, and planning capital investment. Figure 19 is the pinch concept.

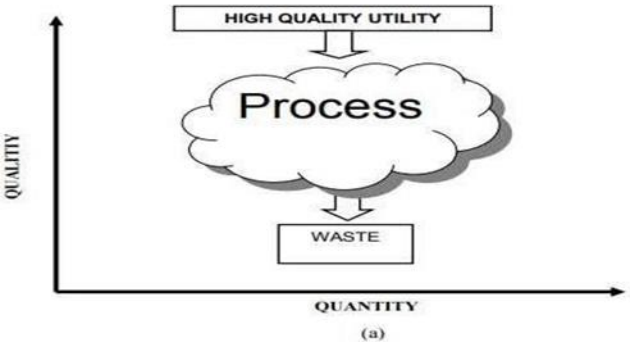


Figure 19 The Pinch concept

4.6.1 Pinch Technology vs. Process Engineering

Pinch Technology is a subdivision of process engineering.

Our engineers are specialized information of thermodynamic and software tools. They can communicate effectively with clients and conceptual design.

Carrying out process engineering projects without the input of pinch study will lead to a less efficient.

4.6.2 How a pinch technology is different from other energy

Pinch technology is used for saving and their corresponding financial benefits.

- Maximum possibility to saving utilities.
- It studies at all general site
- It reveals the highest cogeneration potential.
- It does not include a benchmark but also accounts for all specific factors, age, process equipment, cost product ECT.

4.6.3 Role of Thermodynamic Law in Pinch Technology

Pinch Technology is simple method to analyse the process using 1st and 2 and law of Thermodynamics. The first law gives us equation for calculating manipulative enthalpy change in the streams that are moving in heat exchanger. The Second Law of thermodynamic gives us the direction of heat transfer in the process. The energy moved from higher concentration to lower concentration. This is prohibiting crossing over the temperature of hot temperature and cold temperature through heat exchangers. In the heat exchanger design network, we cannot cool a hot stream below cold stream temperature neither we cannot hot a cooled streams above hot supply temperature. The temperature moves toward ($\Delta Tmin$) in the stream temperature profile for the heat exchanger. The pinch analysis is defined as the minimum driving force is allowed in a heat exchanger network. Pinch analysis is applied to a wide range of applications. It is applied to the petroleum sector and is vast in a mainstream application. There is a realistic target approached in a practical problem that is specified for each site. Wherever cooling and heating utility is taken place where potential opportunity is required.

- Real Saving
- Feasible job
- Significant Target

4.6.4 Importance of Pinch Technology

- Pinch give the best that will be achieved in systems.
- The pinch can give the target to aim for that is less than the theoretical maximum.
- The target is to set the basics of heat exchanger design and design a heat exchanger to attain the target.
- Pinch analysis takes place at comprehensive systems. This allows seeing the interaction of two streams in the process flow diagram or the utility flow sheet.
- Refine the area data where the accuracy factor is essential. The pinch can show incomplete data.
- Pinch Analysis can compare results with other design tools, requiring detailed geometry and flow sheet structure.
- Pinch is one of the best tools that can be used for conceptual design.

4.6.5 Problem Addressed by Pinch Technology Create a new design

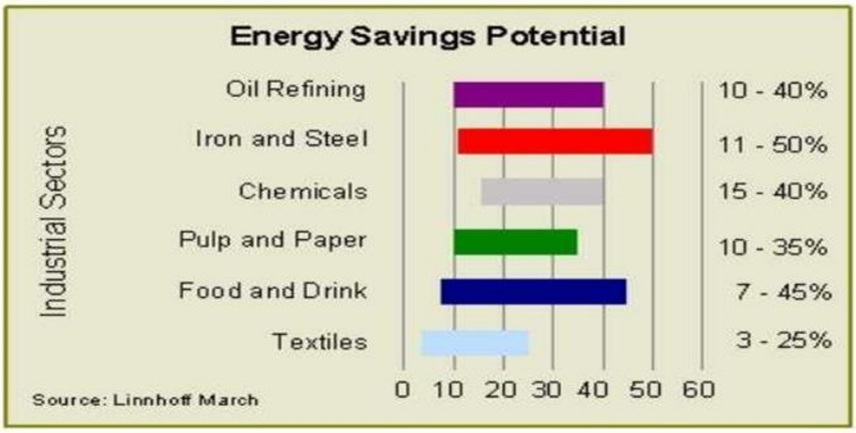
The design of the Heat Exchanger Network applies pinch analysis during the scheduling of process modification. It is required significant investment before the finalization of the heat exchanger network. Pinch analysis is used to maximize energy optimization and reduce cost investment in new chemical plant design. Many process constraints and plant layouts can be reduced by redesign.

Retrofit and revamping the existing design

The retrofitting of the Heat exchanger network in the chemical industry is essential to improve heat exchanger efficiency. In the retrofit project, the energy efficiency improvement and performance are required capital cost. In the pinch analysis, there is an aim to get maximizing the return investment. The requirement of energy is not a need, but it is necessary a most wanted utility. In the chemical industry, the essential utility is cooling water and steam. The cost of utility is no cheaper they are expensive. Pinch analysis takes place to save utility or minimum usage utilities. The pinch technology is a suitable method for minimizing or maximizing utility utilization by maximizing the process-to-process heat recovery. Temperature integral figure identifies the least utility necessity and target maximum process to process heat transfer and target minimum heat exchanger network installed. Try to reduce number of heat exchanger by splitting stream There are many chemical industries in which there are many heats and cool streams at the specific requirement. In both cases, energy transfers take place The heating required is done by using steam and for cooling water is used. However, costs involving heating and cooling process stream and natural resources are also contributed to the energy crisis problem. However, there is a need for minimum usage of external usages like cooling and hot utility, but there is maximum utilization of process-to-process heat transfer. Pinch technology is a method in which are targeted to get a whole process to process heat recovery and minimum usage of external utility. Pinch technology is involved a graphical method is called a thermal pinch diagram. The present research uses a temperature interval diagram to maximize the process-to-process heat transfer and our target to get minimum utility requirements. A heat exchanger network is designed using a pinch design approach with a minimum number of heat exchangers and using the split technique without violating the Second Law of thermodynamics. Figure 20 shows the potential of energy saving.

4.7 Application of Process Intensification

- Heat Integration
- Cogeneration site targeting
- Fractional Distillation Column target
- Hydrogen gas management refinery



Source: Linnhoff March

Figure 20 Potential of energy recovery

4.8 Methodology of Pinch Analysis

Pinch technology is the study of algebraic approach which is followed step by step which are given as. First, collect thermal data of the process. Temperature interval diagram is made on suitable temperature difference. The utility target is determined, and stream splitting technology was employed to create a network.

Table 9 shows coal gasification process streams

Streams	Description	Type	Heat Type	T1 (K)	T2 (K)	H (kW)	m·cp(kW·K)
1	C1	Cold	Sensible	40	400	8793	24.42
2	C2	Cold	Sensible	500	700	13032	65.16
3	C3	Cold	Sensible	432	600	18693	111.26
4	H1	Hot	Sensible	1143	600	-33341.	61.4
5	H2	Hot	Sensible	600	30	-32212.	56.51
6	H3	Hot	Sensible	1143	800	-17288.49	50.40
7	H4	Hot	Sensible	800	30	-17288.49	22.45258

4.8.1 Grid diagram of Coal gasification

Figure shows the grid diagram of Coal gasification process

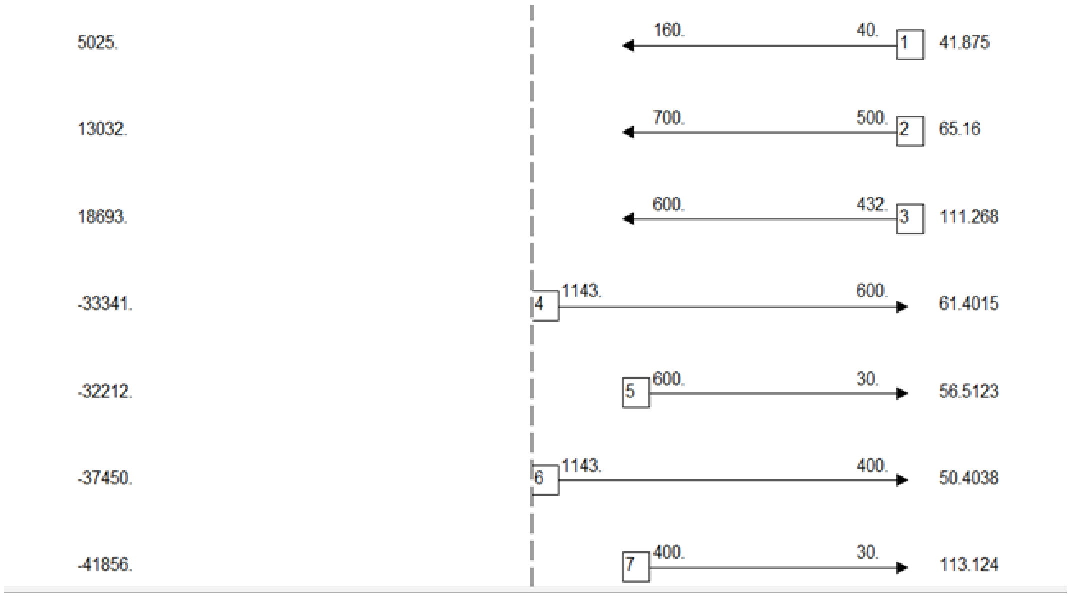


Figure 21 Grid diagram of Coal gasification

4.8.2 Composite Curve

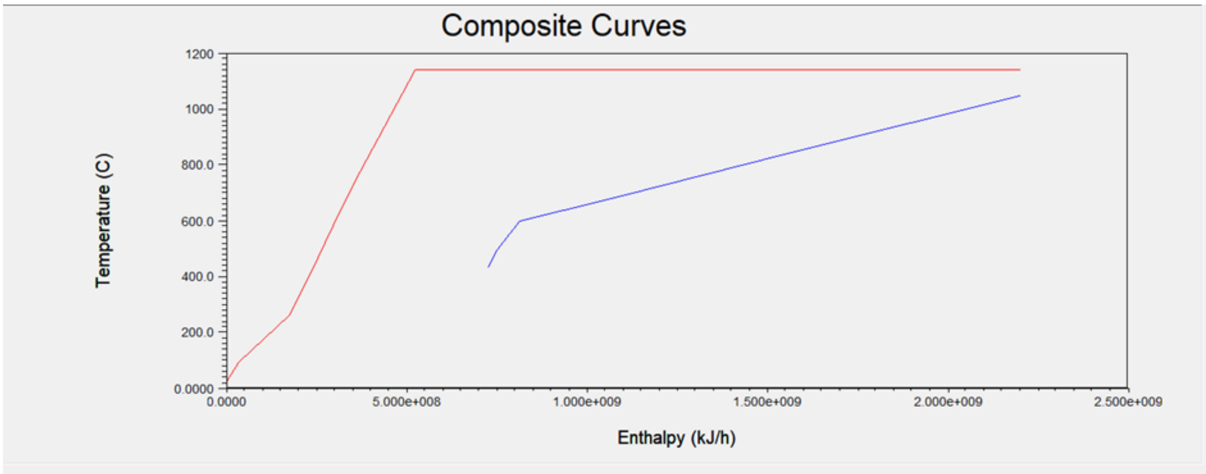


Figure 22 Composite curve of Coal gasification

Composite curve is graphical representation of process which contains hot stream and cold stream and shows the energy available and required for the process. The curve shows the minimum requirements of hot and cold utilities for the specific process. Moreover, the minimum driving force is needed for the process. Next step is to generate a grid diagram which identifies the location and number of heat exchanger required for the specific process. It is noted that changes in process parameters due to optimization and modification will change the pinch point and change the hot and cold utilities. The composite curve diagram shows whether heat exchangers are correctly arranged. Figure shows the composite curve of the Coal gasification process.

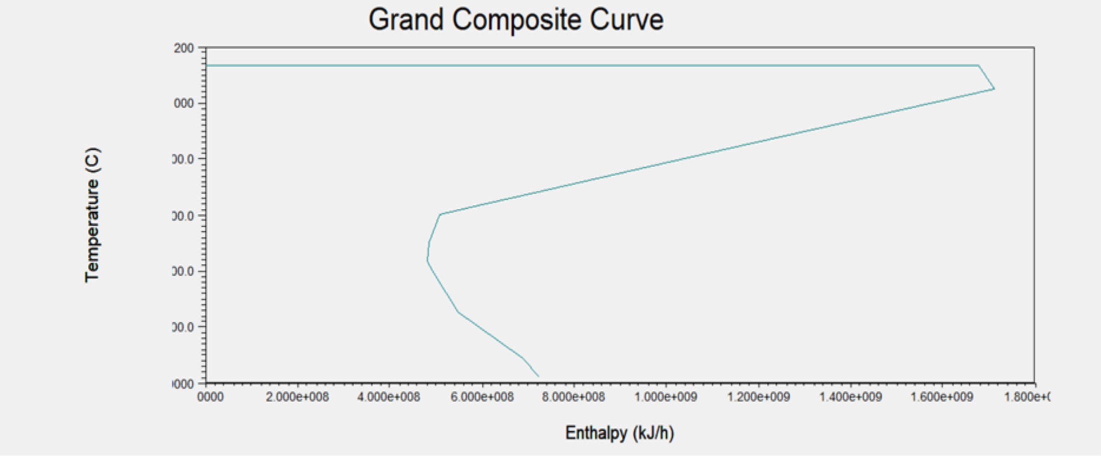


Figure 23 Grand composite curve of Coal gasification

4.9 Area and Cost Targets

Table 12 is the calculating Area and Cost Targets, and the following results are obtained:

Table 10 Area and cost targeting

Minimum Number of Heat Exchangers:	7
Area Target:	420 m^2
Cost Targets:	
Operating:	4.64995e+006 $/yr.

After the optimization, most of the energy is utilized in the process and use of external utilities is reduced by using process energy.

Hot utility: 8821.1 / 15783.8 (KW)

Before process optimization, we need 15783.6 KW of heat to perform desired process, but after optimization, we recover 6962.8 KW of heat from hot streams and only provided 8820.1 KW of external heat.

Cold utility: 70252.2 / 77215.3 (KW)

Before process optimization, we need 77215.8 KW of cold utility to achieve the desired temperature, but after pinch analysis, we recover 6963.2 KW of heat from cold streams and only provided 70252.4 KW of cold utility.

4.10 Heat Exchanger Network Design

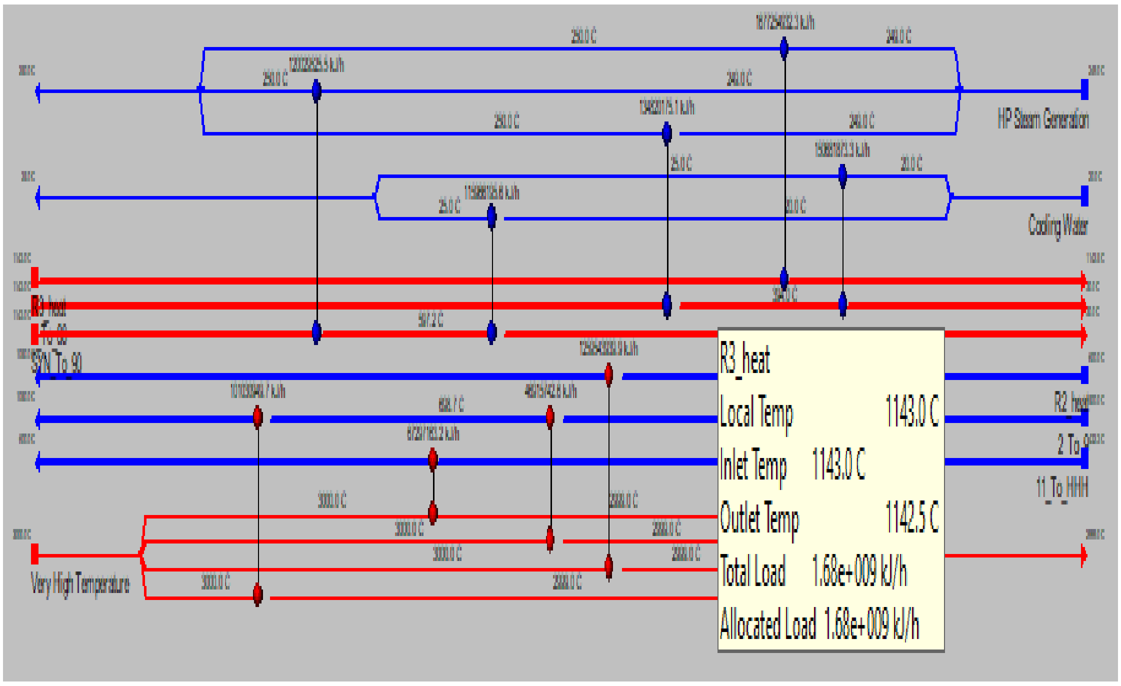


Figure 24 Heat exchanger network design of Coal gasification

4.11 Application of Pinch Analysis

- Profiles of Distillation Column
- Optimization and Pressure drop effect
- Process Integration of total site
- Minimization of wastewater and water usage
- Integration of batch process

Chapter 5

5.1 Cost Analysis

A capital cost is associated with an existing chemical plant and modification of a new chemical plant. The five categorizations are.

- Detailed Estimate
- Definitive Estimate
- Preliminary Estimate
- Study Estimate
- Order of Magnitude

5.2 Order of Magnitude

This estimation is based on cost information for the complete chemical process from a previous chemical plant. This cost information is adjusted by using a scaling factor, capacity, and providing the chemical plant's estimated cost. A block flow diagram is used for the order of Magnitude cost estimation.

5.3 Study Estimation

In this type of cost, estimation enlists a primary component found in the process industry. These are including equipment like compressor, pump-turbine, heat exchanger ECT. Each piece of equipment is roughly sized and determined the cost estimation. This estimation is based on a process flow diagram.

5.4 Preliminary Design Estimate

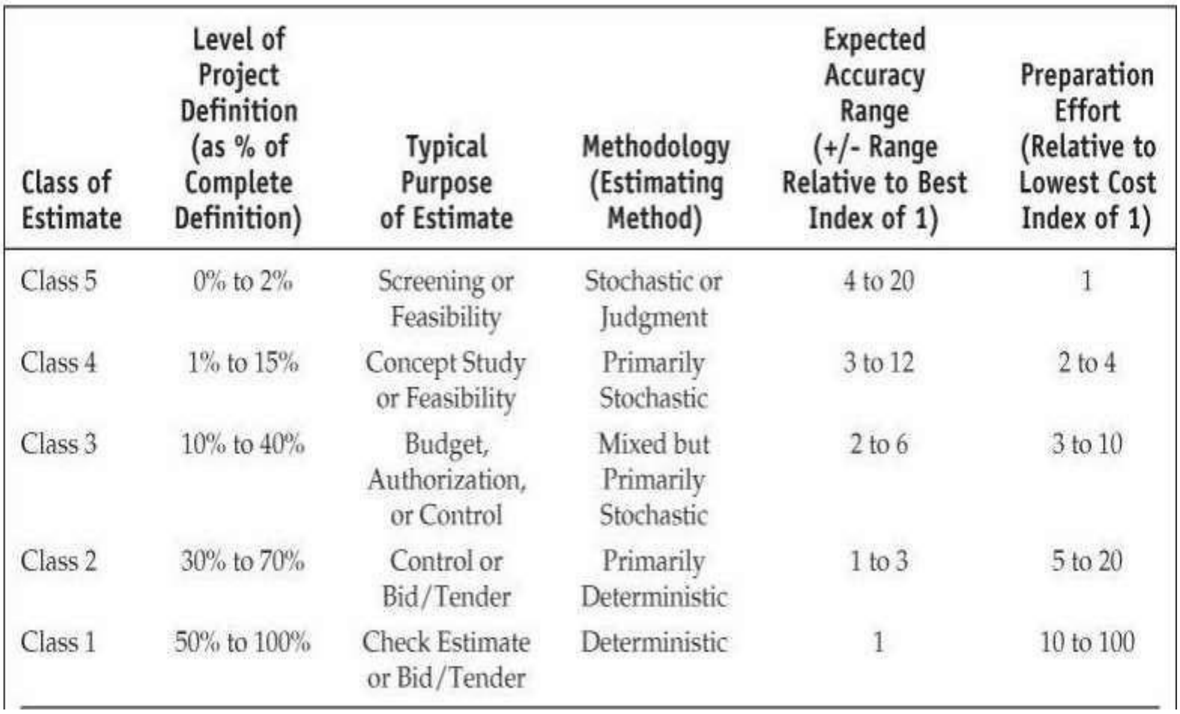
In these types of estimation, precise sizing of equipment that is used in the study is assessed. In addition, the layout of equipment is made up of piping, electrical equipment, and instrumentation and utilities. The preliminary estimate is based on the Process Flow Diagram that included vessel stretches of equipment, elevation diagram.

Definitive Estimation

An estimation requires preliminary specification of all chemical equipment, instrumentation, utilities and off-site. The definitive estimate is including the Process Flow Diagram, utility balance, and P&ID.

Detailed Estimation

This type of information needs complete information about the process and process utilities and off-site utilities. The detailed estimation includes Process Flow Diagram, Process and Instrumentation Diagram, utility balance and vessel sketches.



Class of Estimate	Level of Project Definition (as % of Complete Definition)	Typical Purpose of Estimate	Methodology (Estimating Method)	Expected Accuracy Range (+/- Range Relative to Best Index of 1)	Preparation Effort (Relative to Lowest Cost Index of 1)
Class 5	0% to 2%	Screening or Feasibility	Stochastic or Judgment	4 to 20	1
Class 4	1% to 15%	Concept Study or Feasibility	Primarily Stochastic	3 to 12	2 to 4
Class 3	10% to 40%	Budget, Authorization, or Control	Mixed but Primarily Stochastic	2 to 6	3 to 10
Class 2	30% to 70%	Control or Bid/Tender	Primarily Deterministic	1 to 3	5 to 20
Class 1	50% to 100%	Check Estimate or Bid/Tender	Deterministic	1	10 to 100

Figure 25 Classes of cost estimation

Some points are enlisted of some revenue and cost that needed in engineering economy:

- Capital Investment
- Labour Cost
- Material Cost
- Maintenance Cost
- Taxes and Insurance
- Overhead Cost

- Disposal Cost
- Quality Cost
- Market Value

The level of accuracy of the estimate depends upon:

- Effort and time available
- Technique and Method Employed
- What is the Qualification of the estimator?
- Study sensitivity of different parameter

5.5 Module Costing Technique

This is important and simple technique to estimate the cost of new chemical plant. The preliminary cost estimation is best for chemical plants. This technique is based on all costs back of the purchased cost of chemical equipment evaluation. In addition, there is some technique of Module costing:

- Specify equipment types.
- There is specific equipment pressure.
- There is specific material of construction.

5.6 Source of Cost Estimation

The information of cost analysis is helpful for cost and revenue estimating. There are four primary sources of information.

- Accounting Record
- Other sources take from firm
- Source from outside the firm
- Research and Development

Accounting Record

An accounting record is the primary source of cost analysis, but they are not suitable for direct use. An accounting record consists of operating procedures for saving and keeping records of the detailed transaction between established categories of different assets. Accounting records are sources of historical data, but there is some limitation when used in making future estimation for financial engineering analysis.

Another source takes from a firm

Several people and records are the best sources for estimating information. For example, firms that keep the previous record applicable to economic analysis are engineering, quality, purchased, sales, and personnel.

Source takes form outside firm

Different sources are outside the firm that is helpful information for cost analysis. The primary sources from an outsider are:

- Published Information
- Current Wage

Research and Development

Information about this is not given or published, only alternative to get estimate is research and development. First developed a pilot plant and observing the operating condition and pressure.

Unit Technique

The unit technique is involved per unit factor that can be used for estimation.

- The Capital cost of plant per kilowatt-hour
- Revenue per capacity
- Revenue generated per customer
- Operating cost per capacity
- Temperature loss per 100 feet of steam pipe
- Construction of plant per square feet

Factor Technique

The factoring technique is a sum of several qualities or some components and some other component that add in any components estimate directly.

$C = \sum d\ Cd + \sum m\ fm\ Um$

C = Cost estimate

Cd = Cost of selected components Fm = Cost of per components

Um = No of components

5.7 Factor Affecting Investment and Production Cost

Whenever a Chemical Engineer decides the cost of any product, this cost must be accurate to a reliable decision. The engineer must know the factor that affects the cost of the product.

Many companies have different arrangements with other contractors. In contrast, raw material and equipment may be purchased lower than market value, but a chemical engineer is based on the raw material of reactant available in the marketplace. The engineer must be upgraded with price fluctuation, governmental regulation, company, policies, and other factors.

- Source of Equipment
- Price Fluctuation
- Company Policy
- Operating time and rate of production
- Government Policy

Source of Equipment

The main cost factor in chemical process is cost of equipment. In chemical process mainly standard tank, reactor and furnaces are used that cost a lot. Decline in cost can be done if second-hand equipment is bought from the market. If new equipment is bought, then several quotations should be getting from the company, and it would help get equipment at a low cost.

Price Fluctuation

In modern technology, there are price fluctuation price varies from period to period. The labour cost is changed by changing the price of food and goods. Therefore, a chemical engineer should know the daily price and wage fluctuation.

Company Policy

The policy of the company is a direct effect on the cost of the product. The company policies depend on labour unions because there is an effect of labour charge overtime work and the operator and engineer that work in a company in overtime work.

Operating time and rate of production

The rate of production, operating time and sale demand are next to each other. The chemical plant is operating best time to give us maximum production. The total cost of production is minimum because the fixed cost is fully utilities. If production capacity is more significant than sale demand, the operation is carried on reduced capacity.

Governmental Policy

The government has many regulations and rules that are cause-effect on the direct cost of industrial processes. For example, there is some tariff regulation on imports and export. In addition, there are restrictions on permissible depreciation rates and environmental regulations.

Capital Investment

The capital cost is essential for industrial and plant services is also called fixed capital investment. However, there are necessary for operating chemical plant is called Operating Cost and both fixed cost investment and operating cost is called total cost investment.

Moreover, fixed capital cost consists of two types

- Manufacturing Fixed Capital Investment
- Non-Manufacturing Fixed Capital Investment

5.8 Fixed Capital Investment

Fixed capital cost involves the cost of equipment and installation cost and cost of necessary utilities for the process. There is an expense for instrument, piping, installation, insulation. These all cost are examples of fixed cost A fixed cost investment involves the cost of construction overhead and other utilities that are not related to process. The plant component is processing building, administration, warehouse, shipping, transportation, shop, waste disposal facilities, and other parts. The construction overhead is included supervision expenses, engineering expenses, contractor fees, field office and contingences. The construction overhead is directly proportional between non-manufacturing fixed capital investment and manufacturing fixed capital investment.

5.9 Working Capital

The working capital investment is involving the total cost is an investment in the process:

- Cost of Raw material and Supplies in stock
- Finished product and unfinished product in the process of manufacturing
- Account receivable
- Keep cash on hand for monthly payment & raw material purchaser
- Accounts payables
- Taxes payables

The ratio of total capital investment and working capital differs with different companies, but a chemical engineer at first uses work capital amount to 10 to 20 percent of total cost investment. Sometimes, the percentage may increase to 50% for company product cost demand because of extensive inventories that must be retained.

5.10 Estimation of Capital Investment

Several factors are put in the estimates of capital investment. First, the best method is traceable to sizing equipment, auxiliary facilities rather than gross costing.

There are two types of capital investment

- Direct Cost Investment
- Indirect Cost Investment

Direct Cost Investment

Purchased Equipment

- Freight charge
- Taxes
- Duties Cost

Purchased Equipment Cost Installation

- Installation of all cost equipment
- Insulation
- Structural Cost

Instrumentation and Control

- Purchase
- Calibration
- Installation

Piping

- Piping Carbon Steel
- lead
- ceramic
- copper

Electrical Equipment

- Electrical Equipment
- switch motor
- fitting
- instrument and control

Building (Also including Service)

- Platform Support
- Ladder

- Offices
- Hospital

Yard Improvement

- Grading
- Walkways
- Parking Fences

Service Facilities

- Hot Steam
- Water
- Fuel
- Compressed Air-Land Cost
- Property Cost
- Survey and fee

Indirect Cost

Engineering and Supervision

- Process Design
- General Engineering
- Cost Engineering

Construction Expense4

- Construction Expense
- Warehouse Charge
- Safety
- Taxes

Contractor Fee and Contingency

5.11 Equipment Summary of Coal Gasification

Table 11 Equipment Summary of Coal Gasification

Exchangers	Exchanger Type	Shell Pressure (barg)	Tube Pressure (barg)	MOC	Area (square meters)	Purchased Equipment Cost	Bare Module Cost	Base Equipment Cost	Base Bare Modu eCost
E-101	Floating Head	1	15	Carbon Steel / CarbonSteel	269	$ 94,000	$ 309,000	$ 94,000	$ 309,00
E-102	Floating Head	1	15	Carbon Steel / CarbonSteel	367	$ 95,500	$ 313,000	$ 94,800	$ 312,00
E-103	Floating Head	2	26.8	Carbon Steel / CarbonSteel	175	$ 199,000	$ 645,000	$ 193,000	$ 634,00
E-104	Floating Head	2	25.8	Carbon Steel / CarbonSteel	270	$ 193,000	$ 626,000	$ 187,000	$ 616,00
E-105	Floating Head	2	30	Carbon Steel / CarbonSteel	272	$ 198,000	$ 639,000	$ 191,000	$ 627,00

E-106	Floating Head	2	25.8		Carbon Steel / Carbon Steel	117	$ 191,000	$ 618,000	$ 608,00
E-107	Floating Head	2	30		Carbon Steel / Carbon Steel	280	$ 49,000	$ 158,000	$ 156,00
Heater	**Type**	**Heat Duty (MJ/h)**	**Steam Superheat (°C)**	**MOC**	**Pressure (barg)**		**Purchased**	**Bare Module Cost**	**Base Bare**
H-101	Reformer furnace	67200		CarbonSteel	15	$ 1,100,000	$ 6,780,000	$ 1,700,000	$ 6,780,0 0
H-101	Reformer furnace	67200		CarbonSteel	15	$ 1,100,000	$ 6,780,000	$ 1,700,000	$ 6,780,0 0
Mixers	**Type**	**Power (kilowatts)**	**# Spares**			**Purchased Equipment Cost**	**Bare Module Cost**	**Base Equipment Cost**	**Base Bare Modu eCost**
M-101	Impeller	150	0			355,327	490,351	355,327	490,35
Reactors	**Type**	**Volume (cubic meters)**				**Purchased Equipment Cost**	**Bare Module Cost**	**Base Equipment Cost**	**Base Bare Modu eCost**

R-101	Autoclave	202				$ 1,700,000	$ 6,780,000	$ 1,700,000	$ 6,780,0 0
R-102	Autoclave	150				$ 1,600,000	$ 6,780,000	$ 1,700,000	$ 6,780,0 0
R-103	Autoclave	100				$ 1,300,000	$ 6,780,000	$ 1,700,000	$ 6,780,0 0
Towers	**Tower Description**	**Height (meters)**	**Diameter (meters)**	**TowerMOC**	**Pressure (barg)**	**Purchased Equipment Cost**	**Bare Module Cost**	**Base Equipment Cost**	**Base Bare Modu eCost**
T-101	20 Stainless Steel	12.2	5.6	CarbonSteel	30	$ 5,970,000	$ 10,400,000	$ 1,060,000	$ 1,910,0 0
	Sieve Trays								
					Totals	**$ 14,144,827**	**$ 48,098,351**	**$ 10,907,427**	**$ 39,562 3 51**
					Total Grass Roots Cost	**$ 76,540,000**			

					Total Equipment Cost	**$ 14,144,827**			`
					Lang Factor	**4.74**			
					Lang Factor Cost	**$ 67,000,000**			

5.12 Equipment Summary of Coal Gasification Process

Table 12 Utility summary before pinch analysis

Name	Total Module Cost	Grass Roots Cost	Utility Used	Actual Usage	Annual Utility Cost
E-101	$380,000	$525,000	High-Pressure Steam	94000 MJ/h	$6,950,000
E-102	$369,000	$525,000	High- Pressure Steam	83200 MJ/h	$6,950,000
E-103	$761,000	$1,080,000	High- Pressure Steam	148000 MJ/h	$6,950,000
E-104	$740,000	$1,050,000	Cooling Water	210000 MJ/h	$660,000
E-105	$740,000	$1,050,000	Cooling Water	210000 MJ/h	$660,000

E-106	$730,000	$1,030,000	Cooling Water	21500 MJ/h	$68,000
E-107	$190,000	$265,000	Cooling Water	207000 MJ/h	$650,000
Totals	$3,900,000	$5,500,000			$22,888,000

5.13 COM Summary

Material Name	**Classification**	**Price ($/kg)**	**Flowrate (kg/h)**	**Annual Cost**
Coal	Raw Material	$ 0.05	100000.00	$ 108,186,000
Syngas	Product	$ 0.09	262992.00	$ 130,069,982
Economic Options				
Cost of Land	$ 10,000,000			
Taxation Rate	45%			
Annual Interest Rate	10%			
Salvage Value	$ 15,000,000			
Working Capital	$ 30,000,000			
FCIL	$ 150,000,000			
Total Module Factor	1.18			
Grass Roots Factor	0.50			
Economic Information Calculated from Given Information				

Revenue From Sales	$ (130,069,982)	
CRM (Raw MaterialsCosts)	$ 108,186,000	
CUT (Cost of Utilities)	$ 500	
CWT (Waste TreatmentCosts)	$ -	
COL (Cost of OperatingLabour)	$ -	
Factors Used in Calculation of Cost of Manufacturing (COMd)		
Comd = 0.18*FCIL + 2.76*COL + 1.23*(CUT + CWT + CRM)		
Multiplying factor forFCIL	0.18	
Multiplying factor for COL	2.76	
Factors for CUT, CWT,and CRM	1.23	
COMd	$ 160,069,395	
Factors Used in Calculation of WorkingCapital		
Working Capital = A*CRM + B*FCIL + C*COL		
A	0.10	
B	0.10	
C	0.10	
Project Life (Yearsafter Start up)	10	
Construction period 2	2	
Distribution of Fixed Capital Investment		

End of year One	60%	
End of year Two	40%	
End of year Three		
End of year Four		
End of year Five		

Chapter 6

6.1 Cost Improvement Analysis in Coal Gasification

In the R&D and design of the chemical plant, the capital cost is a universal estimation. In the chemical plant, performance is overestimated. The product cost is trending to increase significantly between realized cost and estimate. Several factors depend upon the decreasing cost of a chemical plant.

- Improving the technology
- Learning by designer and plant operator
- Economic analysis of large equipment
- Using the cheap raw material cost

6.1.1 Cost Improvement

This is the relationship between better worker performance and decreased cost and improved management, production, and technical improvement. This phenomenon is a type of manufacturing process is called a learning curve. The learning phenomena are not factors that promote the relationship between declined cost units and cumulative production. There are generic factors of learning improvement that are learning by plant improvement, improving the technical ability, improving the economic scale, and decreasing raw material cost.

6.2 Rate of Cost Improvement

The Rate of Cost Improvement is defined as there is the same manner as the learning curve. There is a slope of the regression between fitted logarithm cost on the Y-axis and logarithm of industrial production on the X-axis.

$Cn = C1n$

- Cn is the cost of n-equipment
- $C1$ is the cost of the first unit
- n= number of estimate unit

The curve of improvement is 100% is minus with rate of improvement. For example, if the rate of improvement is 20%, then the rate of the curve is 80%.

6.3 Factor Affect Rate of Improvement

- Characterize the technology
- Characterize the marketplace
- Characterize the management

The first factor is essential for the rate of improvement because the state of product and market product and other factors cause less variant product technology.

6.4 The Factors that characterize the technology

We are considering four hypotheses that are regarding the relationship between cost improvement and technical characterizes.

- The higher level of complexity is caused by high improvement

The hypothesis implies that the higher the number of complex causes, the higher number of interlink step processes and offers greater opportunities to improve the process. The more step is implied to improvement through process simplification, and it causes higher proficiency.

- If the product has a price, it causes less cost improvement

Higher capital investment is caused rapid improvement in the chemical process because the process will provide less value of performance and cause less cost improvement.

Solid processing may relate to rapid cost improvement.

A solid process involves more physical unit operation than gas and liquid and physical operation involving less technological improvement. The solid processes are weak as compared to gas processing. Some elementary factors in which heat and material balance are more challenging to extrapolate from one plant to the subsequent changes. There is less show of improvement in solid processing.

There is a relationship between the learning curve and technological innovation and other economic scales discussed in the CPI context. A learning improvement implies the state of a product, labour, improved management and organization, and advanced production technology. Economic scale is shown a range of cost unit decline as well as a level of production increments. Figure 26 shows the Sales economy with/without technical change.

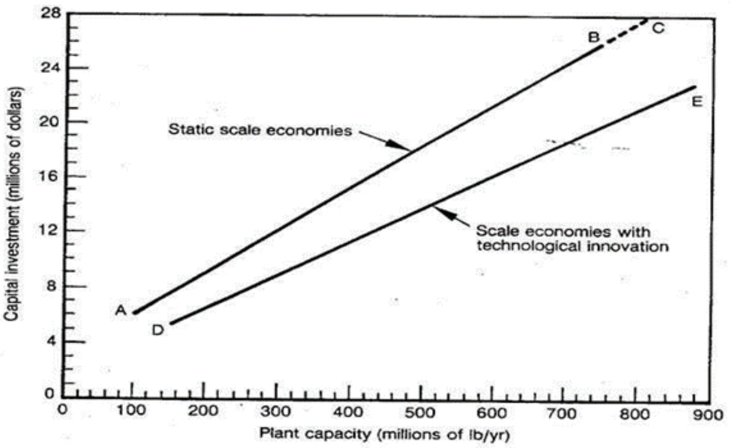


Figure 26 Sales economic with/without technical change

6.5 Cost Improvement and Technology

There are many manufacturing industries in which cost curves were developed. For example, the production of chemicals has required little labor. Increasing plant size causes a rise in the economics scale and trend toward feedstock intensity and capital cost rather than labor intensity and the Figure 26 Improvement Slope for Different Chemical Group.

Chemical Type	Mean	Standard Deviation	Min.	Max.
Organics	73.8	10.2	56	98
Inorganics	77.0	14.8	62	98
Fibers	76.0	5.3	72	82
Metals	88.3	10.9	72	95
All	75.9	11.4	56	98

Figure 27 Improvement Slope for Different Chemical Group

We are dividing a factor into four different groups

- Capital intensity
- Chemical Type

- Process Factors
- Process Complexity

6.5.1 Chemical Type

The purpose of this analysis is binary in chemical types. There is a correlation of this confirm result. The rate of improvement for the metal component is inferior in the applicable rate of other chemical types that are very similar.

6.5.2 Capital Intensity

The capital makes a significant contribution to the product cost and has caused more rapid economic improvement because of cost analysis. There are two relationships between cost improvement and cost analysis that could support the factors that cause cost improvement, better management, the technological innovation that can have a limited effect on the feedstock costs. However, they have potentially had a significant effect on the capital cost.

6.5.3 Process Factor

There is no relationship between the "scaling factor" and cost improvement for technological analysis. The scaling factor is the measure economics scale analysis of capital cost. The most important factor is the cost of chemicals. There is a relationship between cost improvement slope and cost economies after other factors are controlled variables.

6.6 Cost Improvement and Management

In the first hypothesis, there is a relationship between cost improvement and industrial management for the chemical process. They are cause a higher level of development and research expenditure of product cost. It causes rapid improvement. The second hypotheses are on management information transfer and organization of rapid improvement cost.

6.7 Cost Improvement and R&D Expenditure

The magnitude of the relationship between R&D expenditure and cost improvement has an important implication on industrial competitiveness. Therefore, we have hoped to test the relationship between different R&D expenditures on the refinement of different processes and cost improvement slopes using multiple regression models.

Lieberman equation is used for cost improvement; it is the relationship between R&D Expenditure and Cost improvement. Lieberman Equation cannot contain four factors that drive the cost improvement in the chemical processes. This relationship would affect the factors that are taken to unknowns. R&D is causing a significant contribution to examine and explain cost improvement variation, combined with cumulative industry output, and strongly related to cost analysis. The relationship between cost improvement and cumulative output is much stronger than R&D expenditure and cost analysis.

Lieberman has a measure of R&D expenditure that admittedly the crude. It is the ratio of sales of R&D expenditure and company sales. There is a causal link between cost improvement and R&D expenditure.

$$T_{i,j} = \frac{T_{i+1,j} + T_{i-1,j} + T_{i,j+1} + T_{i,j-1}}{4}$$

6.8 Cost Analysis of Coal gasification Process after Improvement

Table 13 Cost Analysis of Coal gasification Process after Improvement

User Added Equipment									
Exchangers	**Exchanger Type**	**Shell Pressure (barg)**	**Tube Pressure (barg)**	**MOC**	**Area (square meters)**	**Purchased Equipment Cost**	**Bare Module Cost**	**Base Equipment Cost**	**Base Bare ModuleCost**
E-101	Floating Head	1	15	Carbon Steel / Carbon Steel	269	$ 94,000	$ 309,000	$ 94,000	$ 309,000
E-102	Floating Head	1	15	CarbonSteel / Carbo	367	$ 95,500	$ 313,000	$ 94,800	$ 312,000

				n Steel					
E-103	Floating Head	2	26.8	Carbon Steel / CarbonSteel	175	$ 199,000	$ 645,000	$ 193,000	$ 634,000
E-104	Floating Head	2	25.8	CarbonSteel / Carbon Steel	270	$ 193,000	$ 626,000	$ 187,000	$ 616,000
E-105	Floating Head	2	30	Carbon Steel / CarbonSteel	272	$ 198,000	$ 639,000	$ 191,000	$ 627,000
E-106	Floating Head	2	25.8	Carbon Steel / Carbon Steel	117	$ 191,000	$ 618,000	$ 185,000	$ 608,000
E-107	Floating Head	2	30	Carbon Steel / CarbonSteel	280	$ 49,000	$ 158,000	$ 47,300	$ 156,000
E-108	Floating	2	30	CarbonSteel	370	$ 180,00	$ 550,	$ 65,60	$ 230,00

	Head			/ Carbon Steel		0	000	0	0
E-109	Floating Head	2	30	Carbon Steel / CarbonSteel	288	$ 150,000	$ 550,000	$ 55,600	$ 230,000
Heater	**Type**	**Heat Duty (MJ/h)**	**Steam Superheat (°C)**	**Pressure(barg)**		**Purchased Equipment Cost**	**Bare Module Cost**	**Base Equipment Cost**	**Base Bare ModuleCost**
H-101	Reformer furnace	67200		15		$ 1,100,000	$ 6,780,000	$ 1,700,000	$ 6,780,000
H-101	Reformer furnace	67200		15		$ 1,100,000	$ 6,780,000	$ 1,700,000	$ 6,780,000
Mixers	**Type**	**Power (kilowatts)**	**# Spares**			**Purchased Equipment Cost**	**Bare Module Cost**	**Base Equipment Cost**	**Base Bare ModuleCost**
M-	Impeller	150	0			355,327	490,3	355,3	490,351

101							51	27	
Reactors	**Type**	**Volume (cubic meters)**				**Purchased Equipment Cost**	**Bare Module Cost**	**Base Equipment Cost**	**Base Bare ModuleCost**
R-101	Autoclave	202				$ 1,700,000	$ 6,780,000	$ 1,700,000	$ 6,780,000
R-102	Autoclave	150				$ 1,600,000	$ 6,780,000	$ 1,700,000	$ 6,780,000
R-103	Autoclave	100				$ 1,300,000	$ 6,780,000	$ 1,700,000	$ 6,780,000
Towers	**Tower Description**	**Height (meters)**	**Diameter (meters)**	**Demister MOC**	**Pressure (barg)**	**Purchased Equipment Cost**	**Bare Module Cost**	**Base Equipment Cost**	**Base Bare ModuleCost**

T-101	20 StainlessSteel Sieve Trays	12.2	5.6	StainlessSteel	30	$ 5,970,000	$ 10,400,000	$ 1,060,000	$ 1,910,000
					Totals	$ 14,673,827		$ 49,843,351	$ 11,221,627
					Total Module Cost	$ 58,820,000			
					Total Grass Roots Cost	$ 79,150,000			
					Total Equipment Cost	$ 14,673,827			`
					Lang Factor	4.74			
					Lang Factor Cost	$ 69,600,000			

Figure 28: Coal gasification process equipment summary after pinch analysis.

6.9 Utility Summary

Table 14 Utility summary after pinch analysis

Name	Total Module Cost	Grass Roots Cost	Utility Used	Actual Usage	Annual Utility Cost
E-101	$ 380,000	$ 525,000	NIL		
E-102	$ 369,000	$ 525,000	High Pressure Steam	83200 MJ/h	$ 6,950,000
E-103	$ 761,000	$ 1,080,000	NIL		
E-104	$ 740,000	$ 1,050,000	NIL		
E-105	$ 740,000	$ 1,050,000	NIL		
E-106	$ 730,000	$ 1,030,000	NIL		
E-107	$ 190,000	$ 265,000	NIL		
E-108	$ 198,000	$ 287,000	Cooling Water	300000MJ/h	$ 6,660,000
E-109	$ 190,000	$ 265,000	Cooling Water	207000 MJ/h	$ 528,000
Total	**$ 4,100,000**	**$ 5,800,000**			**$ 13,610,000**

Chapter 7

7.1 Result and discussion

In the modelling and simulation of Coal gasification process we basically control temperature of reactor and amount of oxygen provided for the reaction as our coal gasification is partial oxidation of carbon. If reactor temperature and amount of oxygen provided is not controlled then by products such as Carbon dioxide, Ammonia, Hydrogen sulphide and water is produced. SYNGAS our main product is produced by partial gasification or oxidation of Coal. Table 13 shows the result when Coal enters the first reactor in Aspen Plus ®.

Table 15 Results after passing reactor R1

Temperature℃	500
Pressure-bar	23.5
Vapor Frac	1
Mole Flow kmol/hr	6770.68
Volume Flow cum/hr	7272
Mass Flow tn/hr	100
Enthalpy flow	20.942
Mass density lb/cuft	30.32
CO	4499.30
NH_3	135.25
H_2	76.91
CH_4	716.63
CO_2	89.56
H_2O	849.93
H_2S	2241.224
O_2	3281.4

After mixing water and oxygen to the feed it enters the reactor R2 where more partial oxidation of Coal takes place.

Table 14 shows the result of reactor R2 in Aspen Plus®

Table 16 Results available after passing reactor R2

Temperature℃	1050
Pressure-bar	25
Vapor Frac	1
Mole Flow kmol/hr	6770
Volume Flow cum/hr	44605.73
Mass Flow kg/hr	233000
Mass density cuft/hr	0.3260952000
Mole Flow kmol/hr	10258.2869
C	3042.0679
CO	0
CO_2	2425.28
H_2O	4082.479
CH_4	0
NH_3	467.236

Feed after passing through Reactor R2 enters the reactor R3 for more oxidation and final product is produced which is SYNGAS (CO+H2). Complete oxidation of Carbon take place in reactor R3.

Table 17 results of reactor R3

Temperature C̊	1143
Pressure-bar	24.5
Vapor Frac	1
Mole Flow kmol/hr.	3945.82
Volume Flow cum/hr.	51942.9
Mass Flow kg/hr.	113708.8
Mass density cuft/hr.	0.3260952000

Mole Flow kmol/hr.	10258.2869
C	0
CO	4063.746
CO_2	1401.05
H_2O	2067.172
H_2	233.4178
CH_4	2.5414
NH_3	0.40059970

Simulation Result v/s Experimental Result and Chemcad Result

Table 18 Simulation results vs experimental and Chemcad result

Stream NO	Experimental result (Final outlet stream)	Chemcad result (Final outlet stream)	Aspen plus result (Final outlet stream)	Difference % Between experimental and Aspen plus (%)	Difference %between Chemcad and Aspen plus (%)
Temperature (℃)	1050	1143	1143		
Pressure (Bar)	22.5	24.3	24.3		
Molar flow (Ton/hr)	40.433	85.194	86.146		
Components flow rate					
Coal	1.27	0	0		
C	1.99	2.37	1.10	57.60	73.20
CO	48.22	50.80	55.030	13.19	7.99
H_2	4.07	5.00	13.464	107.15	91.68
CO_2	28.02	25.88	16.512	51.60	44.20
CH_4	1.34	1.2205	0.040	188.04	187.15

7.2 Optimization Results

For energy optimization of Coal gasification, Pinch technology is used. After optimization we recovered most of the process energy which were waste before. Due to optimization, we reduced the usage of external utilities.

Hot utility: 8821.1 / 15783.8 (KW)

Before process optimization, we need 15783.6 KW of heat to perform desired process, but after optimization, we recover 6962.8 KW of heat from hot streams and only provided 8820.1 KW of external heat.

Cold utility: 70252.2 / 77215.3 (KW)

Before process optimization, we need 77215.8 KW of cold utility to achieve the desired temperature, but after pinch analysis, we recover 6963.2 KW of heat from cold streams and only provided 70252.4 KW of cold utility. Table 16 is the total utility cost before the pinch analysis is:

Table 19 Before optimization utility summary

Name	**Total module**	**Grass root**	**Utility used**	**Actual usage**	**Annual**
E-101	380000	525,000	High pressure	94,000	69,50,000
E-102	369,000	525,000	High pressure	83,200	69,50,000
E-103	761,000	1,080,000	High pressure	148,000	6,950,000
E-104	740,000	1,050,000	Cooling water	210,000	660,000
E-105	740,000	1,050,000	Cooling water	210,000	660,000
E-106	730,000	1,030,000	Cooling water	21,500	68,000
E-107	190,000	265,000	Cooling water	207,000	650,000
Total	**3,900,000**	**5,500,000**			**22,888,000**

When Pinch Technology applied on the process only 1.3 M$ are required to reach desired conditions and saved 20.7M$. Table 18 shows the economic analysis of the Coal gasification process.

Table 20 Before optimization utility summary

Before energy optimization results		After energy optimization results	
Total module Cost	56.76 M$	Total module Cost	58.90 M$
CRW (Cost of raw material)	108.86 M$	CRW (Cost of raw material)	108.9 M$
Annual Cost of Utility	22.89 M$	Annual Cost of Utility	13.61 M$
Gross root cost	76.55 M$	Gross root cost	79.2 M$
Profit	**24.45 M$**	**Profit**	**29.25 M$**

After the economic examination, the results show the increase in profit from 24.45 to 29.25 M$/year.

Conclusion

To produce SYNGAS on commercial level using coal gasification process, we used three types of technology based on the configuration of gasifiers and corresponding to their flow geometry. Entrained flow gasifier which is most used for gasification of Coal. In entrained flow gasifier coal and feed particles flow instantaneously. Fluidised bed gasifier, here in this type of gasifier, coal particles get hanged where gas particles move and combine with gasification. Moving bed gasifiers generates electricity when gases flow up the feed particle. Together co, counter-current technology accessible but counter current is supplementary communal. Entrained flow gasifiers are mostly used in which seven different technologies are used. In entrained gasifiers, coal and other solid fuels reacts with steam or air simultaneously that can be supplied dry or liquid state (slurry). Gasifiers generally work at high temperature of 1200℃ to 1600℃ and pressure of 2-8 MPa mostly large plants operate at pressure of 2.5Mpa.

In moving bed gasifiers, only three types of techniques are used (BGL, BHEL, Dry Laundry Lurg) developed at an industrial level although common types of gasifiers. Moving bed gasifiers are commonly suitable for solid fuels like biomass. Main variance concerning two kind of gasifiers is ash filled gasifiers uses higher rate of moisture then Oxygen which results in decrease in temperature.

In compressed bed gasifiers only six types of techniques are used but most will still be upgraded at the display level. Fluidized bed gasifiers only used for solid digested oil (0.5-5 mm), with no transport reactor in the middle between the drinking bed and the gas that flows internally and functionally in the form of sprayed petrol. Coal is pushed into a high flow of gas (either air or oxygen / smoke) that solidifies the fuel bed while it happens. The bed is made of sand / coke / char / sorbent or ash. Feed time stay in the gasifier is usually set at 10-100 s but can also be very long, where the feed is exposed to high temperatures at the entrance to the gasifier.

This study focused the process of Coal gasification using Entrained flow gasifiers is modelled and simulated in Aspen Plus ®. Coal is mixture of complex hydrocarbons. Coal is taken ‘NC’ (non-conventional) which is special property for coal. In Aspen Plus for coal, special model “HCOALGEN” which is superior for calculating enthalpy of feed comprising Coal. By simulated research, we calculate the behaviour of the actual process. After process simulation, it has been concluded that process can be controlled by controlling concentration of Oxygen and reactor’s temperature. When oxygen concentration increases in the reactor, Carbon is oxidized completely and produces useless by- products such as carbon dioxide, water, and products of sulphur to enhance production. To produce SYNGAS, it is necessary that Carbon must partially be oxidized that is generating our desired product SYNGAS. Energy optimization of SYNGAS production process is done using Pinch analysis technique and using Pinch Technology recovered process energy which were wasted before and save 20.7 million $ per year which were consumed before for cooling and heating of streams.

Recommendation

SYNGAS is most important product to cope with the energy problem as it is used as fuel for internal combustion engines and used for production of Hydrogen which further is processed to produce Ammonia and Methanol. It is used as intermediate to produce synthetic petrochemicals via Fischer-Tropsch process. For future, it is recommended to minimise the production of CO2 and H2S which are most critical for environment.

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