IMPROVING THE FLUID CATALYTIC CRACKING UNIT IN TERM OF ENERGY CONSUMPTION, A SIMULATION STUDY

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ABSTRACT

Fluid catalytic cracking (FCC) process is a unit that converts heavy distillates like gas oil or residues to gasoline and middle distillates using cracking catalyst. Increased global focus on reducing energy consumption and emissions are working together to make FCC unit power recovery more attractive. The flue gas temperature from the FCC unit was about 700-750^{o}C and it holds a lot amount of energy. The heat recovery steam generated (HRSG) was used to recover the heat of fluegas to generate a steam and electricity. Aspen HYSYS (version 7.0) software was used to calculate the energy that will be recovered. From the simulation, besides from the based case, four adjustment of the parameter was made which is the steam pressure requirement, flowrate of feedwater, outlet steam turbine pressure and the efficiency of the steam turbine. The result was obtained by all that adjustment as shown in Section 4.1. For the based case of this study, the required steam pressure, temperature and mass flow was 600psig, 500^{o}C and 45000kg/hr meanwhile for the fluegas was 34psig, 715^{o}C and 241800kg/hr. The electric power generated was 1.46MW. For the adjustment of parameters, it is to know the amount of the electricity at a difference condition. As a conclusion, the objective of this study was achieved by improving the FCC unit in term of energy recovery.

ABSTRAK

Proces Fluid Catalytic Cracking (FCC) adalah unit yang menukar sulingan berat seperti minyak gas, atau baki kepada petrol dan sulingan tengah menggunakan mangkin retak. Peningkatan fokus global dalam mengurangkan penggunaan dan pembebasan tenaga membuat FCC unit lebih menarik untuk ditingkatkan. Suhu gas buang dari unit FCC sekitar 700-750^{o}C yang mempunyai sejumlah tenaga yang banyak. Unit Pemulihan wap (HRSG) digunakan untuk memulihkan tenaga yang ada pada gas untuk menghasilkan stim dan elektrik. Perisian komputer Aspen Hysys (versi 7.0) digunakan untuk mengira tenaga yang akan dipulihkan. Dari hasil simulasi, selain dari kes yang berpusat, empat pengubahan parameter itu dibuat iaitu tekanan stim, jumlah air yang digunakan, tekanan keluar wap turbin dan kecekapan dari turbin stim. Keputusan yang diperolehi oleh semua pengubahan yang seperti yang ditunjukkan dalam Seksyen 4.1. Untuk kes berdasarkan kajian ini, tekanan wap yang diperlukan, suhu dan aliran jisim adalah 600psig, 500^{o}C dan 45000kg/hr manakala untuk gas adalah 34psig, 715^{o}C dan 241800kg/hr. Kuasa yang dihasilkan adalah 1.46MW. Untuk pengubahan parameter yang dibuat, ini adalah untuk mengetahui jumlah elektrik yang dapat dihasilkan dalam keadaan yang berbeza. Sebagai kesimpulan, tujuan dari kajian ini telah tercapai dalam peningakatan FCC unit dari segi tenaga yang dipulihkan.

TABLE OF CONTENT

2 LITERATURE REVIEW

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

F	Degree Fahrenheit
^{o}C	Degree Celsius
kW	kilo Watt
MW	Mega Watt
psig	Pressure gauge
kg	kilogram
hr	hour

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Fluid Catalytic Cracking (FCC) has been used for more than 60 years in order to convert a variety of feed stocks, including straight-run atmospheric gas oils, atmospheric residues, vacuum gas oils, and heavy stocks recovered from refinery operations into high-octane gasoline, light fuel oils and olefin-rich light gases. In the petroleum refineries, this FCC is the most important conversion process. It is widely used to convert the high-boiling, high-molecular weight hydrocarbon fractions of crude oils to valuable gasoline, olefinic gasses and other products. (Yiannis Bessiris and Vassilis Harismiadis, 2007)

The FCC unit consists of two interconnected gas-solid fluidized bed reactor which are the first is the riser reactor, where almost all the endothermic cracking reactions and coke deposition on the catalyst occur. The second is the regenerator reactor, where air is used to burn off the coke deposited on the catalyst. The heat produced is carried from the regenerator to the reactor by the catalyst. Therefore, in addition to reactivating the catalyst, the regenerator provides the heat required by the endothermic cracking reaction. (Harun Taskin, 2005)

Basically, there are two different configurations for an FCC unit: the "stacked" type where the reactor and the catalyst regenerator are contained in a single vessel with the reactor above the catalyst regenerator and the "side-by-side" type where the reactor and catalyst regenerator are in two separate vessels. (Editorial Staff, November 2002)

1.2 Research Background and Problem Statement

As stated before, catalytic cracking is the most important petroleum refining processes. Many improvements for this FCC unit are created for raising the operating efficiency, decreasing the energy consumption, producing high quality products and so on. However, the flexibility of the FCC process is negatively weakened by the excessive energy consumption. (Chun-Min Song *et al.*1995)

The temperature of the exits flue gas from the regenerator is very high (as Figure 1.1). It holds an appreciable amount of energy. Steam can be generating by applying the heat recovery steam generator unit at the exits of the flue gas stream. With presence of high temperature of the flue gas from that regenerator it is possible to generate superheated steam that is useful utility for the plant whether for the used of the FCC unit itself or to generate the electricity. (Reza Sadeghbeigi, 2000)

1.3 Significance of Study

The FCC unit has been around since the 1940s and their technologies have improved continuously. It is important to understanding the concept of the consumption of energy so that the energy can be used effectively.

In this FCC unit the energy will be recovered and generate the steam and electricity by a specific modified heat recovery system process. It will reduce the cost of operation of this FCC unit if this improvement can be done effectively. This improvement also will make the FCC unit is environmental friendly process by reducing the energy emission to the surrounding.

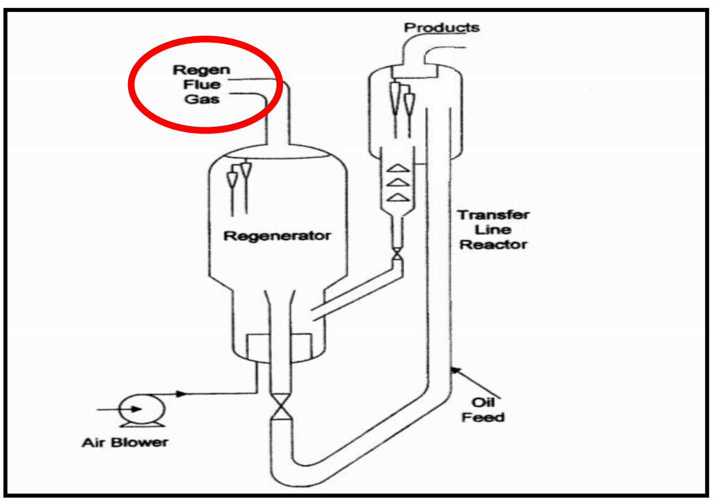

Figure 1.1: Typical schematic of Exxon's flexi cracker (Reza Sadeghbeigi, 2000)

1.4 Scopes of Study

To achieve the objectives, scopes have been identified in this research. The scopes of this research are listed as below:

i. To understand as much as the concept of Fluid Catalytic Cracking unit.
ii. To identify all the variable related to the FCC process
iii. To analyze the data related to the FCC unit.
iv. To understand the heat recovery steam generator unit process.
v. To run the simulation software with all the data collected.
vi. To determine the heat that will be recover.

1.5 Objective

- To recover the heat release from the flue gas stream of the regenerator of FCC unit by applying the heat recovery steam generator unit

CHAPTER 2

LITERATURE REVIEW

2.1 Fluid Catalytic Cracking

2.1.1 Introduction

Fluid catalytic cracking (FCC) is the most important conversion process used in petroleum refineries. The FCC converts heavy crude oil into a range of hydrocarbon product, including LPG, fuel gas, gasoline, light diesel, aviation kerosene, slurry oil, among which high octane number gasoline is most valuable.(Yiannis Bessiris *et al*. 2007)

The feedstock to an FCC is usually that portion of the crude oil that commonly boils in the 650^{o}F to 1050^{o}F (330 – 550^{o}C). The FCC process vaporizes and breaks the long-chain molecules of the high-boiling hydrocarbon liquids into much shorter molecules by contacting the feedstock, at high temperature and moderate pressure, with a fluidized powdered catalyst. (Reza Sadeghbeigi, 2000)

As of 2006, FCC units were in operation at 400 petroleum refineries worldwide and about one-third of the crude oil refined in those refineries is processed in an FCC to produce high-octane gasoline and fuel oils.(James. G. Speight, 2006). During 2007, the FCC units in the United States processed a total of 5,300,000 barrels (834,300,000 litres) per day of feedstock and FCC units worldwide processed about twice that amount (U.S. Dept. of Energy).

2.1.2 History of the FCC unit

As we all already know that, what the world have today must begin with it history. So that with the FCC unit which it was created at first by McAfee of the Gulf Refining Co. in 1915 and he discovered that a Friedel-Crafts aluminum chloride could catalytically crack heavy oil. There an evolution of the FCC unit that by year it is improved until now in order to having an optimum operation in the cracking process. The table below shows the evolution of the FCC unit since the year of 1915 until 1996.

Table 2.1: The Evolution of FCC unit (Reza Sadeghbeigi, 2000)

Year	**The Evolution of the FCC unit**
1915	McAfee of Gulf Refining Co. discovered that a Friedel-Crafts aluminum chloride catalyst could catalytically crack heavy oil.
1936	Use of natural clays as catalyst greatly improved cracking efficiency.
1938	Catalyst Research Associates (CRA) was formed. The original CRA members were: Standard of New Jersey (Exxon), Standard of Indiana (Amoco), Anglo Iranian Oil Company (BP Oil), The Texas Company (Texaco), Royal Dutch Shell, Universal Oil Products (UOP), The M.W. Kellogg Company, and I.G Farben (dropped in 1940).

1942	First commercial FCC unit (Model I up flow design) started up at Standard of New Jersey's Baton Rouge, Louisiana, refinery.
1943	First down-flow design FCC unit was brought on-line. First thermal catalytic cracking (TCC) brought on-line.
1947	First UOP stacked FCC unit was built. Kellogg introduced the Model III FCC unit.
1948	Davison Division of W.R. Grace & Co. developed microspheroidal FCC catalyst.
1950s	Evolution of bed-cracking process designs.
1951	M.W. Kellogg introduced the Orthoflow design.
1952	Exxon introduced the Model IV
1954	High alumina (Al_2O_2) catalyst was introduced.
Mid-50s	UOP introduced side-by-side design.
1956	Shell invented riser cracking.
1961	Kellogg and Phillips developed and put the first resid cracker on stream at Borger, Texas.
1964	Mobil Oil developed USY and ReY FCC catalyst. Last TCC unit completed.
1972	Amoco Oil invented high-temperature regeneration.
1974	Mobil Oil introduced CO promoter.
1975	Phillips Petroleum developed antimony for nickel passivation.
1981	TOTAL invented two-stage regeneration for processing residue.
1983	Mobil reported first commercial use of ZSM-5 octane/olefins additive in FCC.
1985	Mobil started installing closed cyclone system in its FCC units.
1994	Coastal Corporation conducted commercial test of ultra short residence time, selective cracking.
1996	ABB Lummus Global acquired Texaco FCC technologies.

From the table above it shows that, the FCC unit was improving year by year in order to gain the better equipment. It is required to meet the demand today which is the product need to be in a good quality and also the affect of the FCC unit for the environment side. (Reza Sadeghbeigi, 2000)

2.1.3 Flow Diagram and Process Description

The schematic flow diagram of a typical modern FCC unit in Figure 2.1.1 below is based upon the "side-by-side" configuration. The preheated high-boiling petroleum feedstock (at about 315 to 430 °C) consisting of long-chain hydrocarbon molecules is combined with recycle slurry oil from the bottom of the distillation column and injected into the *catalyst riser* where it is vaporized and cracked into smaller molecules of vapor by contact and mixing with the very hot powdered catalyst from the regenerator. (Reza Sadeghbeigi, 2000)

All of the cracking reactions take place in the catalyst riser. The hydrocarbon vapors "fluidize" the powdered catalyst and the mixture of hydrocarbon vapors and catalyst flows upward to enter the *reactor* at a temperature of about 535 °C and a pressure of about 1.72 bar (see in the circle).

The reactor is in fact merely a vessel in which the cracked product vapors are: (a) separated from the so-called spent catalyst by flowing through a set of two-stage cyclones within the reactor and (b) the spent catalyst flows downward through a steam stripping section to remove any hydrocarbon vapors before the spent catalyst returns to the catalyst regenerator. The flow of spent catalyst to the regenerator is regulated by a slide valve in the spent catalyst line. (James H. Gary *et al*. 2001)

Since the cracking reactions produce some carbonaceous material (referred to as coke) that deposits on the catalyst and very quickly reduces the catalyst reactivity, the catalyst is regenerated by burning off the deposited coke with air blown into the regenerator. The regenerator operates at a temperature of about 715 °C and a pressure of about 2.41 bar (see in the circle).

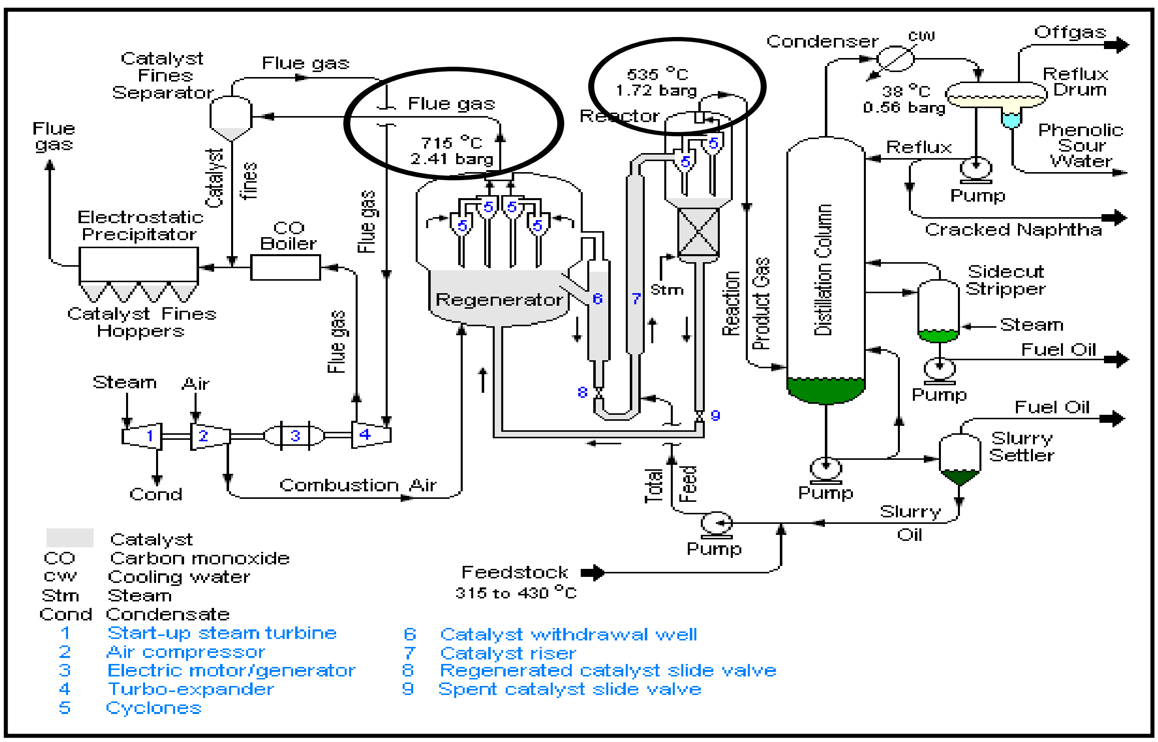

Figure 2.1.1: The Schematic flow diagram of a typical modern FCC unit (James H. Gary *et al*. 2001)

The combustion of the coke is exothermic and it produces a large amount of heat that is partially absorbed by the regenerated catalyst and provides the heat required for the vaporization of the feedstock and the endothermic cracking reactions that take place in the catalyst riser. For that reason, FCC units are often referred to as being heat balanced. (James H. Gary *et al*. 2001)

The hot catalyst (at about 715 °C) leaving the regenerator flows into a catalyst withdrawal well where any entrained combustion flue gases are allowed to escape and flow back into the upper part to the regenerator. The flow of regenerated catalyst to the feedstock injection point below the catalyst riser is regulated by a slide valve in the regenerated catalyst line. The hot flue gas exits the regenerator after passing through multiple sets of two-stage cyclones that remove entrained catalyst from the flue gas. (James H. Gary *et al*. 2001)

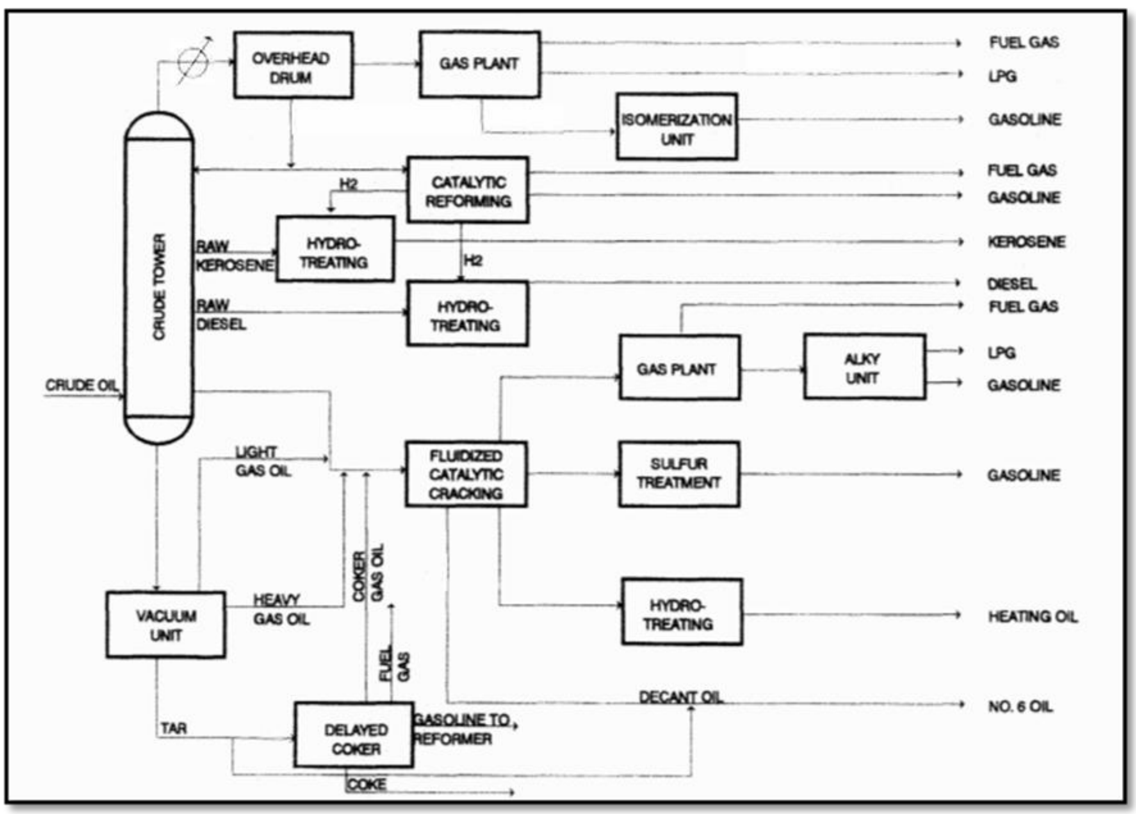

Figure 2.1.2: A typical high conversion refinery (Reza Sadeghbeigi, 2000)

From the Figure 2.1.2 it shows the position of FCC unit in the refinery plant. It is important unit as stated earlier that convert the heavy crude oil to a lighter and valuable products.

2.1.4 Flue gas heat recovery

The flue gas came out from that which is, it holds an appreciable amount of energy. A lot of technology of heat recovery schemes is used to recover this energy. In some unit, the flue gas is sent to a CO boiler where both the sensible and combustible heat is used to generate high-pressure steam. In other units, the flue gas is exchanged with boiler feed water to produce steam via the use of a shell/tube or box heat exchanger. (Reza Sadeghbeigi, 2000)

2.2 Heat and energy recovery

2.2.1 Introduction

Energy is very important and it is a fundamental part of our lives. Without the energy we would mot be able to having a good and comfortable lives. Energy is needed to provide heat, light, and electricity and so on in our daily use. Today energy is required at the flick of a switch or the turn of a key, it is required to be instantaneous and continuous. Energy affects every part of our life and it is vital for the successful running of a healthy economy and for ensuring a healthy population. (Energy Information Administration (EIA). 2006)

From Figure 2.2.1, according to the American Energy Information Administration (EIA) and to the International Energy Agency (IEA), the world-wide energy consumption will on average continue to increase by 2% per year. A yearly increase by 2% leads to a doubling of the energy consumption every 35 years. This means the world-wide energy consumption is predicted to be twice as high in the year 2040 compared to today (2010). (Energy Information Administration (EIA). 2006)

In particular with respect to the emission of greenhouse gases and global warming, it is interesting to study the predicted growth of energy consumption by fuel type as shown in the Figure 2.2.2. By far the highest increase in world-wide energy consumption is predicted to be from all three fossil fuels: oil, coal and natural gas! The renewable energies are predicted to grow as well, but much less than fossil energy. Nuclear energy is predicted to grow relatively moderate. (Energy Information Administration (EIA). 2006)

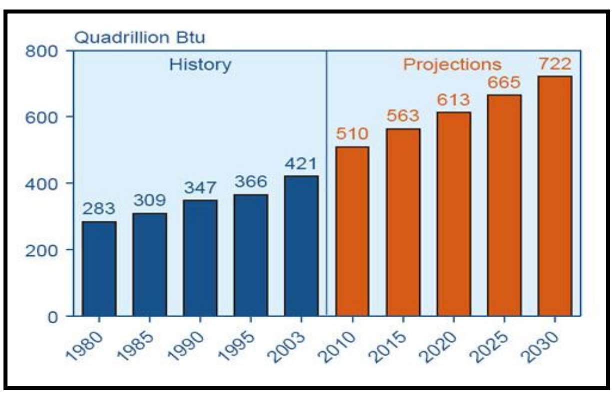

Figure 2.2.1: World Marketed Energy Consumption 1980-2030(Energy Information Administration (EIA). 2006)

Instead of a reduction, the data from EIA and IEA predict a massive increase of the consumption of fossil fuels. According to the above chart, even the share of fossil fuels will increase further, to more than 80%! The consumption of fossil fuels is predicted to be twice as high already in the year 2020 compared to today's consumption. (Energy Information Administration (EIA). 2006)

2.2.2 Energy Management

As stated before, energy is very important to our lives. Well management is needed so that the energy can be use in the right way it would be. When it comes to energy saving, energy management is the process of monitoring, controlling, and conserving energy in a process or plant. Energy need to be managed, it is something that energy supplier (or utility companies) do to ensure that their power stations and renewable energy sources generate enough energy to meet demand (the amount of energy that customer need). (Petroleum Technology Quarterly. 2000)

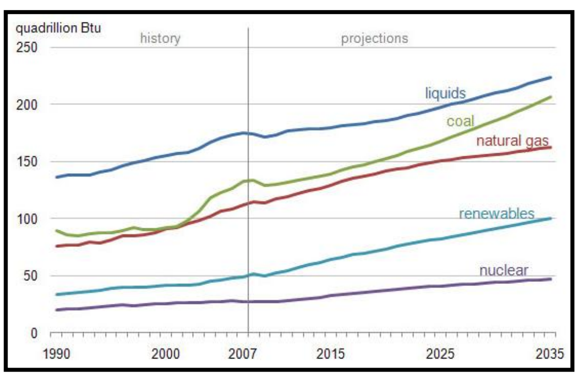

Figure 2.2.2: World marketed energy use by fuel type 1980-2030.(Energy Information Administration (EIA). 2006)

Energy management is the key to the some people to achieve for their business. Much of the important of energy saving is for the global need to save the energy. This global need affects energy prices, emissions target, and legislation, all of which lead to people in get involve in the energy saving matters. (Chris Stakutis. 2008)

Globally we need to save the energy in order to reduce the damage that we are doing in our planet, Earth. As human race we would probably find things rather difficult without the Earth, so it makes good sense to try to make it last. Then, it is also to reduce our dependence on the fossil fuels that are becoming increasingly limited in supply. (Petroleum Technology Quarterly. 2000)

2.3 Steam turbine

2.3.1 Introduction

Steam turbines are one of the most important, versatile and oldest prime mover technologies that still in general production. Power generation using steam turbines has been in use for about 100 years, when they replaced reciprocating steam engines due to their higher efficiencies and lower costs. Conventional steam turbine power plants generate most of the electricity produced in the world. The capacity of steam turbine can range from 50kW to several hundred MWs for large utility power plants. Steam turbine widely used for combined heat and power (CHP) applications. (C. Oh *et al*. June 2007)

Unlike gas turbine and reciprocating engine CHP systems where heat is a byproduct of power generation, steam turbines normally generate electricity as a