THERMODYNAMIC AND ECONOMIC ANALYSIS OF A SYNTHETIC FUEL PRODUCTION PLANT VIA CO2 HYDROGENATION USING WASTE HEAT FROM AN OIL REFINERY

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MASTER THESIS
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I certify that in my opinion the presented thesis that has been submitted by Mohammed Abdulmunem Mohammed ALSUNOUSI titled "THERMODYNAMIC AND ECONOMIC ANALYSIS OF A SYNTHETIC FUEL PRODUCTION PLANT VIA CO2 HYDROGENATION USING WASTE HEAT FROM AN OIL REFINERY" is fully adequate in scope and in quality as a thesis for the degree of Master of Science.

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"I declare that all the information that has been presented in this thesis was gathered and presented in accordance with ethical principles and academic regulations and I have according to requirements of those regulations and principles that were cited all those which don’t originate in this work too."

Mohammed Abdulmunem Mohammed ALSUNOUSI

ÖZET

Yüksek Lisans Tezi

BİR PETROL RAFİNERİSİNDEN ÇIKAN ATIK ISIYI KULLANARAK CO2 HİDROJENASYONU YOLUYLA SENTETİK YAKIT ÜRETİMİ YAPAN BİR TESİSİN TERMODİNAMİK VE EKONOMİK ANALİZİ

Mohammed Abdulmunem Mohammed ALSUNOUSI

Karabük Üniversitesi
Lisansüstü Eğitim Enstitüsü
Makine Mühendisliği Anabilim Dalı

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Dr. Öğr. Üyesi Erhan KAYABAŞI

Şubat 2023, 64 sayfa

Bu çalışma, yenilenebilir enerji kullanan bir petrol rafinerisinden çıkan atık gazdaki karbondioksiti hidrojene ederek metanol üreten bir tesisin termoekonomik analizini amaçlamaktadır. İlk olarak, baca gazındaki karbondioksit karbon yakalama tesisinde (CCP) yakalanmakta ve hidrojen tesisinde (HP) deniz suyundan fotovoltaik enerji yardımıyla elde edilen hidrojen, metanol tesisinde (MPP) birleştirilmektedir ve metanol yakıtı elde edilmektedir Engineering Equation Solver (EES) kullanılarak bu talebi karşılamak için gerekli enerji miktarı ve gerekli olacak güneş paneli alanı hesaplanmış ve sonrasında metanol santralinin çevresel etkisi incelenmiştir. Bu çalışmada Libya Az-Zawiya rafineri tesisi örnek olay yeri olarak seçilerek tesisin CO_2 emisyonları, ısı entegrasyonu, enerji verimliliği ve termo-ekonomik performans süreçleri dikkate alınmıştır. Çalışmanın sonucunda, yenilenebilir enerji santralinin verimi %21 kabul edilerek, sentetik yakıt ve metanol tesisi verimleri sırasıyla %0,5872 ve %0,1626 elde edilmiştir. Elektrolizörün optimum yoğunluğu olan 2,2 kA/m^2'de elektrolizörün verimliliği %0,782 bulunmuşltur. Bu çalışmaya göre proseste baca gazı artışı ile birlikte tüm çıkış parametrelerinin artması, baca gazının çıkışları etkileyen en önemli girdi parametresi olduğunu göstermektedir. Tesisin 30 yıllık işletimi için toplam maliyeti 11.350 milyar $ olarak bulunmuştur ve 43.360 milyon tonun üzerinde metanol üretim kapasitesi ile ton başına 412.9 $ ve kg başına 0.4129 $'a eşittir. Çevresel olarak, yakalanan emisyonların oranı günde yaklaşık 4890 ton ve azaltma oranı günde yaklaşık 4513 ton bulunmuştur. Elde edilen sonuçlara göre mevcut tesis, diğer temiz sentetik yakıt üretim tesisleri ile rekabet edebilecek durumdadır.

Anahtar Sözcükler : Petrol rafinerisi, Emisyonlar, Karbondioksit, Termoekonomik analizler

.**Bilim Kodu :** 91408

ABSTRACT

Master. Thesis

THERMODYNAMIC AND ECONOMIC ANALYSIS OF A SYNTHETIC FUEL PRODUCTION PLANT VIA CO_2 HYDROGENATION USING WASTE HEAT FROM AN OIL REFINERY

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February 2023, 64 pages

This study aims a thermoeconomic analysis of a plant that produces methanol by hydrogenating carbon dioxide in the waste gas from an oil refinery using renewable energy was carried out. First, carbon dioxide in the flue gas is captured in the carbon capture plant (CCP), and the hydrogen obtained from the seawater in the hydrogen plant (HP) with the help of photovoltaic energy is combined in the methanol plant (MPP) to produce methanol fuel. Using the Engineering Equation Solver (EES), a calculation was made of the amount of energy required and the number of solar panels or wind turbines that would be required to meet this demand, and then the environmental impact of the methanol plant was investigated. The Libyan Az-Zawiya refinery facility has been selected as a case study location. Systems' processes for CO2 emissions, heat integration, energy efficiency, and thermo-economic performance were all taken into consideration. Renewable energy, synthetic fuel, and the methanol plant showed efficiencies of 0.21%, 0.5872%, and 0.1626%, respectively, and at the optimum density of the electrolyzer, 2.2 kA/m^2, the efficiency of the electrolyzer was 0.782%. According to this study, all output parameters increase with the increase in the flue gas in the process, showing that flue gas is the most important input parameter affecting the outputs. The total cost of the plant for 30 years of operation was found to be $11.350 billion, with a production capacity of over 43.360 million tons of methanol, which equates to $412.9 per ton and $0.4129 per kg. Environmentally, the rate of captured emissions was about 4890 tons per day, and the mitigation rate was approximately 4513 tons per day. According to the results, the current plant is competitive with other clean synthetic fuel production plants.

Key Word : Oil refinery, Emissions, Carbon dioxide, Thermoeconomic analysis.

Science Code : 91408

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SYMBOLS

CRF : capital recovery factor, dimensionless

Cp : specific heat, kJ/kgK

ι : annual interest rate, %

N : annual operating hours, h

n : system lifetime, y

$\dot{Z}$: capital cost rate, $/s

Z : capital cost, $

η : efficiency

ϕ : maintenance factor, dimensionless

$\dot{n}$: Molar Flowrate, kmol/s

$\dot{Q}$: Heat, kW

$\dot{W}$: Work, kW

$\dot{m}$: Mass Flowrate, kg/h

C_C : Factor of Carbon Emissions t C/TJ

H_V : Gross Calorific Value of Coal TJ/kiloton

h : Enthalpy kJ/kg

ABBREVITIONS

CO_2	: Carbon Dioxide
PEC	: Purchased Equipment Cost
EES	: Engineering Equation Solver
MPP	: Methanol Production Plant
HP	: Hydrogen Plant
CCP	: Carbon Capture Plant
PEM	: Proton Exchange Membrane
PV	: Photovoltaic
MEA	: Mono Ethanol Amine
IPCC	: Intergovernmental Panel on Climate Change

PART 1

INTRODUCTION

Energy is critical for all countries' economic and social development, as well as for improving the quality of life. In terms of utilization, energy resources are renewable and non-renewable; they are categorized as main and secondary energy resources based on their transformation capacities. The increasing energy demand, coupled with the world's limited energy resources and their continuous depletion, has resulted in ever-increasing demands for energy. This prompted many countries to reconsider their energy policies and to use energy efficiently [1].

The increasing amounts of the emissions of CO_2 have led to great environmental impacts [2]. Based on a report that has been released by International Energy Agency (IEA) in Feb 2020, global energy-related carbon dioxide (CO_2) emissions peaked in 2019, at 33 gigatons (Gt) [3]. Humanity is currently attempting to discover additional innovative forms of power production that allow for CO_2 emission reduction because of an issue of global warming caused by fossil fuel consumption [4], which is totally dominated by petroleum, natural gas, and coal [3]. In addition, global warming had led to an increase in Earth's average temperature by 0.60 °C between 1982 and 2012. Total world energy consumption is estimated to increase by 0.7 - 1.4 percent each year during the period from 2008 to 2035. Consequently, increased energy consumption has led to increased CO_2 emissions in addition to the emissions of other greenhouse gases as a result of using these fossil fuels, resulting in an increase in the average Earth's temperature [5].

Fossil fuels presently account for 85 percent of the world's energy usage by source, as seen in Figure 1.1 [6]. However, due to limited resources and environmental implications, this consumption cannot be continued in the long run. To help meet rising energy needs, alternative energy generation options must be discovered.

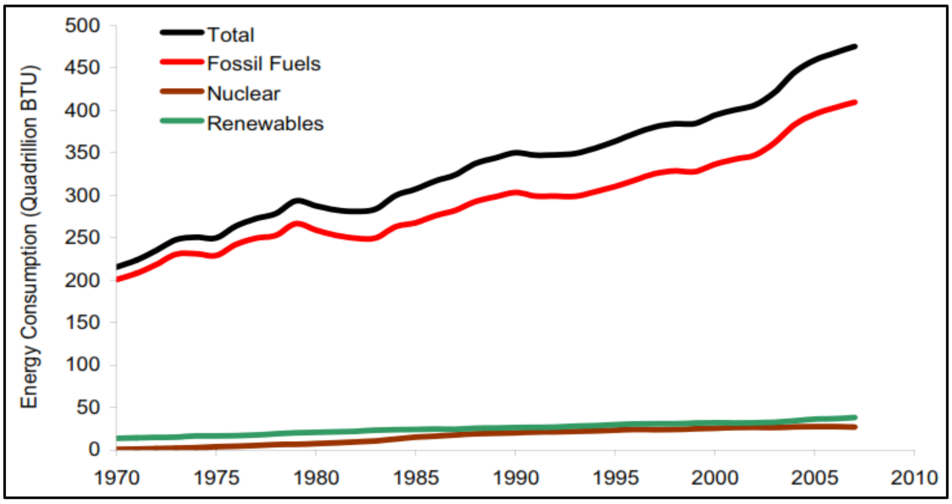

Figure 1.1. Global energy consumption by source (1970-2007) [6]

On the other hand, the oil refining industry resulting big amounts of CO_2. The most considerable air emissions sources in the refineries of oil are catalytic or thermal cracking units, steam boilers, catalytic reformer units, and fare that is associated with the refinery process, in Libya the oil refining sector accounted for 67.30% of total carbon monoxide emissions and about 1.83% of carbon dioxide CO_2, as it's shown in Figures 1.2, 1.3 [7].

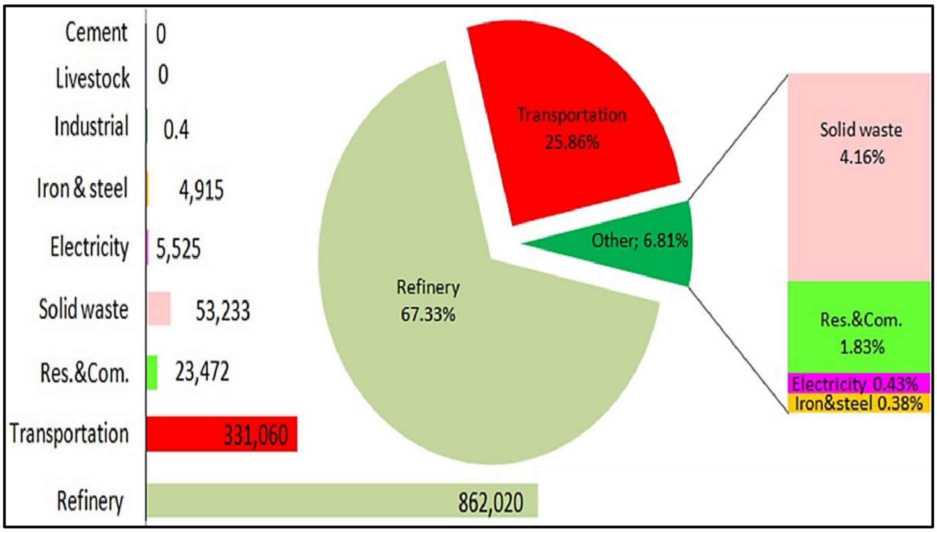

Figure 1.2. Annual CO (ton/year) emitted by the sectors and the share of every one of the sectors in total emissions of CO [7]

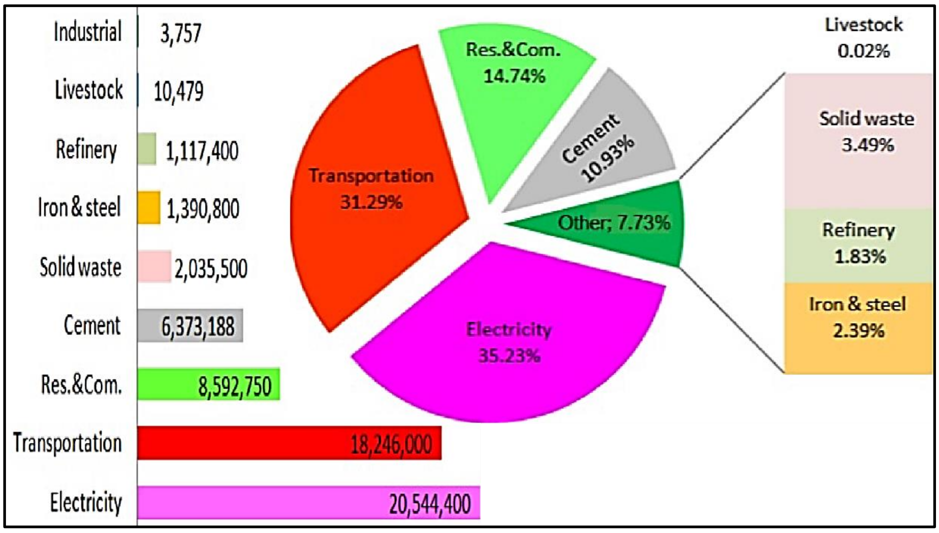

Figure 1.3. Annual CO_2 (ton/year) that is emitted by the sectors and the share of every one of the sectors in total emissions of CO_2 [7]

1.1. IMPORTANCE OF ENERGY

Energy is critical for all countries' economic and social development, as well as for improving quality of life. Energy is played a paramount and significant role in the advancement of human society. Energy has become an essential element for the world in this era of technical progress and materialist ways of life [8]. Energy has many uses in the fields of life, such as thermal, geothermal, chemical, biomass, mechanical, nuclear, wind, solar, and electric energy.

1.2. RENEWABLES

Renewable energy has been defined as an energy type that is inexhaustible and never runs out; its name implies that when it’s nearing completion, it reappears; and its source is one of the natural resources, like the wind, sun, and water; and its most significant feature is that it is an environmentally friendly and clean energy, as it doesn’t emit harmful gases like CO_2 and has no negative impact on the environment.

The sources of renewable energy are in direct opposition to non-renewable energy sources like nuclear power and natural gas, which cause global warming and the release of CO_2 when utilized.

Climate change and its consequences, energy security, and energy access are global problems for sustainable development [9]. The world's reliance on fossil fuels and their effect on the global economy and environment has resulted in many global issues, including global warming Increased, climate change and carbon emissions are all impacts of utilizing fossil fuel. The principal sources of greenhouse gases are flue gases produced by burning fossil fuels [10]. All those problems require solutions, and this promotes the direction toward renewable energy [11]. Renewable energy sources include hydropower, solar, wind energy, and biomass, all of which are sustainable, clean, and economic when compared to conventional sources [12].

1.3. STATUS OF LIBYA

Libya depends totally on fossil fuels for generating electricity production. Libya is in the middle of North Africa, with 1,759,540 km^2 of the geographical zone, which has about 88 percent of the vast desert area, with its coast of about 2000 km^2 on the Mediterranean Sea. With a population of 6 million spread over an area of 1.7 million km^2 [13]. The location offers the highest potential for renewable energy, especially wind and solar, and the amount of energy demand has increased enormously from 2000 to 2010 over the past decade [14].

1.3.1 Fossil Fuels in Libya

Libyan oil prospecting began in 1955. Libya's first oil fields have been discovered in the northeast of the country in 1959, and the country began exporting oil in 1961. Libya's oil sector is managed by the state-owned National Oil Corporation (NOC) and smaller subsidiary businesses, accounting for about 50% of the country's oil output. A few foreign oil corporations have been involved in exploration and production activities. Libya has 2064 crude oilfields that produce an average of 2,300 bpd per well. Libya is one of North Africa's top oil producers, producing 1.2 million barrels daily compared to 1.68 million barrels before 2011, according to the National Oil Corporation (NOC). Libya had proven crude oil reserves of 48 billion barrels since the end of 2014, which has made it the greatest reserve in Africa, as it accounts for 38% of the continent’s total and ranking 9th internationally. Figure.1.4 [15].

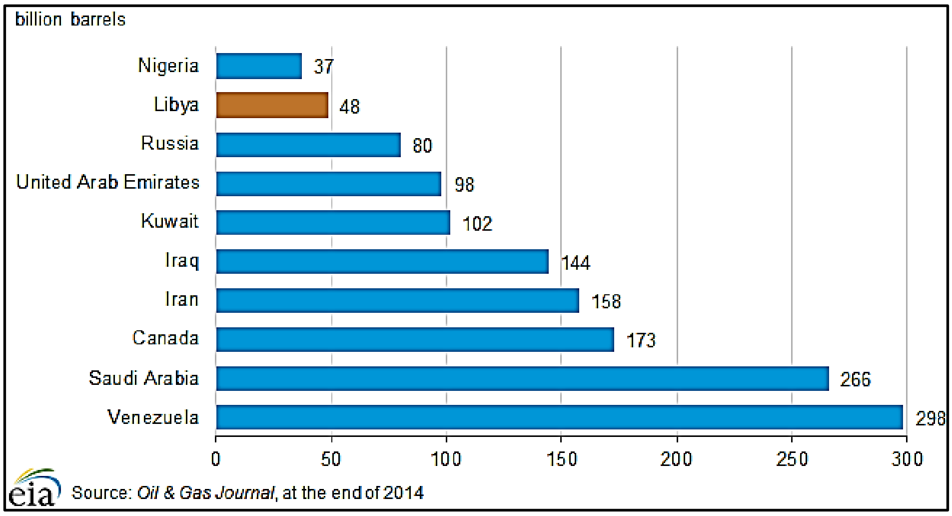

Figure 1.4. The world's top 10 holders of proved reserves of crude oil [15].

Before the 2011 upheaval, the NOC, a state-owned business, was the dominant player in the oil sector. The NOC has set a target of 2.5 million barrels daily by 2015, although this can't be met unless production levels reach pre-upheaval levels in 2011. For multinational companies to restart oil exploration in Libya. This recovery requires a safe environment and rest. As shown in Figure 1.5, many of Libya's oil resources are in the country's east (Sirte Basin), with the remaining 25% located in the country's south (this is called the Murzuk Basin). The infrastructure of Libyan petroleum facilities is depicted in Figure 1.6 [16].

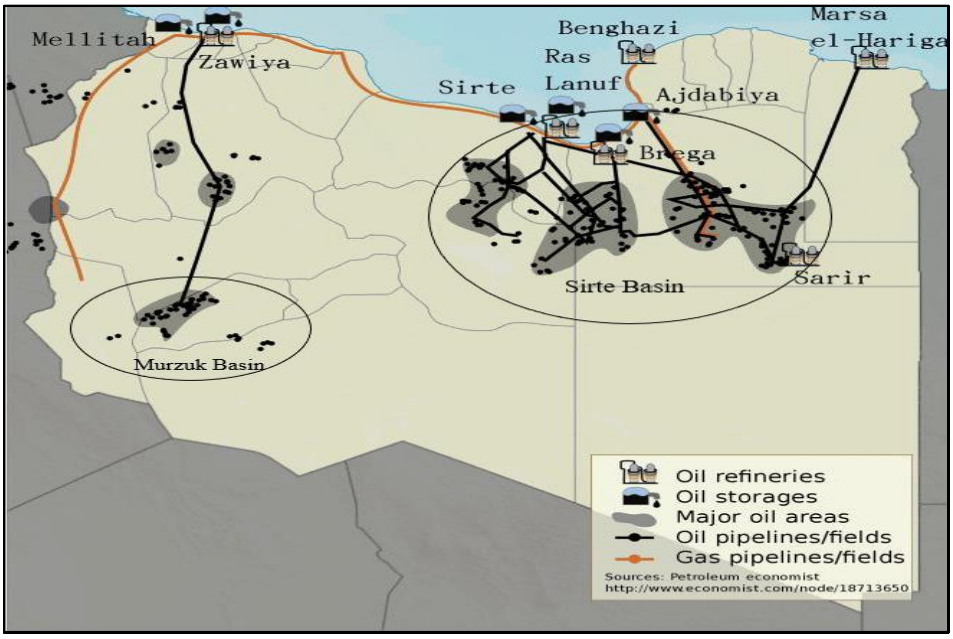

Figure 1.5. Libyan map indicating the oil activities [16].

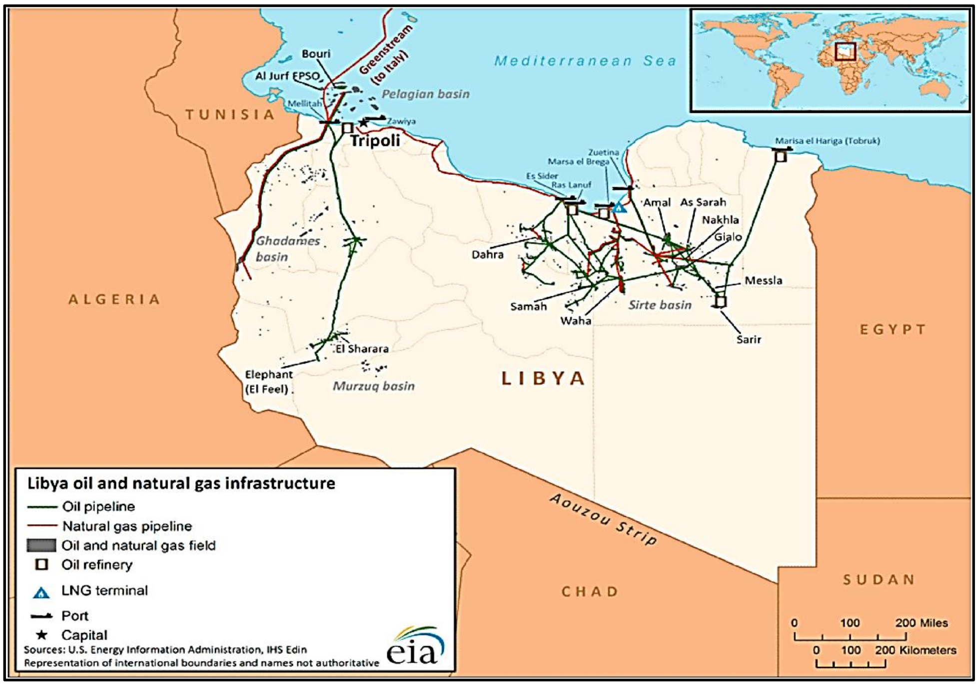

Figure 1.6. Oil and natural gas infrastructure of Libya [16].

Libya has 5 domestic refineries with a total capacity of around 380,000 bbl/d (51,351 tons/day). This is much more than the 227,000 bbl/d of domestic oil use. The rest, on the other hand, is exported. Libya’s refineries include:

1. Ras Lanuf Export Refinery, which is located on the Gulf of Sirte, has a crude oil refining capacity of 220000 barrels per day.
2. Tobruk refinery, located on Libya's eastern coast, with a capacity of 20000 barrels a day.
3. Az-Zawiya refinery, located in northwestern Libya, with a crude processing capacity of 120000 barrels per day.
4. Sarir refinery, located in the east, with a capacity of 10000 barrels per day.
5. Brega refinery, located in north-eastern Libya, has a crude capacity of 10000 barrels per day.

1.3.2. Renewables in Libya

Libya is endowed with an abundance of sources of renewable energy, like solar and wind, which might play a major role in meeting a significant portion of the country's energy needs. However, being an oil-producing country, there was no need for other alternative energy sources. According to information that is currently accessible in the public domain on renewable energy in Libya, the country is rich in wind and solar energy potential [17]. The planned projects are mostly wind and solar energy systems, which are the top renewable energy choices in Libya.

1.3.2.1. Solar Energy Potential

Solar energy is thought to be Libya's most significant and suitable renewable energy source. Libya's geographical location makes it one of the countries blessed with abundant solar energy between (15º N and 35º N). The average solar radiation is roughly 7.5kWh/m^2/day, with about 3,000 to 3,500 hrs of sunshine per year [18].

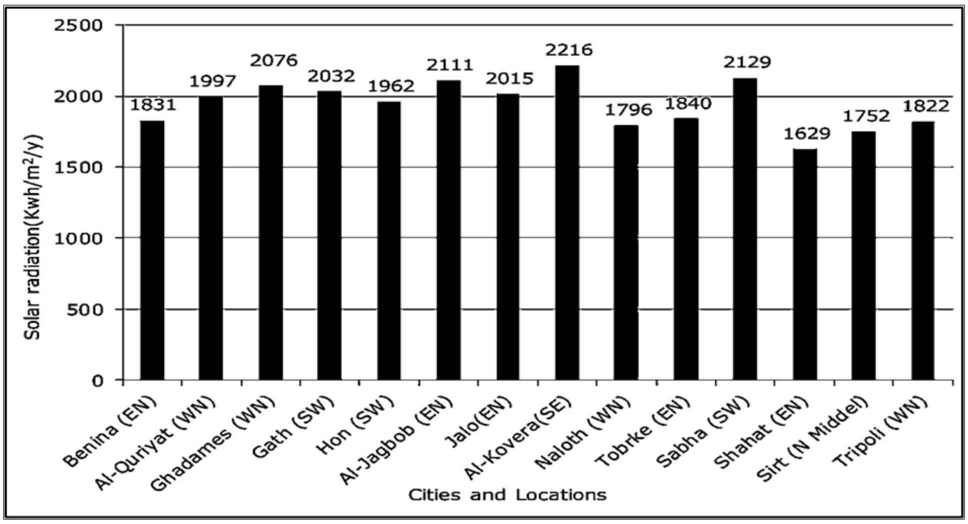

Figure 1.7. Average yearly solar radiation in some cities in Libya [17].

Concerning solar energy, it can be argued that it is the most important renewable source of energy. The average annual solar radiation in some regions of Libya is summarized in Fig1.7, based upon data that had been obtained from the Center for Solar Energy Researches and Studies. During summer, when there is a lot of solar radiation, therefore, during the warmest months of the summer, the maximum load increases dramatically (June, July, August, September, and Oct). The main reason for this is that people use air conditioners in an unreasonable manner. Load demand increases during the coolest months of the year (Dec., Jan., & Feb.). The behavior of electrical loads in Libya, as well as the sun's radiation in the area, has been studied to indicate that solar energy may be used to efficiently reduce peak demand.

1.3.2.2. Wind Energy Potential

Wind energy had been considered the next best alternate renewable energy source, as it is taken from the kinetic energy of the wind by utilizing wind turbines to generate electrical energy. Wind speeds depend on geographical location, topography, and season, as some sites are more effective than others for wind energy generation. At three different heights, the average wind speed ranges between (4.50 - 8.50m/sec). Fig. 1.8 shows the speed of the wind in coastal cities.

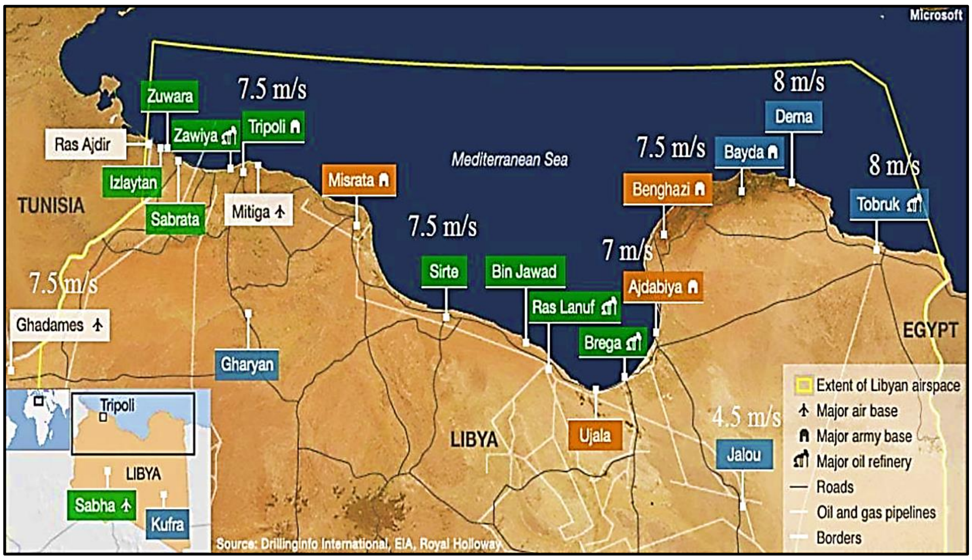

Figure 1.8. Speed of wind in coastal cities of Libya [11].

Wind energy is important in the production of power during the winter when sunlight hours are few. By 2025, the aim is to produce two gigawatts of wind energy, which will create employment and contribute to the broader local economy.

1.3.2.3. Other Energy Sources

There are alternative energies such as biomass energy, geothermal energy, and hydroelectricity. Bio-mass energy has been considered one of the most common renewable energy sources. This type uses fewer carbon emissions and is an emerging energy source that can meet increasing demands for energy in some countries. Biomass is a fuel type that has been created from organic materials which store heat due to photosynthesis. Currently, the use of biomass energy in Libya is limited as a result of a number of factors[19, 20]. One of them is the unavailability of these materials as they are collected and used as the main fertilizer in Libya. However, there are many landfills in Libya that can be used to manufacture methane. Therefore, the chances of developing biomass energy theoretically exist in Libya. Geo-thermal energy is also another type of renewable energy source, and it is defined as the natural heat that we get from the earth's core. Libya's geothermal capacity has not yet been analyzed. However, in the last few years of the twentieth century, one study discovered a site near Wadan, a city in southern Libya, with low-temperature thermal resources that generate approximately 1.3 MW or cooling 1284 tons at 5 °C. or 835 tons at 0 °C [21].

Heavy rains in the winter create huge pools of large amounts of surface water. There are about 16 main rainwater collection dams with a capacity of 385 cm3 and an annual storage capacity of 61 mm. This water is used for industrial, agricultural, and domestic purposes in most cases [22]. In North African nations, Libya has a poorly developed hydroelectric power potential. In Libya, there are many dams, and the three largest dams are Wadi Al-Qattara with a capacity of 135 mm^3, Wadi Al-Qaa with 111 mm3, and Wadi Al-Majinin with 58 mm^3. It is expected that the percentage of water that will be collected after the approval of the construction of modern dams will be about 120 mm 3 annually [22].

1.4. SYNTHETIC FUEL PRODUCTION

Synthetic fuel production is a hydrogen-addition process. The hydrogen source could be intramolecular (the formation of a carbonaceous low-hydrogen residue) or intermolecular (the addition of hydrogen from an external source).

1.4.1. Methanol Fuel

Methanol is an alternative, renewable, economically, and environmentally attractive fuel; which has been regarded as one of the most promising replacements for conventional fossil-based fuel types [23]. Methanol fuel had been considered as an alternative bio-fuel for internal combustion and other engines, either independently with gasoline or in combination. Methanol has been first produced as a small byproduct of the destructive distillation of wood and has been hence known as wood alcohol. Methanol made in this manner had been utilized for lighting, heating, and cooking in the 19th century, but was ultimately displaced by cheaper fuels, particularly kerosene [24].

The synthesis of Methanol underwent continuous enhancements for almost 100 years [25]. Currently, methanol as a substitute fuel may be produced by several methods, for example, it may be produced from biomass or natural gas. For the time being, methanol is nearly entirely produced from synthesis gas, and it is the most common method, which is a blend of CO and H_2, including chemical reactions in Eqs. (3.1-3.3) [26,27].

1.4.2. Ammonia Fuel

Ammonia is a nitrogen-hydrogen compound with a formula of NH_3, a colorless gas with a distinct pungent smell. Ammonia is one of the most commonly produced types of inorganic chemicals, with 175 million tons produced globally in 2018, where China accounted for 28.50 percent of that, with the US accounting for 9.10 percent, Russia accounting for 10.30 percent, and India accounting for 6.70 percent. [28]. Liquid ammonia has a raw energy density of 11.5MJ/L, which is approximately 1/3 of that of diesel [29]. For internal combustion engines, ammonia is occasionally proposed as a viable substitute for fossil fuels.

1.5. CARBON CAPTURE METHODS

The oil refining industry emits big quantities of carbon dioxide (CO_2). CO_2 is constructed during combustion, and the type of combustion process has a direct influence on the selection of a suitable CO_2 removal technique. CO_2 capture and storage (CCS) is an alternate technique that can decrease CO_2 emissions from the oil refining processes even further. There are three major CO_2 capture systems linked to various combustion processes: post-combustion, precombustion, and oxyfuel combustion. Figure 1.9 shows a diagram of those CO_2 capture methods in a fossil fuel plant.

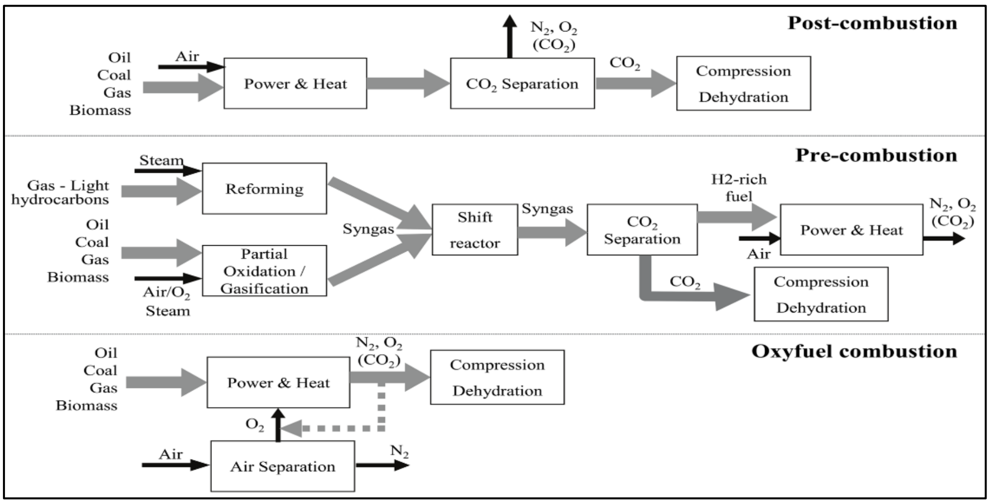

Figure 1.9. Schematic diagram of these CO_2 capture methods in a fossil fuel plant [30].

1.5.1. Post-Combustion

The idea of post-combustion carbon capture (PCC) began in the 1970s. The capture of carbon by post-combustion (PCC) from flue gas is well comprehended and is being utilized in a variety of industrial applications. This method removes CO_2 from flue gas following combustion, and post-combustion technologies have been considered the better method for rebuilding current power plants. The method has been tested on a small scale, recovering CO_2 at rates of up to 800 t/day [31]. Based on National Energy Technology Laboratory, CO_2 post-combustion capture would raise the cost of the production of electricity by 70% [32].

1.5.2. Pre-Combustion

Pre-combustion capture can be defined as the method of removing CO_2 from fossil fuel (usually coal or natural gas) before the burn is complete. In gasification operations, for example, a feedstock (like coal) is partly oxidized in steam and oxygen/air at high pressure and temperature for the production of the synthesis gas.

1.5.3. Oxyfuel-Combustion

In the oxyfuel combustion capture method, oxygen has been utilized rather than the air for the combustion. To ensure that the products of combustion (flue gas) include CO_2 and water with only trace quantities of other gases, the fuel is combusted in the case of the availability of almost pure (about 98 %) oxygen [33].

1.6. CURRENT STUDY

This current study is a thermodynamic, economic, and environmental analysis of a plant that produces synthetic fuel by means of renewables and CO_2 hydrogenation utilizing waste heat from an oil refinery. In this study, a thermoeconomic analysis of a plant that produces methanol by hydrogenating carbon dioxide in the waste gas from an oil refinery using renewable energy was carried out.

The carbon dioxide in the flue gas is captured in the carbon capture plant, and the hydrogen obtained from the sea water in the hydrogen plant with the help of photovoltaic energy is combined in the methanol plant to produce methanol fuel. After the environmental impact of the methanol plant is investigated.

The procedure of calculating the amount of energy that is required and the number of solar panels or wind turbines that will be required to meet that demand. The Libyan Az-zawiya refinery facility has been selected as the case study location. The system's process CO_2 emissions, heat integration, energy efficiency, and thermo-economic performance were all taken into consideration.

The findings of the present research provide refineries with a method for the simultaneous reduction of CO_2 emissions and produce a product with a high added value (i.e., methanol). Additionally, this study examines the practicability of economic values and the impact of this production on the environment, and it compares this calculation with other work that has been done in the past in other countries.

PART 2

LITERATURE REVIEW

Several studies have looked into how to development of green refineries. Berghout et al. (2012) This study developed an integrated approach to determining deployment paths to reduce GHG emissions in an industrial facility. The approach was effectively implemented at a big petroleum refinery in northwest Europe (4.1 Mt CO_2/y). Post-combustion capture, biomass gasification, oxyfuel combustion capture, and biomass gasification with carbon capture and storage were each explored as potential next steps after implementing energy efficiency measures [34].

Yu et al. (2016) concentrated on the recovery of waste heat at low temperatures in order to enhance the energy efficiency, which would in turn help refineries cut their emissions of greenhouse gases [35].

Demirel et al. (2015) aimed to explore the range of decreasing thermal energy consumption and emissions of CO_2 for a more sustainable refinery process. The thermo-dynamic analyses have been performed with the use of a thermal analysis ability column targeting tool to process energy density metrics and an energy analyzer for designing and enhancing the performance of a process heat integration heat exchanger network system. Results have indicated that the tool of column targeting, carbon tracking tool, and energy analyzer can estimate environmental metrics sustainability and energy of a design and quantify significant improvements to reduce required thermal energy costs and CO_2 emissions in the crude oil refinery process [36].

Comodi et al. (2016) enhanced refinery energy efficiency with the use of torch gas recovery technology to achieve emission trading requirements. The flare gas had a highly variable composition and flow rate, according to the results. A liquid annular pressure device with a capacity of 400 kg/h was selected, and the annual energy recovery is estimated at 2,900, which corresponds to 6,600 tons of CO_2 equivalent. Also showed that the period of the payback is approximately 2.5 years [37].

Perez-Fortes et al. (2016) conducted a technoeconomic valuation of synthesis of the methanol via hydrogen and captured CO_2 based on CHEMCAD. Due to the results of the process of heat integration, the assessed methanol plant produces 440ktM/year, and the methanol and carbon capture plant studied uses approximately 21.50% of emissions of CO_2 from pulverized coal power plant, which produces 550MW of the electric energy. Results showed that there's a net but small possibility to reduce CO_2 emissions as the net decrease in CO_2 emissions can reach 2.71 million tons of CO_2 each year [38].

Rivarolo, M. et al. (2016) performed a thermoeconomic feasibility analysis for syntheses of methanol from different sources of renewable energy (like wind energy, hydroelectric and solar energy). Analysis was carried out with the use of W-ECoMP (i.e. Web-Based Economic Cogeneration Modular Program). The results show that methanol production from renewable sources has promising advantages and economic performance can be even better if European financial incentives for biofuel production are considered [39].

Bellotti, D. et al. (2017) carried out a feasibility study of a power-to-fuel plant for the production of methanol through thermo-economic analysis. Assuming a mean cost for the electrical energy to feed the electrolyzer and analyzing the impact of the most important parameters (such as methanol selling cost, oxygen selling option, and electrolyzer capital costs) on plant profitability, 3 different capacity plants for the production of the methanol (4,000, 10,000 and 50,000ton/yr) have been researched, analyses were conducted by the W-ECoMP, program for thermo-economic analyses and plant enhancements [40].

Van-Dal et al. (2013) focused on a process for the production of methanol fuel grade through the capturing of the CO_2 from flue gases of the thermal power plant. Aspen Plus is used for simulation and design, chemical absorption is used to collect CO_2, and water electrolysis generates hydrogen. As results showed, the methanol plant provides 36% of the thermal energy that is needed for the capturing of CO_2, decreasing cost. The CO_2 balance of the process had shown the potential to reduce 1.60 tons of CO_2 per ton of the methanol that has been produced in the case where oxygen byproduct has been sold, or 1.2t if it's not [41].

Holmgren et al. (2014) evaluated the effects of the reduction of emissions of greenhouse gases on a methanol plant utilizing gasified biomass. Results have indicated that integrated methanol production plants are more useful compared to traditional approaches to methanol production [42].

Kiss et al. (2016) have proposed a CO_2-hydrogenation-based Methanol-producing plant. They utilized a wet hydrogen byproduct from the chloralkali process. The study led to the achievement of 100.07kt/yr methanol and 0.48tons-1.16tons of steam per ton of the methanol and 550kWh/ton methanol of electricity usage [43].

Bellotti, D. et al. (2019) offered comprehensive analyses of sensitivity for the synthesis of methanol from hydrogen and CO_2, as well as an economic analysis based on studies of sensitivity. The simulation tool Aspen Plus has been utilized to do thermodynamic analysis. As a result of the study, high pressures result in a significant increase in methanol yield, according to thermodynamic analyses (131 %). Simultaneously, higher levels of pressure result in higher compressor energy consumption (329 %), because of its high energy consumption and maintenance costs, the electrolyzer has proven to be the most critical component from an economic standpoint, accounting for over 70% of fixed cost and the largest share of variable cost. With a similar variation of the percentage, electrical energy cost is the most affecting parameter, which is followed by PEMEL capital costs and oxygen cost, according to sensitivity analyses. Finally, this study found that the methanol production method based on H_2 produced by a water electrolyzer and CO_2 sequestered from the flue gases isn't economically competitive in comparison with the conventional natural gas-based approach [44].

Kotowicz et al. (2021) suggested a renewable-powered methanol plant using a carbon capture plant and hydrogen from water electrolysis. They have achieved an overall energy efficiency of 52.9 percent for the plant. Furthermore, they stated that the methanol production efficiency has been equal to 69.64 percent [45].

Eggemann et al. (2020) have investigated the lifecycle evaluation of a biogas-powered methanol production plant. They employed waste gas from a biogas plant as a CO_2 source, and wind power was utilized for the water electrolysis. They have explained that if the raw materials are available and the joint products have been produced at sufficient pricing, their suggested method can surpass the conventional production of methanol [46].

Abdelaziz et al. (2017) offered novel technologies for producing methanol from waste gases from industrial operations like steel and iron manufacture, cement, power plants, and the petroleum sector. They conducted a case study on a power station with a capacity of 112 MW that burns natural gas and emits 328t/h of flue gas. They have reached 0.625ton of the methanol output per ton of CO_2, resulting in 56.55 million dollars in profits each year from methanol production [47].

Ozcan & Kayabasi (2021) investigated the economic and thermodynamic feasibility of an iron and steel plant by using waste heat to produce synthetic fuels via hydrogenation of captured carbon dioxide. The waste heat has been utilized as the heat source for the Kalina cycle (KC) for a purpose of generating electric power and heating the reboiler in the amine-based CCP, also the generated electric energy was used for the PEM electrolyzer, and the generated hydrogen and captured carbon dioxide were used in MPP. KC modeling has been carried out with the use of an ammonia-water mix data-base in the EES software package. As a result of the study, it was found that the production efficiency of synthetic fuel reaches 19% at the cost of methanol of $532 one ton for a daily methanol capacity of 3.69 tons. KC had shown the maximal efficiency at a maximal temperature of 488K, with a proportion of the ammonia at 65%, and the optimum current density of electrolyzer PEM was 2.2kA/m^2 [10].

Nguyen, T. & E. Zondervan. (2019) explored three detailed processes of CO_2 transformation to methanol, such as bi- and tri-reforming processed, and hydrogenation. This paper targeted simulating, optimizing, and heating processes of the conversion from the CO_2 at 3 different capacity values (300, 1,500, and 3,500ton/day), comparing operational costs and investment and assessing the reduction of the CO_2 emissions. In Aspen Plus, a flow sheet model of the process of hydrogenation has been created, then the thermodynamic properties of the high-press were evaluated using RKSMHV2. According to the results, concerning the environmental factors, the technology of hydrogenation (with the hydrogen from renewable sources) is better than other approaches as an outcome of the use of more carbon dioxide than emitting. When compared to the hydrogenation way, tri- and bi-reforming achieve better results through the lowering of the annualized total costs of methanol production by 39 and 37 percent, respectively. If these strategies are executed technology of hydrogenation can play a critical role in delaying carbon emissions into the atmosphere [48].

Battaglia et al. (2021) assessed an opportunity of utilizing green methanol (MeOH) that has been produced from renewable electric energy as a carrier to remove carbon from the chemical process industry. They have evaluated an integrated system that converts about 1.25ton/hour of CO_2 that had been captured from a coal-fired power plant to 788kg/hour of the methanol via green hydrogen from the electrolysis of the water (10MW), the method used Power-to-MeOH for the determination of energy and mass balances of plant and evaluate its energy and the environmental performances, a detailed model was developed for simulating operation of various sections (carbon capture, water electrolysis, and methanol syntheses). According to the results, the Levelized cost of methanol (LCOM) was estimated. In the case of hydropower, LCOM ranges between 874€/t and 1356€/t, which is close to the future market price of MeOH with a margin of improvement (655–1,135€/t) in the case of lower costs of the hydropower electric energy (26.2 €/MWh) [49].

Tozlu, A. (2022) conducted an economic and thermodynamic analysis of a facility of synthetic fuel production performed by hydrogenation of the carbon dioxide that has been taken from the biogas. A methanol production process is designed that is based upon CO_2 separation within the biogas that has been produced in actual WWTP and H_2 that had been obtained by solar Photovoltaic driven polymer electrolyte membrane electrolysis (PEM), equations and related reference values have been used and analyzes were carried out by EES. According to the findings of this study, the daily production of methanol is 1674 kg. The costs of producing electricity, methanol, and hydrogen have been determined to be $0.043kWh1, $ 0.693 kg1, and $ 3.156 kg1, respectively [50].

Muhammad, Y, et al. (2022) studied a techno-economic analysis of methanol production (by hydrogenation of CO_2) with the solid oxide electrolyzer (SOE) with steam electrolysis. Aspen process economic analyzer (APEA) has been utilized for performing economic analyses of this procedure. According to the results, the Integration of a solid oxide electrolyzer with the process of methanol production led to a 22.30% decrease in hydrogen cost in comparison with the alkaline water electrolyzer, also costs of 63.5ton/h of the production of the methanol reduced, from 1,063 to 701.50 $/ton. A decrease of 21.40% in share capital and 22.40% in operating costs of the production of hydrogen from the steam has been noticed in the case where the SOE has been utilized instead of Alkaline electrolysis (AEL). The production of Methanol Contributes to a potential to abate 1.13ton of the CO_2 per ton of its production in the case where renewable energy sources (hydro or wind) have been utilized to achieve the energy demand of this process and electro-chemical hydrogen has been produced by the solid oxide electrolyzer [51].

M. Bos. Et al. (2020) investigated the options for heat integration between processes, and steps. 100MW wind power to the methanol plant was assessed based on capital costs and energy requirements. Direct air capture is used to obtain the stoichiometric amounts of the CO_2 needed for the production of methanol. This paper has been the first that combined direct air capture of water and CO_2 with methanol production utilizing renewable sources of energy. Power to the efficiency of the methanol of about 50% was discovered. Methanol cost is 300 €/ton, which excludes 800 €/ton, which includes the capital cost of the wind turbine. Excluding 300M€ investment costs for 100MW of the wind turbines, the total plant capital cost has been approximately 200 M€. Up to 45% of capital costs have been reserved for the electrolysis, 50% for CO_2 air capture installation, and 5% for the system of methanol syntheses [52].

In the study of Ma, Qian et al. (2022) they aimed to build a system for the synthesis of methanol that could collect CO_2 from flue gas of a fluid catalytic cracking unit as well as hydrogen and methane from dry gas to lower the emissions of carbon and promote green refinery evolution. Carbon dioxide–dry gas to methanol system has been modeled by the use of Aspen Plus, and its energy performance, Carbon dioxide reduction, and economic performance have all been studied. This study's technology achieves yearly CO_2 alleviation of 2.8 million tons and raises the energy efficiency of fluid catalytic cracking units by 2.80%, making it more cost-effective compared to traditional coal-to-methanol production. Refineries can reap the energy and environmental benefits of this method because it vastly improves upon the original fluid catalytic cracking's energy efficiency while also drastically reducing greenhouse gas emissions. In addition, the developed system's product cost was 1746 Yuan/t, making it more cost-effective than the typical methanol price in China (approximately 2500 Yuan/t) [53].

PART 3

MATERIALS AND METHODS

In the present study, first, the following are points to be determined:

1) Waste gas resources and properties such as:
   - Temperature
   - Volumetric flow rate
   - Composition
2) Renewable energy type and closest to the location for the plant
3) Determination capture method of CO_2 from waste gas
4) Composition method of H_2 with C atoms
5) Selecting the suitable software to solve energy and economy equation (EES)

Flue gas has a 30°C temperature and a 0.11MPa pressure, with a 27,890 kmol/hr flow rate by reff. [54]. The flue gas from the fluid catalytic cracking (FCC) unit is made up of a mix with a mole composition of CO_2 (16.6%), CO (0.6%), N_2 (82%), and O_2 (0.8%) [55]. The water from the sea has a flow rate of 34.75kg/s. We employed post-combustion capture (PCC) as the CO_2 capture unit. Electricity is generated to run the factory by solar panels that are connected to all units of the plant. The software selected to solve the energy and economy equation is Engineering Equation Solver (EES).

3.1. PROPOSED METHANOL PRODUCTION SYSTEM

In the present work, we designed a process for the conversion of waste gases into valuable products in an oil refinery for a purpose of finding a practical solution that would allow the petrochemical industry to achieve green and low-carbon development. The process design of the methanol plant is based on previous studies conducted by H. Ozcan and E. Kayabasi [10], and Kiss, et al [43]. The suggested methanol production plant includes 4 main components as has been depicted in Figure 3.1.

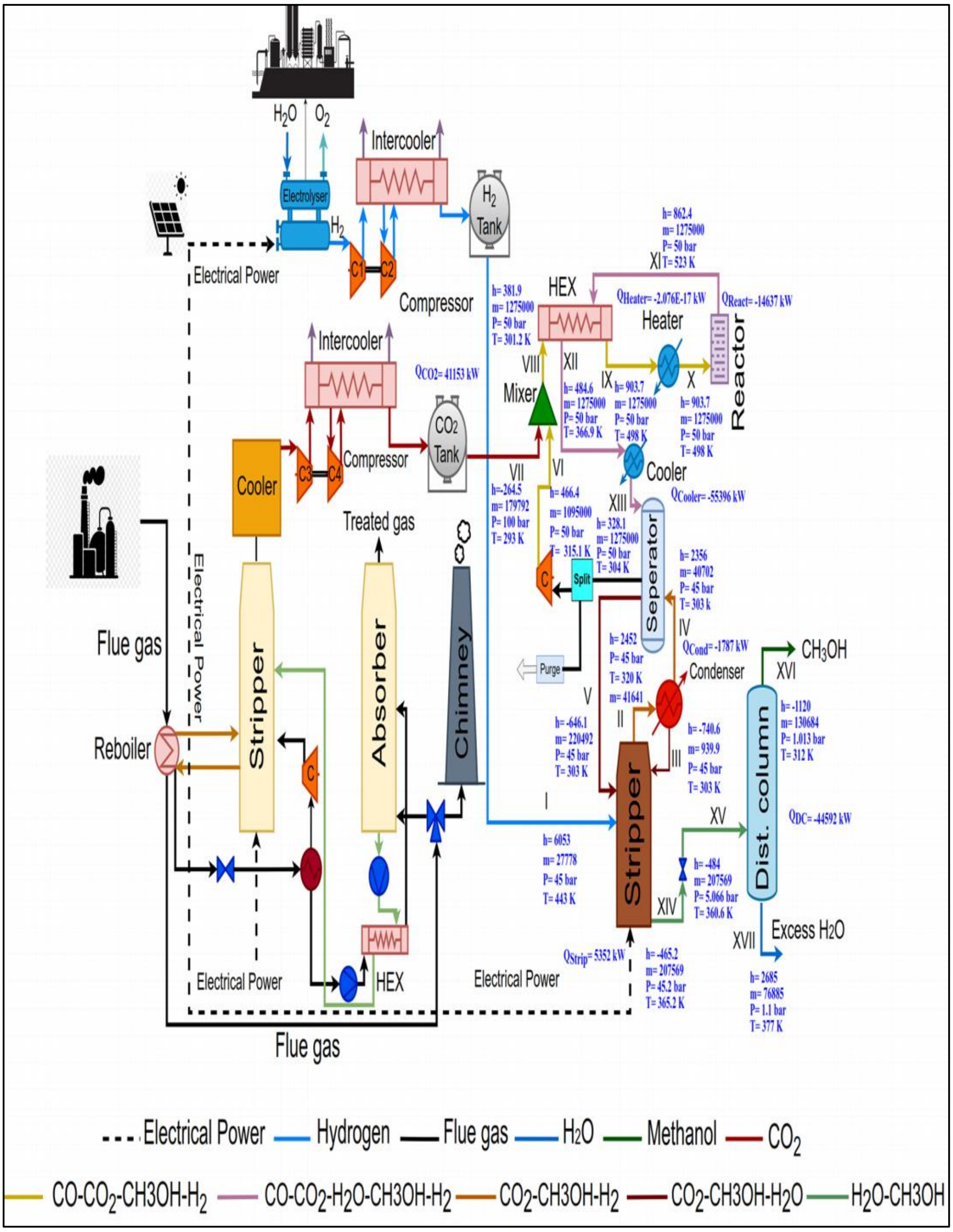

Figure 3.1. Detailed flow diagram of the Methanol production plant

3.1.1. Photovoltaic Plant (PV)

To do this process we need a power source. Solar panels were used to generate power for the factory. We assumed that floating panels would be installed near the refinery on the sea, where the sea is about 700 m away from the refinery and the panels are about 1000 m and on an area of 1 m^2. The location was determined, and the data was obtained from Global Solar Atlas [56]. Figure 3.2 shows the installation locations of the panels and the oil refinery, as Table 3.1 shows information about location data.

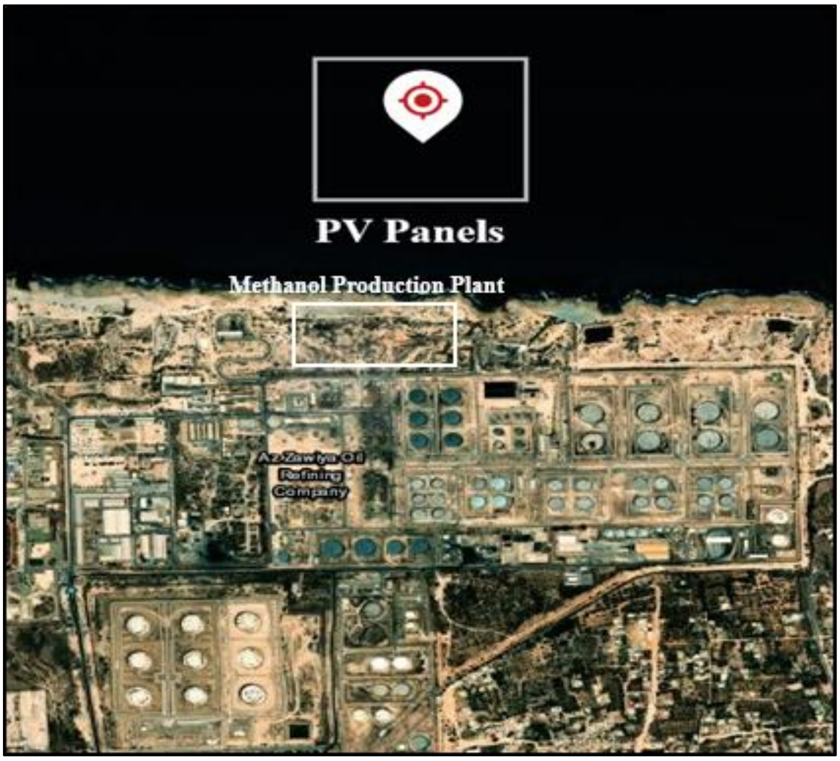

Figure 3.2. The installation locations of the panels and the oil refinery [56].

Table 3.1. Shows information about the location data [56]

Map data	Per day
Direct normal irradiation DNI	5.102kWh/m^2
Diffuse horizontal irradiation DIF	2.018kWh/m^2
Global horizontal irradiation GHI	5.264kWh/m^2
The optimal tilt of PV modules OPTA	30 / 180º
Global tilted irradiation at optimal angle GTIopta	5.820kWh/m^2
Terrain elevation ELE	-4m
Air temperature TEMP	21.30 °C

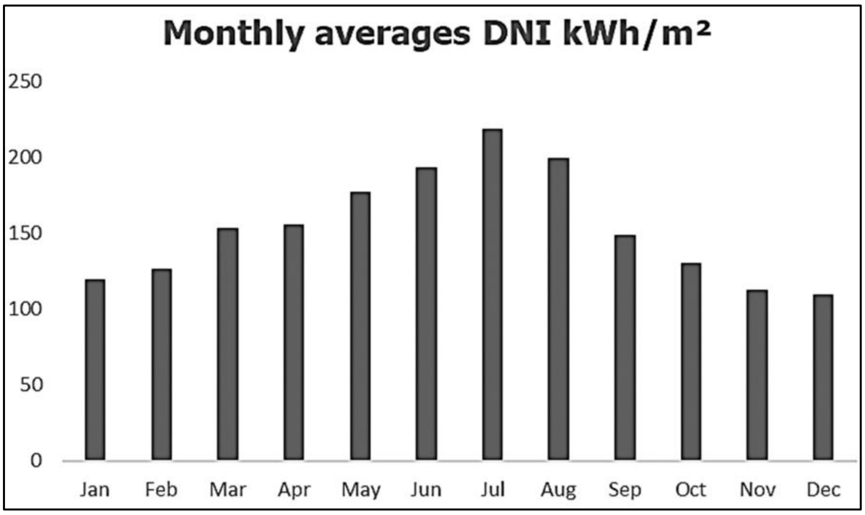

Figure 3.3. Monthly averages direct normal irradiation [56].

Figure 3.3 showed monthly averages of direct normal irradiation, where the highest percentage of radiation appears throughout May, June, July, and August. During October, November, and December until February, the radiation rate is low. Also, there are rate hours for sun radiation in Table 3.2 shows the average hourly direct normal irradiations.

Table 3.2. Average hourly profiles DNI [kWh/m²] [56]

Hrs.	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
5 - 6	0	0	0	0	28	57	32	1	0	0	0	0
6 - 7	0	0	28	127	223	263	274	194	88	37	0	0
7 - 8	73	125	261	308	350	395	437	401	303	258	170	84
8 - 9	329	371	403	412	451	503	556	522	418	384	360	326
9 - 10	435	463	482	492	531	586	643	608	500	460	442	422
10 - 11	485	525	535	546	591	637	699	666	559	501	484	462
11 - 12	506	558	569	584	612	659	722	693	594	531	498	478
12 - 13	510	570	587	592	615	660	727	697	601	531	491	476
13 - 14	495	556	579	567	595	649	712	678	566	501	467	454
14 - 15	449	513	522	519	543	608	667	630	505	444	410	406
15 - 16	375	451	463	458	474	545	604	557	427	365	324	322
16 - 17	201	346	371	361	386	457	513	459	322	205	113	109
17 - 18	3	55	165	212	271	340	386	298	79	4	0	0
18 -19	0	0	0	14	50	111	102	32	0	0	0	0

3.1.2. Carbon Capture Plant (CCP)

The carbon in the flue gas of an oil refinery is captured by the carbon capture plant (CCP) using aqueous monoethanolamine (MEA). The flue gas has also been used to heat carbon capture plant re-boiler, which releases CO_2 with the weakly bound amine. After that, the rich amine has been sent to the stripper and then heated to a temperature of 123^oC in the re-boiler, where pure carbon dioxide has been extracted from it [57]. Captured carbon dioxide has been compressed to MPP pressure and stored in a carbon dioxide tank.

CCP consists of 9 components: stripper, absorber, heat exchanger, pump, condenser, compressor, reboiler, intercooler, and CO_2 tank.

3.1.3. Hydrogen Production (HP)

Hydrogen has been taken under consideration to supply sustainable energy and may be utilized also as feedstock in a variety of industrial operations. Hydrogen is essential in the process of carbon transformation. Various feedstocks, which include hydrocarbons, fossil fuels, biomass, and water, may be used to create hydrogen. Biomass operations are unreliable because of seasonal dependence. Fossil fuel and hydrocarbon methods, although well developed, are currently not sustainable due to their greenhouse gas emission. Hydrogen may as well be created by separating the molecules of the water by electrolysis or thermolysis.

Water electrolysis methods are classified into three types namely, SOE, AEL, and proton exchange membrane (PEM). SOE has minimal operating costs (because of high-temperature operation), on the other hand, the selection of the cell materials is currently considered the most difficult hurdle [58]. AEL is a well-developed technology, but the running costs connected with it are very high due to the massive electricity requirements. PEM water electrolysis can lower operating costs through the increase of the operational current density values, however, the main hurdle to adoption is cell material selection [59].

In this section, water has been separated in an electrolyzer and the hydrogen has been obtained then compressed to an H_2 tank and stored. The hydrogen that has been produced is compressed into the Methanol Production Plant pressure and used to generate fuel. The HP consists of 4 components: electrolyzer, compressor, intercooler, and H_2 tank.

3.1.4. Methanol Production Plant (MPP)

Methanol fuel represents some alternative biofuel for internal combustion and other engines, either independently with gasoline or in combination. Methanol has first been produced as a small by-product of the destructive distillation of wood and has hence been known as wood alcohol, it can be created from CO_2 with one or two steps, depending on the procedure.

The first step transformation represents the direct carbon dioxide hydrogenation to methanol as in Eq1, in the second steps transformation, CO_2 is initially converted to carbon monoxide through Reverse Water Gas Shift (RWGS) reaction in Eq. (3.2) and hydrogenated after that into methanol as in Eq. (3.3). These reactions as follows [41,53]:

$$CO_2 + 3H_2 \leftrightarrow CH_3OH \quad \Delta H_{298K} = -87\ kJ/mol \tag{3.1}$$

$$CO_2 + H_2 \leftrightarrow CO + H_2O \quad \Delta H_{298K} = +41\ kJ/mol \tag{3.2}$$

$$CO + H_2 \leftrightarrow CO + H_2O \quad \Delta H_{298K} = -128\ kJ/mol \tag{3.3}$$

The source of carbon dioxide might be flue gases from factories producing cement, steel, and oil refineries or thermal power plants such as coal, natural gas, and other major emissions of carbon dioxide. Wasted heat was used from an oil refinery to meet the energy requirements of one-step in Eq. (3.2) methanol synthesis utilizing CO_2 capture from the flue gas of an oil refinery and hydrogen through electrolysis of the water with the use of renewable energy. Table 3.5 represents several input data and parameters used to model MPP.

In this process, methanol production relies on an efficient process where hydrogen after sent to a stripper to efficiently produce methanol then mixed with carbon dioxide [43]. There is a possibility for the production of methanol more efficiently with this method and with acceptable carbon dioxide to the methanol yields. After the hydrogen has been sent to the separator, it is mixed with the products of the reactor, and then the stream rich in hydrogen and carbon dioxide is mixed with carbon dioxide, pre-heated in the recuperator, and then heated to the temperature of the reactor. Following the stripper's separation of the methane and H_2O-rich stream, 100% pure methanol is produced at the distillation column. The several input data and parameters used for MPP, HP, and CCP plants have been listed in Table 3.3.

Table 3.3. Several input data and parameters used for MPP, HP, and CCP [43,57,60].

Flue gas characteristics	Units	Symbols	Ranges
MPP			
The ratio of CO_2 compressor pressure	_	PR_{CO2C}	5.916
Pressure of Reaction	bar	P_R	70
Ratio of H_2 compressor pressure	_	PR_{H2C}	8.367
H/C molar ratio	_	H/C	3
Temperature of the Reaction	K	T_R	523
Methanol lower heating value	kJ/kg	LHV_{met}	19900
HP			
Number of the transferred electrons	_	z	2
Universal gas constant	$J/kmol$	R	8.314
Faraday constant	C/mol	F	96485
Coefficient of water activity	_	α_w	0.99
Limiting Current Density	kA/m^2	J_L	20
Cell temperature	K	T_{cell}	400
Cell pressure	bar	P_{cell}	100000
Thickness of Membrane	m	t_{mem}	50×10^{-6}
Charge transfer coefficients	_	α_C, α_a	1, 0.5
Concentration overpotential constant	_	β	0.1953
Conductivity of the Membrane	_	σ_{mem}	0.1895
Electrolyser life cycle	years	_	10
CCP			
Work duty	$kJ/molCO_2$	Q_{af}	3.960
Heat duty	$kJ/molCO_2$	Q_{bf}	32

3.2. THERMODYNAMIC MODEL

Analyses of the plant have been performed with the use of thermo-dynamic and thermoeconomic tools. The thermodynamic model is done using Engineering Equation Solver (EES) [10]. Thermophysical properties of flue gas were taken from a plant.

The energy and mass balance equations calculate by [61]:

$$\dot{Q} - \dot{W} = \sum m_{out} \cdot h_{out} - \sum m_{in} \cdot h_{in} \tag{3.4}$$

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \tag{3.5}$$

$\dot{Q}$ and $\dot{W}$ refer to the heat and the workflow, respectively. The thermal efficiency of a plant obtained and calculated by [62]:

$$\eta = \frac{W_{net}}{Q_{in}} \tag{3.6}$$

Pure CO_2 is compressed into the tank by two compressor units. The power for this process is two stages and calculated using the following Eqs. (3.7) – (3.8).

$$\dot{W}_{c1,co2} = \dot{m}_{co2}(h_2 - h_1) \tag{3.7}$$

$$\dot{W}_{c2,co2} = \dot{m}_{co2}(h_4 - h_3) \tag{3.8}$$

Where $\dot{W}$ is the power of compressors and $\dot{m}_{co2}$ is the mass flow rate of CO_2. Hydrogen generation has been done by a PEM-type electrolyzer that works at medium-level pressure (10,000kPa) and low temperature (400 K). The power consumption was calculated using Eq. (3.9).

$$\dot{W}_{C,H2} = \dot{m}_{H2}[h_6 - h_5] + [h_8 - h_7] \tag{3.9}$$

Where $\dot{m}_{H2}$ is mass flow rate of hydrogen. The total cell potential is calculated using Eq. (3.10).

$$E_{tot} = E_{rev} + E_{act} + E_{ohm} + E_{con} \tag{3.10}$$

Where E_{rev}, E_{act}, E_{ohm} and E_{con} are defined as reversible, activation, ohmic and concentration, respectively [63,64]. Reversible cell voltage was calculated using Eq. (3.11) [60].

$$E_{rev} = E_o - 85 \times 10^{-4}(T_{cell} - T_o) + 4{,}3085 \times 10^{-5}(T_{cell}) \ln\left(\frac{P_{H2}P_{O2}^{0.5}}{P_{H_2O}}\right) \tag{3.11}$$

E_o is given as $(-\Delta G/zF)$, here $-\Delta G$ refers to Gibbs energy of the reaction of water splitting, F represents Faraday's constant, and z represents the number of the transferred electrons. The activation cell voltage, ohmic cell voltage, and concentration cell voltage overpotentials were defined and calculated as follows:

$$E_{act} = \left(\frac{\alpha_a+\alpha_c}{\alpha_a\alpha_c}\right)\frac{RT_{cell}}{zF}\frac{J}{J_o} \tag{3.12}$$

R represents the universal gas constant, T_{cell} represents cell temperature, α_c and α_a are change coefficients. J_o is exchange current density and defined as follows:

$$J_o = 1.08 \times 10^{-17} \exp\,(0.086T_{cell}) \tag{3.13}$$

The ohmic cell voltage has been estimated with the use of Eq. (3.14).

$$E_{ohm} = J\,\frac{t_{mem}}{\sigma_{mem}} \tag{3.14}$$

Where σ_{mem} and t_{mem} represent membrane conductivity and thickness. Cell voltage concentration can be calculated from:

$$E_{con} = J\left(\beta\frac{J}{J_c}\right)^{\beta} \tag{3.15}$$

Where β represents a constant as cell temperature and pressure function, J_c is limiting current density [65]. The hydrogen rate was calculated using by:

$$\dot{n}_{H2} = \frac{\dot{W}_{elec}}{E_{tot} \times Fz} \tag{3.16}$$

To calculate the efficiency of the electrolyzer as follow:

$$\eta_{elec} = \frac{-DG_t}{E_{tot} \times Fz} \tag{3.17}$$

The heat load in components of a methanol plant was calculated by:

$$\dot{Q}_{heating} = \dot{Q}_{st} + \dot{Q}_{het} + \dot{Q}_{CO2} \tag{3.18}$$

$$\dot{Q}_{cooling} = \dot{Q}_{dc} + \dot{Q}_{cond} + \dot{Q}_{col} + \dot{Q}_{rea} \tag{3.19}$$

Where $\dot{Q}_{heating}$ and $\dot{Q}_{cooling}$ refer to the heat and cold utility. $\dot{Q}_{dc}$, $\dot{Q}_{st}$, $\dot{Q}_{cond}$, $\dot{Q}_{col}$, $\dot{Q}_{het}$ and $\dot{Q}_{rea}$ refer to heat loads for each distillation column, stripper, condenser, cooler, heater, and reactor, respectively. The fuel efficiency of a methanol production plant (MPP) may be expressed as follows:

$$\eta_{fuel} = \frac{\frac{m_{45}}{3600} LHV_{met}}{\dot{W}_{Renewable}} \tag{3.20}$$

The plant efficiency was calculated by:

$$\eta_{MP} = \frac{m_{45}h_{45} + m_{46}h_{46}}{(m_{30}h_{30} + m_{36}h_{36} + \dot{W}_{comp,CO2}\dot{W}_{comp,H2}) \times 3600} \tag{3.21}$$

3.3. THERMOECONOMIC ANALYSIS

The system investment cost is critical for the initial design of thermal systems [66]. In this study, a thermodynamic model is designed using the EES software program. For economic analyses, annual operation time, plant life, interest rates, and maintenance costs had been taken into consideration, in addition to the employment and operating costs.

For every component capital cost rate has been written as $\dot{Z}$ by [10]:

$$\dot{Z}_{tot,Renewable} = CRF\frac{\phi}{\tau}PEC_{tot,Renewable} \tag{3.22}$$

Where CRF is the capital recovery factor, τ represents annual operating time, ϕ represents the maintenance factor, and PEC is the equipment purchase cost for each component in the plant. CRF was calculated by Eq. (3.23):

$$CRF = \frac{i_{eff}(1+i_{eff})^n}{(1+i_{eff})^n-1} \tag{3.23}$$

In the current study, the effective interest rate (i_{eff}), the plant life (n). Assumed to be 10% for interest rate and 30 years for plant life. $PEC_{tot,Renewable}$ were calculated using Eq (3.24):

$$PEC_{tot,Renewable} = PEC_{PV} + PEC_L \tag{3.24}$$

Where $PEC_{tot,Renewable}$, PEC_{PV}, PEC_L are the equipment purchase cost for the PV panels. The PV panels cost PEC_{PV} is calculated as a function of rated power P_{PV}. The purchase equipment cost values of system components have been shown in Table 3.4.

Table 3.4. Purchase equipment costs of system components

Components	Cost Correlation	REF
PEM Electrolyser	$PEC_{elc} = 940\dot{W}_{electrolyser}$	[50]
Compressors CO_2, H_2	$PEC_{comp} = \frac{711\dot{m}}{0.9\eta_s}Pr\ln(Pr)$	[67]
CCP	$PEC_{ccp} = \frac{172.95\dot{V}_{fg}3600}{10}$	
MPP **Separator and Splitter**	$PEC_{sep} = \frac{1773\left(\frac{dailymethanol}{0.7}\right)}{350}$	[43]
Catalytic Reactor	$PEC_{sep} = \frac{6582\left(\frac{dailymethanol}{0.7}\right)}{350}$	[43]
Distillation	$PEC_{sep} = \frac{4350\left(\frac{dailymethanol}{0.7}\right)}{350}$	[43]

PV Panels	$PEC_{PV} = 1500 \times P_{PV}$	[68]
Inverter of PV panels	$PEC_{L} = 180 \times P_{PV}$	[68]

Electricity, carbon dioxide, hydrogen, and methanol product costs have been estimated with the use of Eq.'s (3.25 – 3.28) [10].

$$\dot{Z}_{elec} = \frac{\sum \dot{Z}_{tot,Renewable}}{\dot{W}_{Renewable}} \tag{3.25}$$

$$\dot{Z}_{H2} = \frac{\sum \dot{Z}_{Renewable} + \sum \dot{Z}_{elec}}{\dot{m}_{H2}} \tag{3.26}$$

$$\dot{Z}_{CO2} = \frac{\sum \dot{Z}_{CCP}}{\dot{m}_{CO2}} \tag{3.27}$$

$$\dot{Z}_{CH3OH} = \frac{\sum \dot{Z}_{Total}}{\dot{m}_{CH3OH}} \tag{3.28}$$

Where $\dot{Z}_{tot,Renewable}$, $\dot{Z}_{elec}$, and $\dot{Z}_{CCP}$ represent total cost rates of the PV plant, electrolyzer, and CCP whereas $\dot{Z}_{Total}$ represents the cost rate of the whole plant. The cost of electricity has been expressed in $/kWh, whereas other prices are expressed in units of $/kg. A comparison of different pathways of methanol production had been listed in Table3.5

Table 3.5. Comparisons of different pathways of methanol production.

Source	Methanol Production	CO_2 emissions	CO_2 reduction	Methanol production cost	Cost of plant
Blug et al. [69]	4931 t/day	N/A	N/A	0.203 $/kg	N/A
Lara Carvalho et al. [70]	N/A	N/A	N/A	0.609 $/kg	N/A
B. Ramachandra [71]	N/A	N/A	N/A	0.507 $/kg	N/A
Hank et al.[72]	29 t/day	N/A	N/A	0.617-1.64 $/kg	N/A
Mar Pérez-fortes et al.[38]	1320 t/day	1.23 t/t $_{meth}$	2 t/t $_{meth}$	0.406 $/kg	26.47 $M
Mccord et al. [73]	1020 t/day	62.08 t/h	3.32 t/h	1.37 $/kg	N/A
R. Rivera-Tinoco et al. [74]	43.83 t/day	N/A	N/A	0.904 $/kg	N/A

M.J. Bos et al. [52]	178 t/day	0.0281 t/day	N/A	0.812 $/kg	196 $M
H. Ozcan, E. Kayabasi [10]	3.694 t/day	5.75 t/day	N/A	0.532 $/kg	121636 $/y
Mohammed Soltanieh et al. [75]	625.97 t/day	N/A	N/A	0.576 $/kg	N/A
Muhammed Yousaf et al. [51]	2.645 t/day	2.965 t/t $_{meth}$	1.13 t/t $_{meth}$	0.7015 $/kg	N/A
Qian Ma et al. [53]	3972 t/day	0.333 t/t $_{methanol}$	7671 t/day	0.2429 $/kg	N/A
O.Y. Abdelaziz et al.[47]	0.6096 t/day	13.66 t/day	-0.07 t/day	0.38 $/kg	80.31 $M
Bo-Ping Ren et al.[76]	0.6645 t/day	0.2741 t/day	N/A	0.1 $/kg	11,799$M/y
Anton A. Kiss et al. [43]	274.16 t/day	0.717 t/day	N/A	N/A	N/A
Alperen T. [50]	1.674 t/day	N/A	N/A	0.693 $/kg	N/A
Current study	3136 t/day	4.890 t/day	4513 t/day	0.4129 $/kg	993 134 $/y

3.4. ENVIRONMENTAL ANALYSIS

Environmental analysis is essential for measuring the number of pollutants emitted into the atmosphere and reducing emissions can reduce environmental costs [77,78]. The processes that are related to CO_2 must decrease the emissions of CO_2 throw the atmosphere and the net amount of CO_2 emissions should be assessed.

Both between and even within the different types of primary fuels, there may be significant variations in the carbon emission factors that are used. The carbon emission factor for natural gas is dependent on the gas's composition, which consists mainly of methane but may also contain trace amounts of ethane, butane, propane, and other heavier hydro-carbons when delivered. At the production site, flared natural gas is "wet," meaning it has a higher concentration of hydrocarbons other than methane. Thus, the carbon emission factor will also change. Lightly refined products, such as gasoline, often have a lower carbon content per unit of energy than heavily refined products, such as residual fuel oil. The coal's carbon, sulphur, hydrogen, oxygen, ash, and nitrogen content has a major impact on the coal's carbon emissions per tonne.
Estimates of emissions from all combustion sources are made using the amount of fuel used and the average emission factor. The IPCC Tier 1 methodology, as shown in Eq. (3.29) [79], was used to calculate the C emissions factor from coal.

$$C_C = 32.15 - (0.234 \times H_V) \quad (3.29)$$

Where C_C represents the factor of carbon emissions in t C/TJ and H_V represents the gross calorific value of coal, with a calorific value between 31 and 37TJ/kiloton on a dry mineral matter-free basis.

The system has a significant impact on reducing GHG emissions by consuming vast quantities of carbon dioxide. The system's reliance on thermal energy, however, results in significant indirect greenhouse gas emissions. The system's CO2 mitigation can then be determined using Eq. (3.30) :

$$ER_{net} = ER_{utilization} + ER_{substitution} - ER_{generation} \quad (3.30)$$

Where ER_{net} the net amount of CO_2 emissions, $ER_{utilization}$ the amount of CO_2 used in the system processes, $ER_{substitution}$ the amount of CO_2 reduction and $ER_{generation}$ the amount of CO_2 generated by the process.

3.5. ENGINEERING EQUATION SOLVER (EES)

EES can be described as a general program equation solver which is utilized for the solution of systems of differential equations and nonlinear algebraic equations. This software is also used to solve differential and integral equations, provide uncertainty analyses, perform linear and nonlinear regression, perform optimization, convert units, check units, and create graphs.

The main advantage of EES is its highly accurate thermo-dynamic and transport possession data-base provided for hundreds of substances in a way that lets them be utilized with the equation-solving ability, where there are also basic features which are:

- Ultra-fast calculation of many equations in an instant
- Equations and coefficients may be entered in any order.
- The ability to optimize for both single and multiple variables.
- Professional 2-D, 3-D, and contour plotting with automatic updating.

- Link to Fortran, Excel, Python, C/C++, and MATLAB

There are many mathematical and thermophysical properties built into EES, and it prepares its database by classifying fluids, making its thermodynamic calculations very accurate.

To apply EES user defines the input, then the dependent variables are calculated. It can solve many basic problems in thermodynamics, heat transfer, fluid mechanics, and other more complex problems and is therefore a useful program. EES is a useful and valuable all-purpose engineering solution. In this study, EES was used to analyze and calculate the proposed system and all parts of the methanol production plant [80].

3.6. HEAT INTEGRATION

Heat integration has existed since thermal engineering began. It was first employed in oil refining crude preheat trains. In refineries, thermal energy from diverse product streams is employed to prepare crude before final heating upstream of the atmospheric column. Refineries process significant amounts of oil, therefore their product streams include a lot of heat energy. Even when energy costs were low, integrating process-stream energy made economic sense and was commonly done [81].

In its simplest form, heat integration is the process of matching heat additions and removals within a process. In this manner, the overall number of utilities that are required to execute these energy transfers can be decreased or more precisely enhanced.

Heat exchanger networks are used in many industrial processes to transfer heat between more than two process streams, heating cold streams with hot streams which need to be cooled and inversely. By recovering heat from process streams, external heating, and cooling loads (hot and cold utilities) can be drastically decreased. It is important to strike a balance between utility expenditures and investment costs for the reason that using heat exchangers for heat recovery also raises the cost of investment [82]. The best way to set up a heat exchanger network is to set up a heat recovery system or modify an existing network so that it can do the tasks required at the lowest total annual cost, which is mostly determined by the cost of utilities and the cost of initial investment [83].

There are always limits to a system's design that must be considered. Most of the time, these restrictions take the form of mechanical limitations. The 1^{st} and 2^{nd} laws of thermo-dynamics impose limitations on the design of heat exchangers and other unit processes and constrain what one can accomplish with such tools. In heat exchangers, for instance, a wide heat transfer area is needed due to the proximity of cold and hot streams. In a similar vein, the number of equilibrium stages in the distillation column increases exponentially as the reflux ratio approaches the minimal value for some particular separation. When driving forces for mass or heat exchanges are small, the required transfer equipment becomes big, and it can be said that the design has a pinch. When looking at systems with a lot of devices that exchange mass or heat (referred to as the "exchanger networks"), there will be a point where the driving force for mass or energy exchange is at its minimal value. Which shows a pinch or pinch point. Therefore, to ensure the success of designing those networks, one must locate the pinch point and use its information to design the entire network.

For a given minimum approach temperature, a general algorithm is presented that determines how many heat exchangers are needed to meet the minimum utility demands. The steps in the algorithm to solve the minimum utility (MUMNE) problem are:

- Select a minimum approach temperature.
- Create a diagram that depicts the temperature interval.
- Create a cascade diagram to find pinch temperatures and minimal utility requirements.
- Calculate the minimal number of the heat exchangers
- Construct a network of heat exchangers.

There are a total of 6 process streams in a process that requires being heated or cooled. Table 3.8 provides thermal and flow information for these. If a stream needs to be cooled, it is said to be "hot," and if it needs to be heated, it is said to be "cold." The stream's temperature has nothing to do with whether or not it is considered "hot" or "cold".

Table 3.6. Thermal Data for Streams [81]

Stream No.	Flow Type	Flow rate ṁ (kg/s)	C_p (kJ/kg °C)	ṁ*C_p (kW/°C)	T_{in} (°C)	T_{out} (°C)	$\dot{Q}$=ṁ*CpΔT (kW)
1	Hot	10	0.80	8.00	300	150	1200
2	Hot	2.500	0.80	2.00	150	50	200
3	Hot	3.000	1.00	3.00	200	50	450
4	Cold	6.250	0.80	5.00	190	290	500
5	Cold	10	0.80	8.00	90	190	800
6	Cold	4.000	1.00	4.00	40	190	600
Total							-50

The range of the minimum allowable difference in temperature between two streams going in and out of a heat exchanger is typically 5–20 C. Noting that using different temperatures will yield different results, the value of 10 °C is selected for this issue. Temperatures between 5 and 20^{o}C are typical, but it is not cast in concrete. A functional heat-exchanger network can be achieved for any value greater than zero.

All streams in a process are shown in a Diagram of temperature intervals as vertical lines, with the tenet that streams that required being cooled have been shown on the left and streams which require being heated are shown on the right. Figure 3.4 is shown a simple Diagram of temperature intervals, the right and left axes are shifted by the minimal difference of temperature selected for the problem, with the right side shifted down in comparison with the left side.

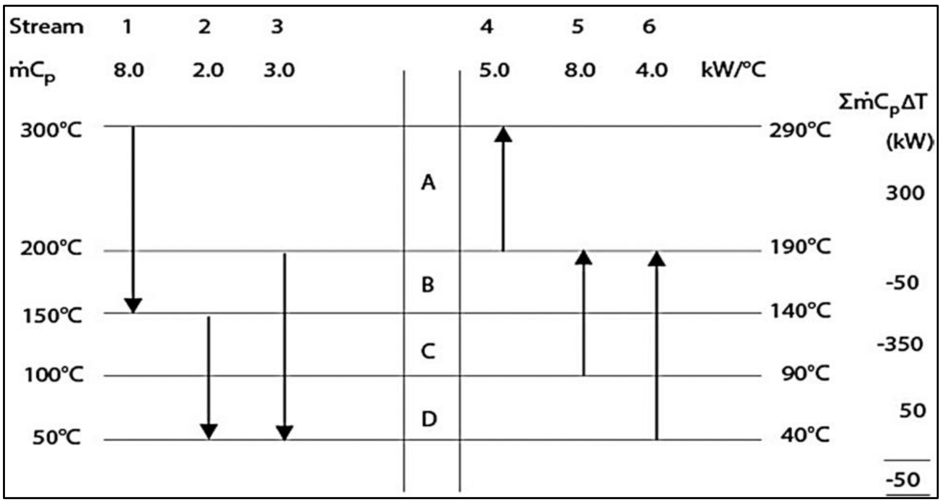

Figure 3.4. A sample Diagram of temperature intervals [81].

A vertical line with an arrow indicates a temperature change for each process stream. To make temperature interval sections, horizontal lines have been drawn through intersections. Energy surpluses are positive, and energy deficits are negative. A positive right-hand column implies that hot streams can heat cold streams. Because the minimum approach temperature constraint has lowered the cold streams, energy can transfer from the left to right in a temperature range without the violation of the second law of thermo-dynamics or constraint. The total enthalpy deficit or excess for all streams is shown in the right column as -50 kW.

The next step is to create a "cascade diagram," which is similar to the one shown in Figure 3.4, which depicts the net amount of energy in every interval of temperature. Heat is transferred down the temperature gradient if energy is plentiful. Lines a and b in the diagram represent this point. Cascading could continue below this line, but eventually, the hot utility will have to send the extra heat to the cold one, as depicted in Figure 3.5. line a–b is known as the pinch zone or the pinch temperature.

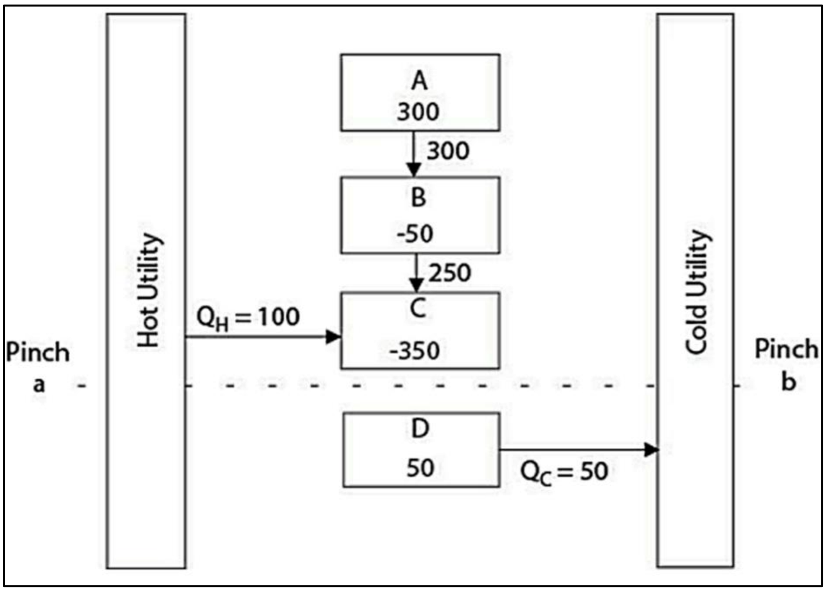

Figure 3.5. A Sample cascade diagram [81].

After the pinch temperatures are found in Step 3, the minimal number of heat exchangers needed to transfer heat for minimal utility design must be found. From this point on, systems that are above and below the pinch will be treated as two independent parts of the heat transfer problem. The hot streams and utilities are now transferring energy to the cold streams. The following relationship can be written for a problem above or below the pinch if the groups of hot and cold streams do not match:

$$\min No.of exchangers = no.of\ hot\ streams + No.of\ cold\ streams + No.of\ utility - 1 \quad (3.31)$$

As before, the systems both above and below the pinch are treated independently. The rules for matching hot streams and cold streams are:

For blocks above the pinch point:

1. Lay out a diagram of temperature intervals featuring all blocks above the pinch.
2. Start from the bottom block and go up.
3. Transfer heat from the hot side to the cold side horizontally (preferred) or diagonally down, but never diagonally up.
4. First, match the hot stream with the smallest mdot*CpΔT.

5. For streams that touch the pinch point, $mdot*Cp_{hot}$ must be ≤ $mdot*Cp_{cold}$. If it is not, split the hot stream in half or thirds.
6. Use hot utilities as soon as possible.
7. Remember the information we determined from the cascade diagram.

For blocks below the pinch point:

1. Lay out a diagram of temperature intervals featuring all blocks below the pinch.
2. Start from the top block and go down.
3. Transfer heat from the hot side to the cold side horizontally (preferred) or diagonally down, but never diagonally up.
4. First, match the hot stream with the smallest mdot*CpΔT.
5. For streams that touch the pinch point, mdot*Cphot must be ≤ mdot*Cpcold. if it is not, split the cold stream in half or thirds.
6. Use cold utilities as soon as possible.
7. Remember the information we determined from the cascade diagram.

Taking into account the logarithmic mean temperature difference (ΔT_m) and overall coefficient of heat transfer (U), the heat transfer equation can be written as:

$$Q = UA\Delta T_m \tag{3.32}$$

PART 4

RESULTS AND DISCUSSIONS

That proposed process for the synthesis of methanol by CO2 hydrogenation utilizing waste heat from an oil refinery, and the results of net power renewable ($\dot{W}_{Renewable}$), fuel efficiency (η_{fuel}), electrolyzer (η_{elec}), a methanol plant (η_{MP}), purchased equipment costs (PEC), renewable generation costs ($\dot{Z}_{tot,Renewable}$), and costs of the methanol plant, methanol production, daily CO2 capture, and hydrogen product were analyzed. The needed calculations were made using oil refinery flue gas measurement data. Below, the results calculated for the system and the results obtained will be given section by section.

4.1. THERMODYNAMIC ANALYSIS

The thermodynamic analysis is of enormous importance in making a decision about the system's behavior according to the operating pressure, operating temperature, and mass flow. Therefore, the best way to evaluate a system's operation is to take into account the parameters determined by the first and second laws of thermodynamics. This aids in providing granular details on the current state of the system.

In this section, thermodynamic analysis was obtained according to the varying mass flow rate from 27778 to 76885 (kg/h), the enthalpy 6053 to 2684 (kJ/kg), pressure 45 to 1.1 (bar), and temperature 443 to 377.9 (K) are shown in Table 4.1, the energy and material balance of the methanol production plant. The energy duties of the subsystem are represented in Table 4.2.

Table 4.1. Methanol Production Plant energy and material balance.

State	Enthalpy (kJ/kg)	Mass Flow Rate (kg/h)	Pressure (bar)	Temp. (K)
I	6053	27778	45	443
II	2456	41641	45	320
III	-740.6	939.9	45	303
IV	2372	40702	45	303
V	-646.1	220492	45	303
VI	466.4	1.095E+06	50	315.1
VII	-264.5	179792	100	293
VIII	381.9	1.275E+06	50	301.2
IX	903.7	1.275E+06	50	498
X	903.7	1.275E+06	50	498
XI	862.4	1.275E+06	50	523
XII	484.6	1.275E+06	50	366.9
XIII	328.1	1.275E+06	50	304
XIV	-465.2	207569	45.2	365.2
XV	-484	207569	5.066	360.6
XVI	-1120	130684	1.013	312
XVII	2684	76885	1.1	377.9

Table 4.2. Energy duties of the plant

Component	Value
CCP	
CCP heat load	41135 kW
CCP workload	5093 kW
HP	
Daily H_2 production	666.7 kg
Cell voltage	1.57 V
MPP	
CO_2 Compressor power	13263 kW
H_2 Compressor power	55848 kW
Cooler heat duty	55396 kW
Reactor heat duty	14637 kW
Distillation column heat duty	-44592 kW
Stripper heat duty	5352 kW
Condenser heat duty	1787 kW
Daily methanol production	3136 ton/day

Figure 4.1 concerning rising flue gas levels, this figure shows hydrogen production rises at the highest flue gas levels to be 3.442 billion (kg/day).

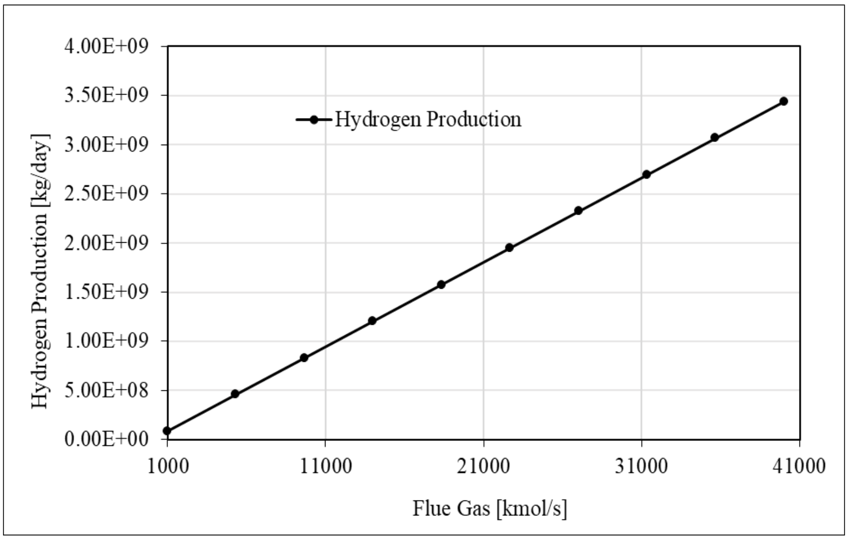

Figure 4.1. Effects of increasing flue gas on hydrogen production

Figure 4.2, shows the daily amount of carbon dioxide captured at flue gas levels during the process, where the amount of captured carbon dioxide increases with the increase in flue gas, reaching the highest level of 25.250 billion tons per day.

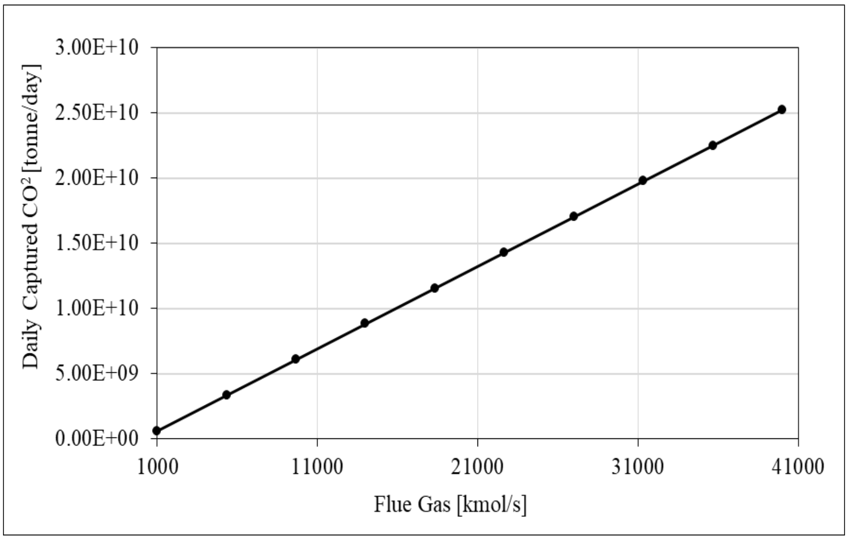

Figure 4.2. Effects of Increasing flue gas on daily captured CO_2

Figure 4.3 shows the daily amount of methanol at flue gas levels during the process, where the amount of methanol increases with the increase in flue gas, where reaching the highest level of 16,190 million tonnes per day.

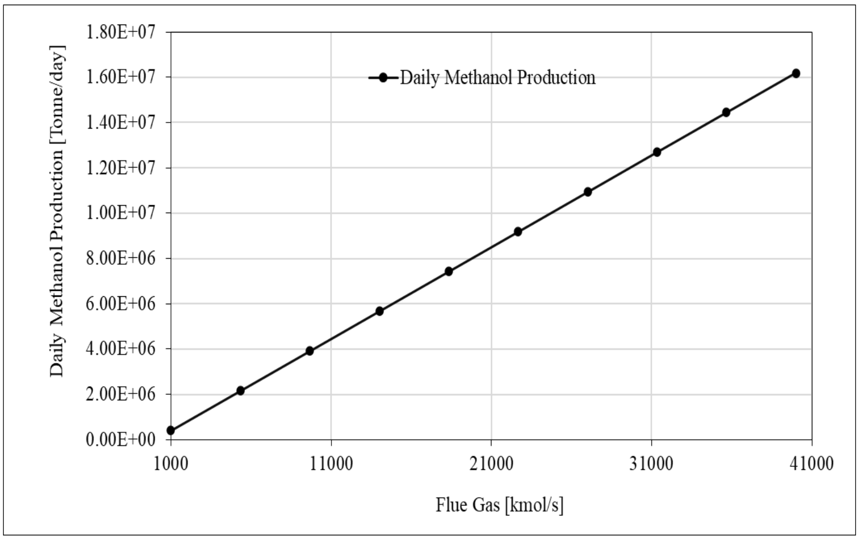

Figure 4.3. Effects of Increasing flue gas on daily methanol production.

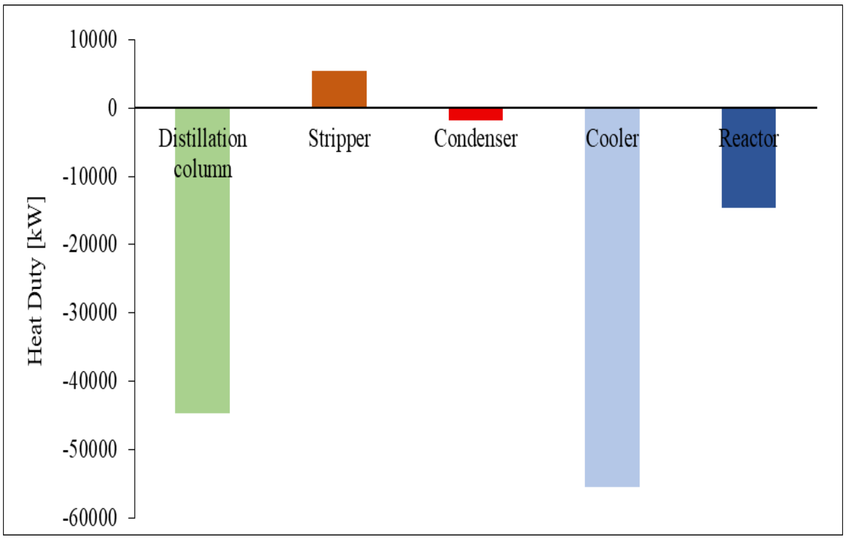

Figure 4.4. Heat duty for each unit in MPP.

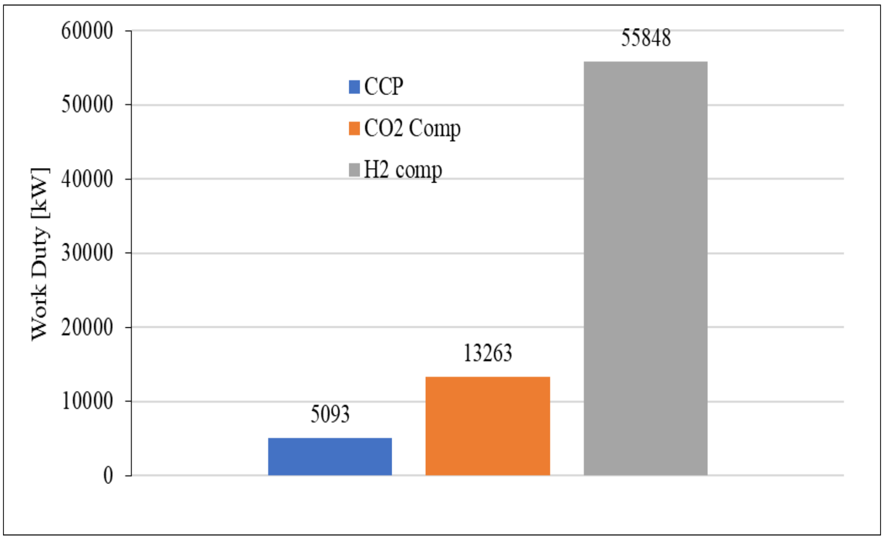

Figure 4.5. Work duty for the unit in the system.

4.2. THERMOECONOMIC ANALYSIS

A component-based cost analysis is used to figure out how much each product costs and how much it costs to run the plant each year. Costs are based on the results of a thermodynamic analysis, where power-consuming and energy-producing components are basically taken as a function of how much energy they consume or produce. Costs for CCP and MPP also depend on the size of the plant. Plant life is taken as 30 years. The main results of the economic analysis are provided in Table 4.3.

According to Figure 4.6, the cost of the plant decreases in the long run for the life of the plant, as the cost at 40 years is 10.940 billion dollars, while notice that at 30 years, the value is approximately 11.350 billion dollars, which is the period for the life of the plant that was considered in the accounts where the costs are lower at an increased life of the plant.

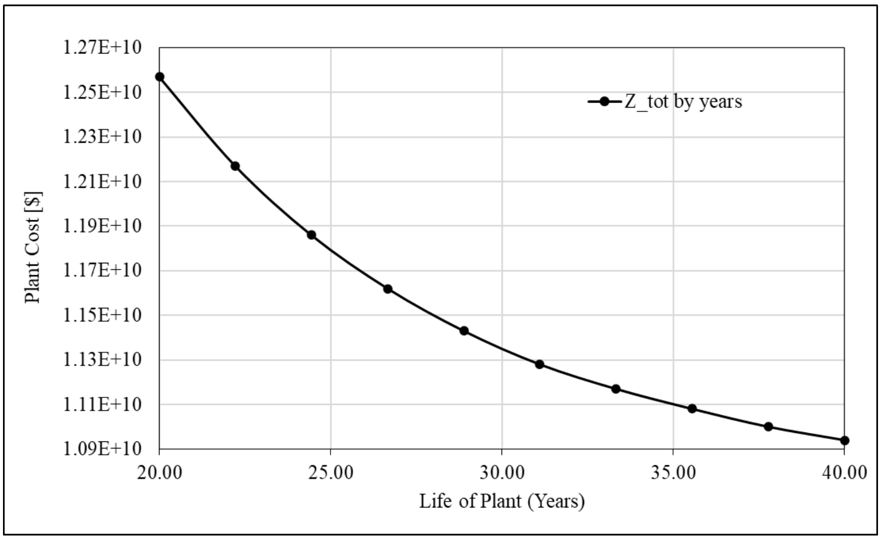

Figure 4.6. Effects of increasing the life of a plant on plant costs.

Figure 4.7, both the area of solar panels and the cost of equipment for renewable energy are shown with higher levels of flue gas; the maximum cost at $10.670 trillion, and the maximum area of solar panels is 66.190 million (m^2) at 41000 (kmol/s) of flue gas.

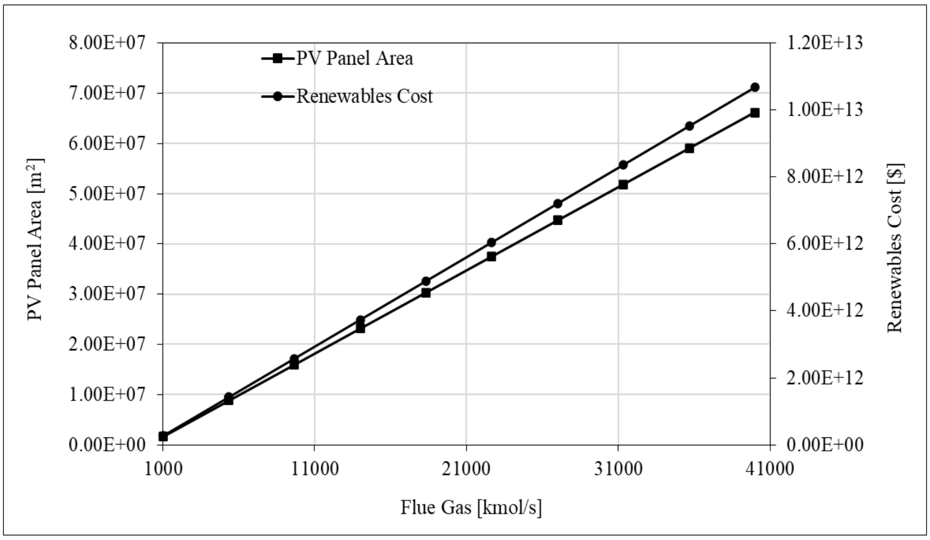

Figure 4.7. Effects of increasing flue gas on PV panel area and renewable energy costs.

Figure 4.8 depicts the total cost of renewable energy $\dot{Z}_{tot,Renewable}$ and the total cost of methanol $\dot{Z}_{Methanol}$ as the plant's life changes, with the total cost of renewable energy at point 30th of the plant's life being $9.744 per second and the cost of methanol being $0.4129 per kg, indicating that the costs decreased as the plant's life increased.

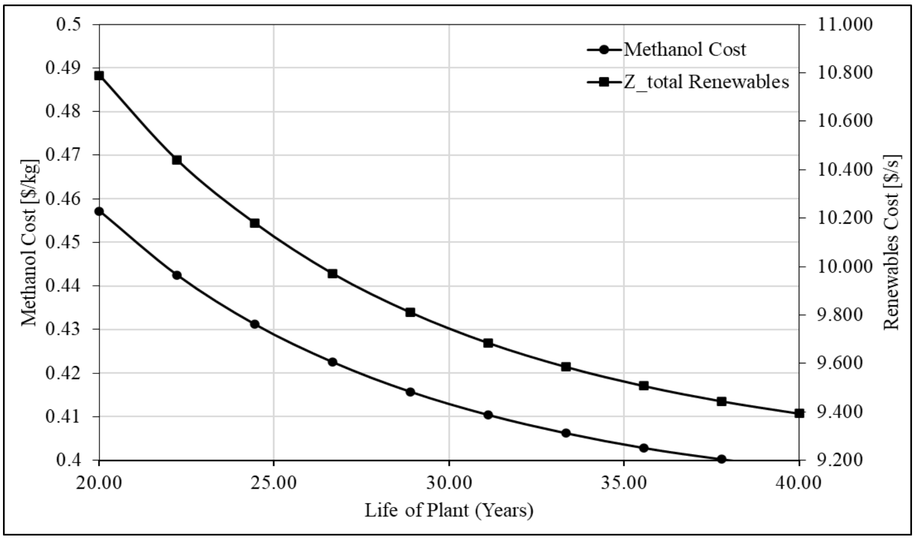

Figure 4.8. Effects of increased plant life on Methanol Costs and Total Renewable Energy Costs

Table 4.3. Economic analysis results

Parameter	Value
Renewable cost	245,6 M$/y
Electricity cost	0.02851 $/kWh
CCP cost	1,326 M$/y
Electrolyser cost	130,6 M$/y
CO_2 production cost	0.0014 $/kg
Hydrogen production cost	1.936 $/kg
MPP cost	993 134 $/y
Methanol production cost	0.4129 $/kg

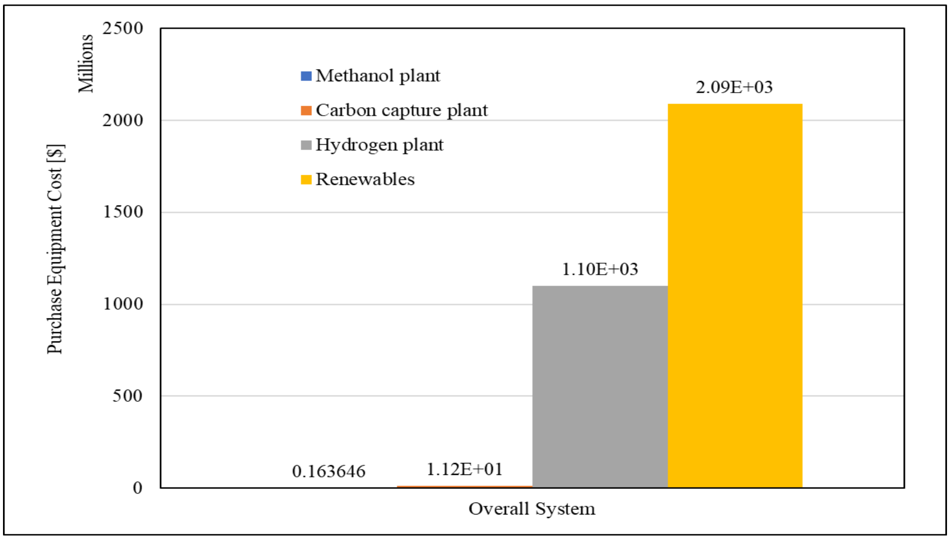

Figure 4.9. The effect of variation on the overall system's purchase equipment cost.

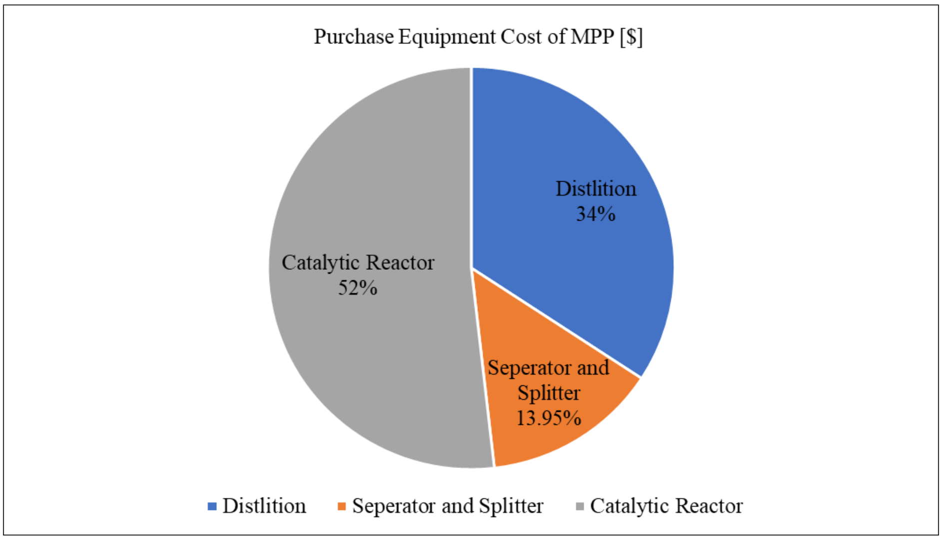

Figure 4.10. The effect of variation on purchase equipment cost for a Methanol Production Plant.

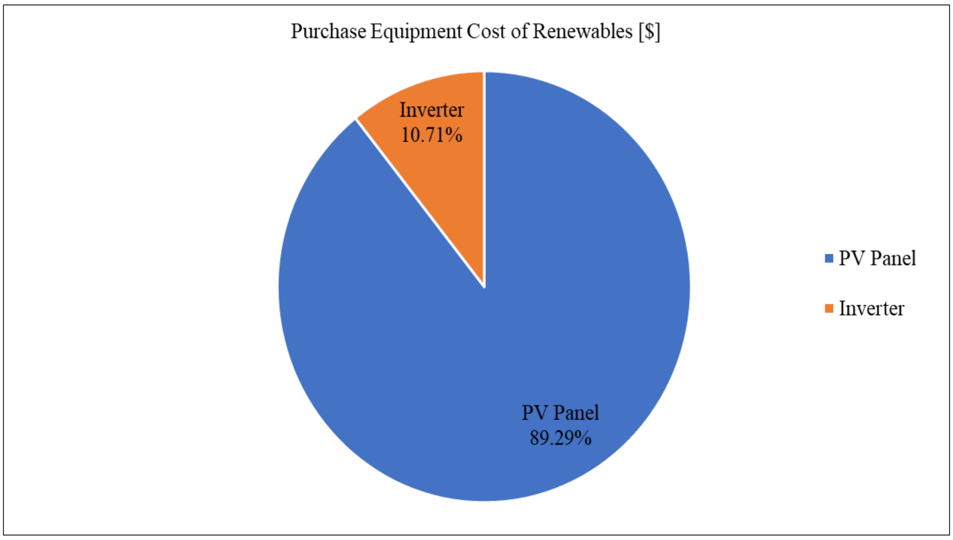

Figure 4.11. Impact of variation on the purchase equipment cost of renewables.

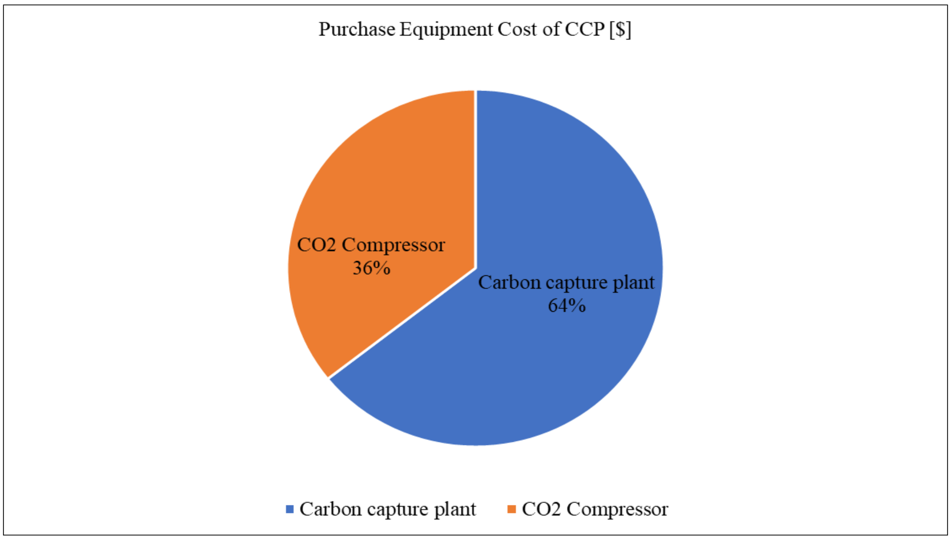

Figure 4.12. Impact of variation on the purchase of equipment cost for a carbon capture plant.

4.3. ENVIRONMENTAL ANALYSIS

In this section, we calculated the carbon dioxide emissions from the factory and their reduction in several different ways, as well as the rate of reduction before and after heat integration.

Figure 4.13, shows the relationship between flue gas levels with the emission reduction level, depending on the curvature. The maximum emission reduction is 23.300 million tons per day at the maximum flue gas level.

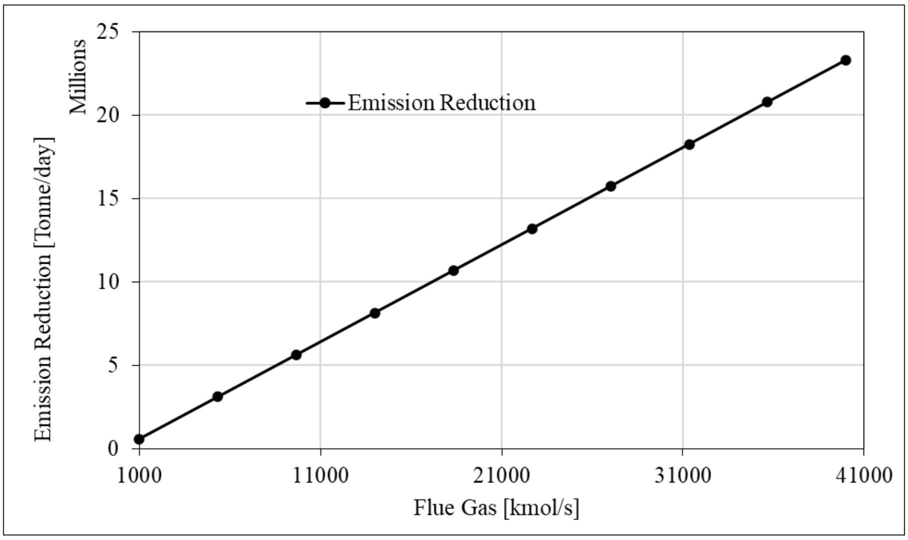

Figure 4.13. Effects of increasing flue gas on emission reduction.

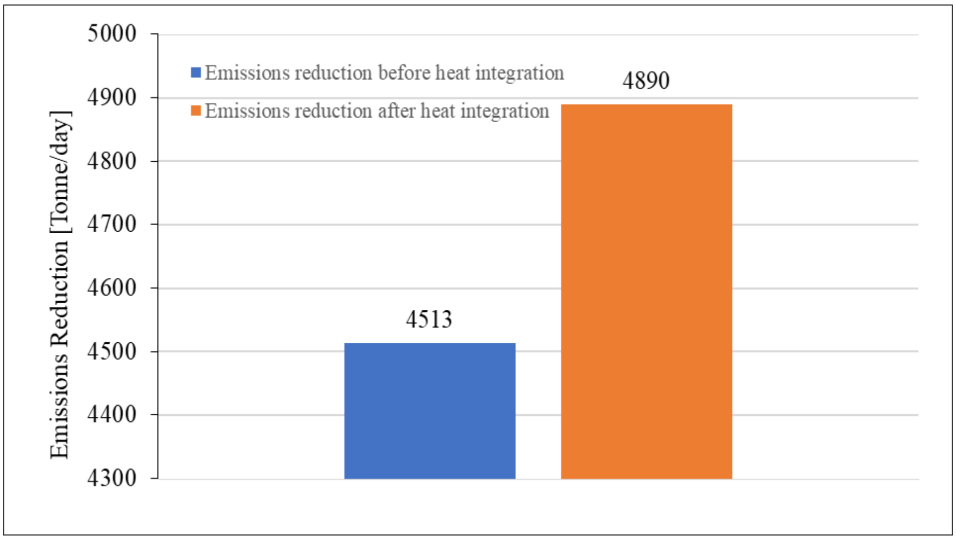

Figure 4.14. Emissions reduction before and after heat integration.

4.4. HEAT INTEGRATION

For the maximization of energy recovery and reduction of MPP system utility consumptions, the heat exchanger network has been analyzed based on the pinch theory and comprehensive guides that have been provided by [81]. The methanol production system's minimal heat transfer temperature difference (Δ Tmin), or minimum driving force for heat exchange, has been calculated to be 10°C, as shown in Table 4.4, taking into account actual operating conditions, heat exchange area, and economic benefits.

All of the streams were drawn in a Diagram of temperature intervals as vertical lines, with the streams that needed to be cooled shown on the left and the streams which needed to be heated shown on the right. Figure 4.15 shows the Diagram of temperature intervals; the left and right axes have been shifted by the minimal difference of temperature that has been selected chosen for the problem, with the right side shifted down in comparison to the left side.

Table 4.4. Thermal Data for Streams

Stream No.	**Flow Type**	**Flow rate ṁ (kg/s)**	**C_p (kJ/kg °C)**	**ṁ*C_p (kW/°C)**	***T_{in}* (°C)**	***T_{out}* (°C)**	**$\dot{Q}$=ṁ*CpΔT (kW)**
1	Hot	354	2.44	863.76	523	304	189163.44
2	Hot	12	5	60	320	303	1020
3	Cold	354	2.652	938.808	301.2	498	184757.4144
Total							5426.0256

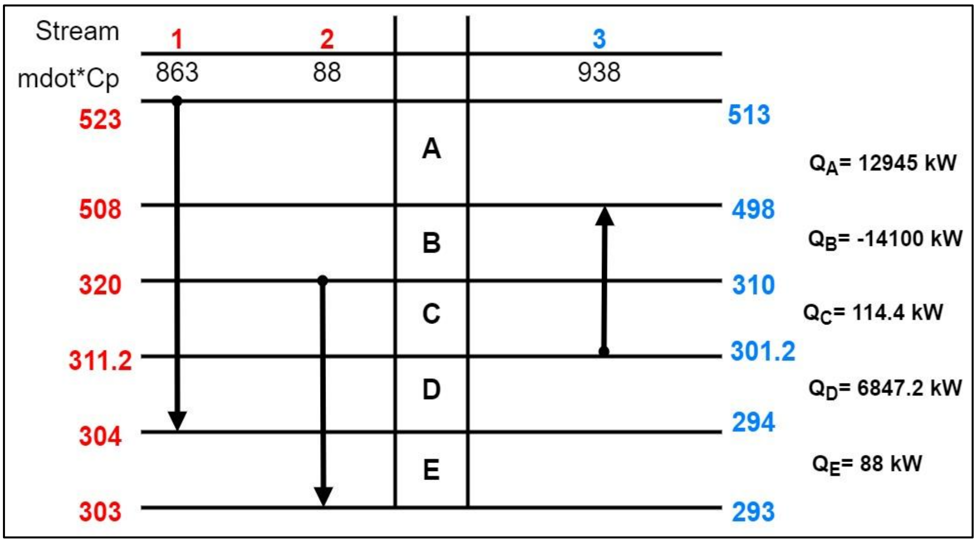

Figure 4.15. Diagram of temperature intervals

The total enthalpy excess for all streams is given in the right column as 5894.6 (kW). As shown in Figure 4.16, the net amount of energy in every interval of the temperature is 7049.6 (kW) from hot to cold. The pinch point appears at point B. Heat is transferred down the temperature gradient; if energy is plentiful, then eventually the hot utility will have to send the extra heat to the cold one.

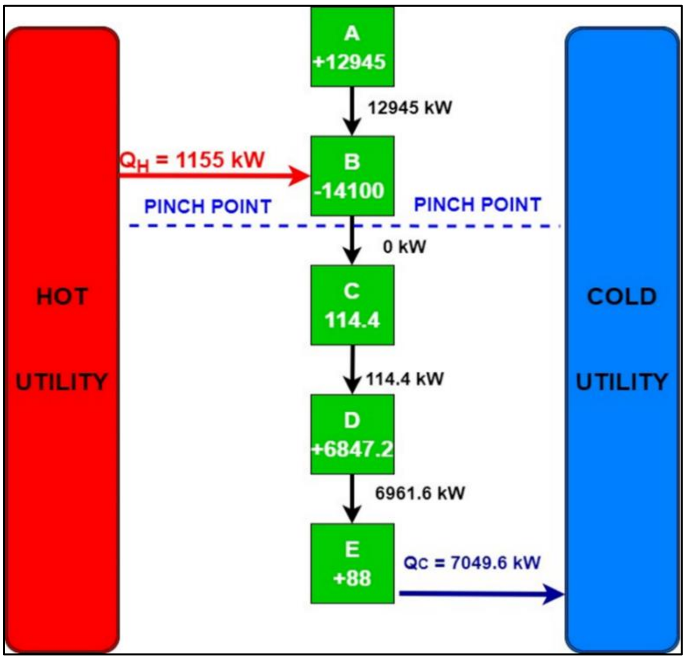

Figure 4.16. Cascade diagram

Following the heat integration process, the system's optimized heat exchanger network was determined, as shown in Figure 4.17, along with the minimal number of heat exchangers that are needed in order to transfer heat to minimum facility design.

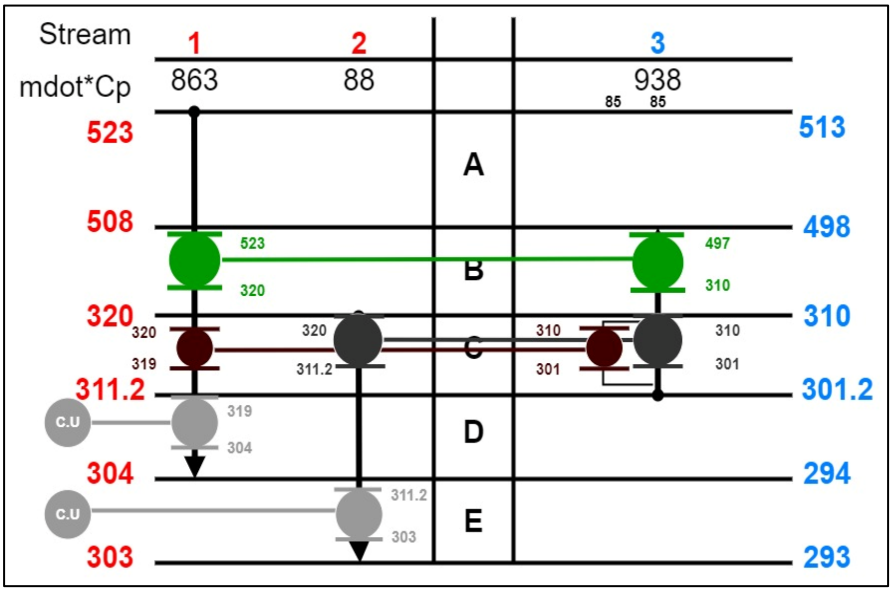

Figure 4.17. Design of heat exchanger network

By Eq. (3.32), the logarithmic average temperature difference, general heat transfer coefficient, heat transfer, and surface area for each of the process heat exchangers in networks 1, 2, and 3 were determined. Figure 4.18, shows a detailed flow diagram of the heat exchanger network, and following Table 4.3, provides a summary of these findings :

Table 4.5. Summary of findings for exchangers

Exchanger	**Δ*T*m (K)**	***U* (kW/m²$\cdot$K)**	***Q* (kW)**	***A* (m²)**
1	16.74	0.5	175189	20924
2	13.61	0.5	863	126.8
3	10.1	0.5	774.4	153.4
Total				21204.2

The final heat-exchanger network is shown in Figure 4.18. This network has the minimum number of heat exchangers, three, for the minimum utility requirements, using a minimum approach temperature, ΔT = 10°C.

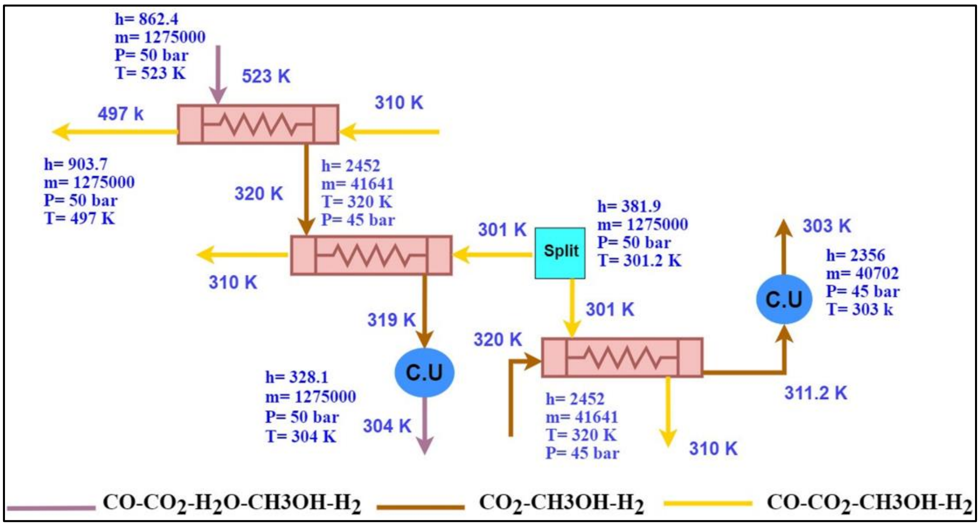

Figure 4.18. Detailed flow diagram of heat exchanger network.

PART 5

CONCLUSIONS

This study aims to a thermoeconomic analysis of a plant that produces methanol by hydrogenating carbon dioxide in the waste gas from an oil refinery using renewable energy.

The main results have been listed as follows:

- PEM electrolyzer, at 400K cell temperature and 2.2kA/m^2 current density, cell efficiency has been found at a maximal value of 0.782%. Under those conditions, the daily production of hydrogen has been observed at the value of 666683kg/day.
- The heating load of CCP has been estimated at 41153kW in the case where the H/C ratio has been assumed as stoichiometric, captured CO_2 amount has been estimated at 4890 tons/day.
- The production yield of the methanol may increase as high as 88.09% at 70 bar reaction pressure in the case where the H/C ratio is 3.
- The daily production of the methanol has been estimated to be 3136 tons/day at the optimum temperatures and pressure of the reactor.
- The MPP fuel efficiency has been estimated at 0.5872% through the consideration of the column of distillation products as beneficial outputs, whereas carbon dioxide and H_2 have been considered as key system inputs.
- The general efficiency of the plant has been estimated at 0.1626% through the consideration of the lower heating value of the methanol.
- The total plant cost for 30 years of operation is $11.350 billion, and that can result in the production of over 43.360 million tons of methanol, which corresponds to $0.4129 per kg and $412.9 per tonne.

- Environmentally, the rate of captured emissions was about 4890 tons/day, and the mitigation rate was approximately 4513 tons/day.
- Larger plants have been expected to result in the production of more cost-effective methanol, and that can, in the short-long term, result in providing better alternatives to diverse.

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RESUME

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