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ANALYTICAL STUDY FOR COMMON CO2 CAPTURE TECHNOLOGIES

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ABSTRACT

The climate change problem as a result of the escalation of carbon dioxide emissions resulting from the combustion of organic materials is one of the most important problems that call for searching for an effective way to get rid of these emissions. CO2 capture, utilization and storage has been considered as the first option to reduce the climate change phenomenon caused by the utilization of fossil fuels. There are many ways and strategies to capture of atmospheric carbon dioxide such as absorption and adsorption, membranes and chemical rings, moisture and the use of enzymes. This study aims to shed light on simulating the famous techniques used to get rid of carbon dioxide emissions in the atmosphere using the HYSYS program by taking an overview of previous research that dealt with carbon dioxide disposal technologies in order to facilitate the required modifications of these technologies to reach them To the highest possible levels of performance.

Keywords: *CO_2 capture, Emission*

Nomenclature

ASU	Air Separation Unit

CCS	CO_2 Capture Strategy
CCUS	CO_2 Capture Utilization and Storage
CLC	Chemical looping Combustion
CO_2	Carbon Dioxide
CPU	Compression and Purification Unit
DD	Down Distillation
DOE	Department of Energy
FB	Fluidized Bed
H_2S	Hydrogen Sulphide
IGCC	Integrated Gasification Combined Cycle
MEA	Mono Ethylene Amine
NG	Natural Gas
NOx	Nitrogen Oxides
PFD	Process flow diagram
SOx	Sulpher Oxides
WGS	Water Gas Shift

Introduction

Energy and environmental concerns have lately drawn worldwide attention. Although more energy from non-fossil energy sources is being developed, the main energy supply will still come from fossil fuels [1]. As a result, there is an accelerated need for the use of fair and renewable fossil fuels with minimal environmental consequences [2]. As one of the most important greenhouse gases, CO2 generated by fossil fuel combustion plays an important role in climate change. Among the various sources of pollution, coal-fired power plants are one of the most powerful sources of CO2 emissions in the world and produce nearly 2 billion tons of CO2 per year, as shown in Figure.1 [3, 4]

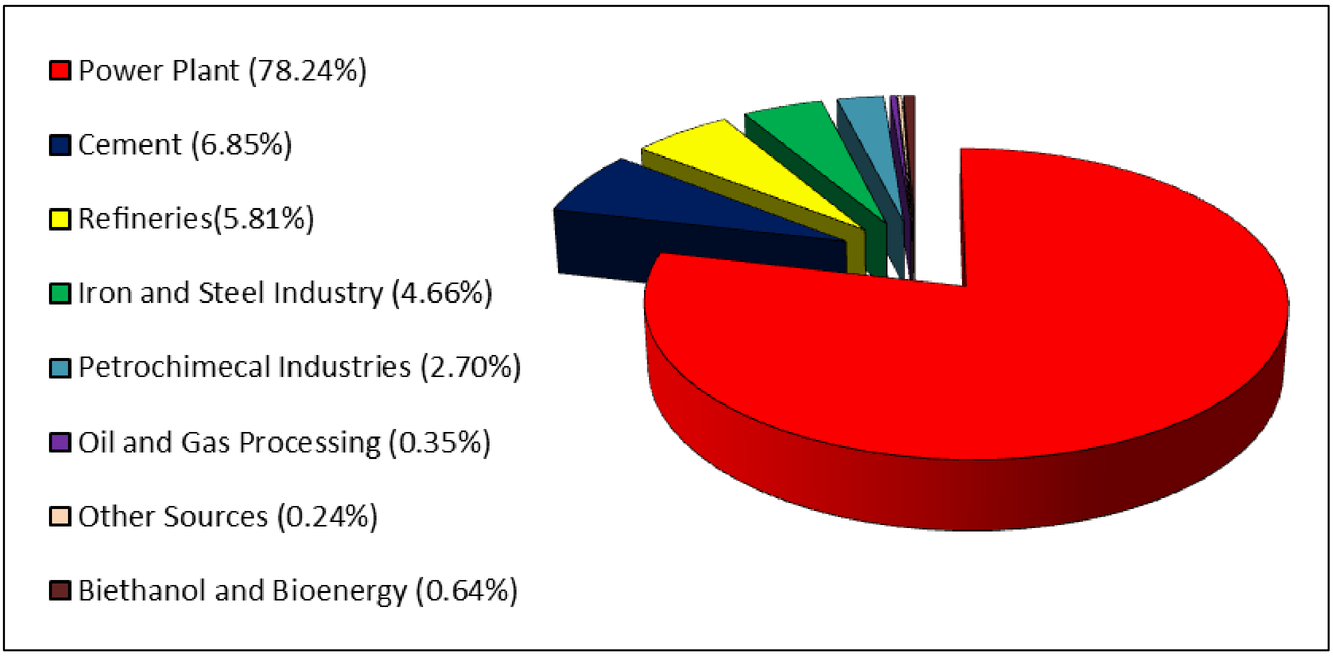


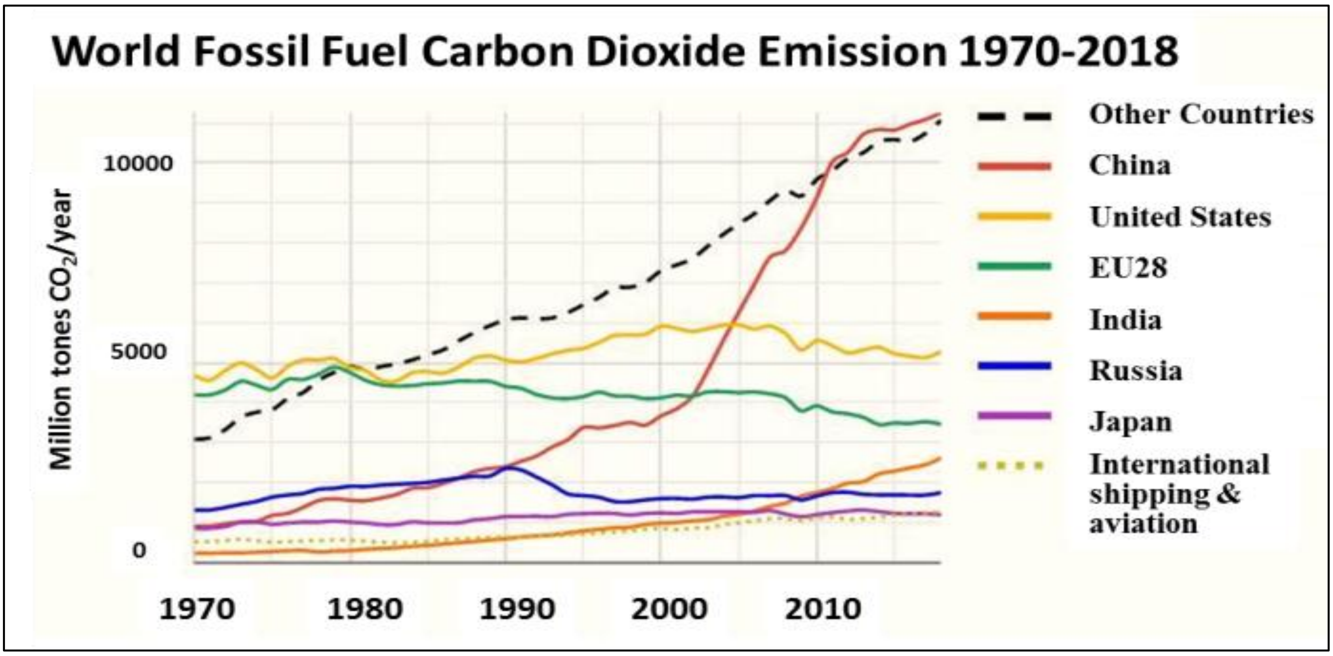
Fig. 1. Percentage of CO2 emission sources [6].

Global CO2 emissions have increased rapidly in recent decades, as shown in Figure 2. 2[1].

Fig. 2. CO2 annual emission from fuel combustion [1].

Based on the study of the Intergovernmental Panel on Climate Change, by the year 2100, the environment rising produce up to 570 ppm of CO2, leading to an increase of about 1.9 ° C in mean global temperature and an increase of about 4 m in average sea level [2]. Collecting, using and processing CO2 (CCUS) is a viable strategy to reduce CO2 pollution by collecting it from broad point sources (e.g. Building materials production factories, coal-fired power plants etc.), storing it in the porous rocks (under about 700 m underground) and reusing it for oil extraction, chemical synthesis and fertilizers, etc.[3]. Through retrofitting CO2 capture and processing systems to a conventional power plant, CO2 emissions could be lowered through about 80–90 per cent [2]. Various technologies for catching and extracting CO2 have been extensively researched by scientists, and the key issue is the creation of novel materials or frameworks that will require a minimum energy penalty and an optimum capture efficiency [4-8]. Although there are many methods for trapping CO2 from broad pollution sources (i.e. membrane, absorption, adsorption, or cryogenic, etc.), the choice of an effective capture strategy is dependent on particular discharge conditions[9]. The primary criteria are the condition of the flue gas, including its structure, size, flow rate and concentration of CO2 (i.e., the partial pressure of CO2). In contrast, the requirements for controlled output (e.g. CO2 concentration or transport pressure) and discharged criteria (e.g. H2S, SOx and NOx, etc.) also has a strong influence on the application of capture technology [10]. For instance, in order to facilitate transport and processing, CO2 capture should be condensed to more than 110 bar [11, 12]. This paper will summarize HYSYS simulation for the common CO2 capture strategies and technologies.

Common CO2 capture strategies



The major CO2 recovery techniques from fossil fuel combustion processes are pre-combustion recovery, oxy-fuel capture and post-combustion capture (as seen in Fig. 3) [13]. The selection of a CO2 capture technique is based primarily on its evaluation and on the conditions of CO2 pollution (e.g. CO2 concentration in the flue gas, gas stream pressure), as shown in Tables 1 and [13].

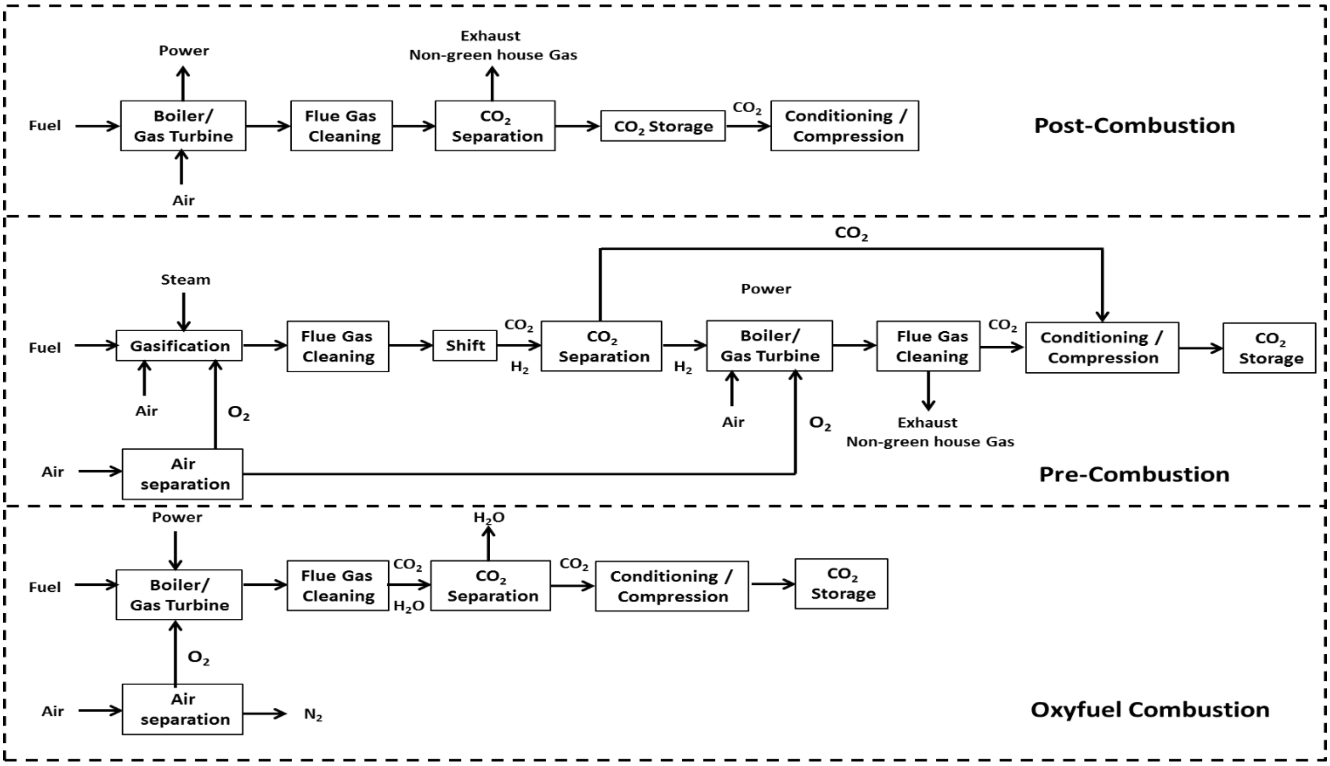


Fig. 3. CO2 mitigation strategies for fossil fuel combustion.

Table.1. Evaluation of the common CO2 capture strategies.

CO2 capture strategies	Advantages	Disadvantages	Ref.
Pre-combustion	• High CO2 concentration (~45 vol%) and pressure	• Severe operating conditions (15–20 bar and 190–210 °C)	[14, 15]

	• Commercial applied in some industrial sectors	• Energy penalty due to sorbent regeneration	
Oxy-fuel combustion	• Lower capital cost	• High efficiency drop and energy penalty due to ASU	[16, 17]
	• High CO2 concentration (80–98%)		
	• Low investment of boiler and other equipments		
Post-combustion	• Refitting a straightforward approach	• Dilute CO2 concentration (5–15 vol%) at near atmospheric pressure	[14-16, 18-22]
	• More mature than other strategies	• Energy penalty due to solvent/sorbent regeneration	

Table .2. Flue gas composition of different CO2 capture strategies.

Composition of flue gas	Pre-combustion [23, 24]	Oxy-fuel Combustion [9, 25]	Post-combustion [23, 24]
CO2	37.7%	85.0%	10–15%
N2	3.9%	5.8%	70–75%
H2O	0.14%	100 ppm	5–10%
H2	55.5%	–	–
O2	–	4.7%	3–4%
CO	1.7%	50 ppm	20 ppm

NOx	–	100 ppm	< 800 ppm
SOx	–	50 ppm	< 500 ppm
H2S	0.4%	–	–

Pre-combustion CO2 capture

In the pre-combustion capture process, fuel reacts with O2 and H2O. During the reaction, the carbon in the fuel is converted to CO2 and CO, and simultaneously, H2 is produced. After the water-gas shift (WGS) reaction, CO is converted into CO2, and the main components in the mixed gas (namely, syngas) are approximately 60–80% H2 and 20–40% CO2[7] . This capture strategy is mainly used for coal gasification in an integrated gasification combined cycle (IGCC). The significant advantage of pre-combustion is that the produced H2 is an ideal green energy source because its combustion emits no waste gas and only generates water[26]. Meanwhile, H2 can be used in many areas, such as in fuel batteries, new energy vehicles, the aerospace industry, chemical industry, etc.[27].

Oxy-fuel combustion CO2 capture

In the oxy-fuel combustion CO2 capture process, fuel combusts in pure O2, causing a high CO2 concentration (over 80%) in the flue gas, and thus, in this process the purification of CO2 is more easy than that in post-combustion strategies[28, 29]. Moreover, the NOx content in the flue gas is also lower with oxy-fuel combustion. Due to the combustion taking place in pure O2, the high temperature flue gas is often recycled to the combustor to recover waste heat. Currently, oxy-fuel combustion is usually accompanied by pulverized coal combustion, and fluidized bed (FB) combustors could be a promising alternative technology. The greatest advantage of a fluidized bed combustor over pulverized coal oxy-fuel combustion is its ability to reduce the flue gas flow for a given coal input while maintaining a high furnace temperature [29]. The greatest challenge is that the efficiency of coal-fired power plants would be reduced by 10–12% if oxy-fuel CCS utilities were retrofitted to it, due to the air separation unit (ASU) and compression and purification unit (CPU) [30]. To capture CO2 in an efficient way by oxy-fuel combustion, the energy penalty caused by the need for an ASU and CPU must be further minimized via optimization of the process and heat integration

Post-combustion CO2 capture

In the post-combustion CO2 capture process, fuel combusts in the air. In the conventional combustion process, the concentration of CO2 in the flue gas is low (typically 4–14%) of the atmospheric pressure [20]. For this reason, there is a rigorous demand for energy and equipment to enable CO2 separation and achieve the required CO2 concentration (above 95.5%) for transport and storage [18]. Compared with pre-combustion and oxy-fuel combustion, post-combustion CO2 capture units can be directly added to existing coal-fired power plants with little retrofitting, and this method has been demonstrated at some pilot-scale sites. As one of the most mature post-combustion CO2 separation technologies, the energy requirements for solvent regeneration in the (MEA) absorption process vary from 3.0 to4.5 MJ/kg CO2, which contributes to approximately 80% of the total energy consumption [19, 20]. In contrast, a target of 2 MJ/kg CO2(including both the capture and compression steps) is often mentioned in the European Union recommendations [22, 31].

Principals of CO2 capture technologies

Currently, several CO2 separation technologies are in use, such as membrane, absorption, adsorption, and cryogenic, etc. Each of these systems are focused on a number of separation standards. For this purpose, the choice of suitable technology of various sources of industrial pollutants are important for achieving high efficiencies and performance depends on different parameters (e.g. flow conditions, flue gas composition, target products and economics)[32].

Absorption

Mono-ethanolamine (MEA) absorption is the most common technique used for post-combustion CO2 recovery, with two segments of absorption and stripping / desorption, as shown in Figure. 4.

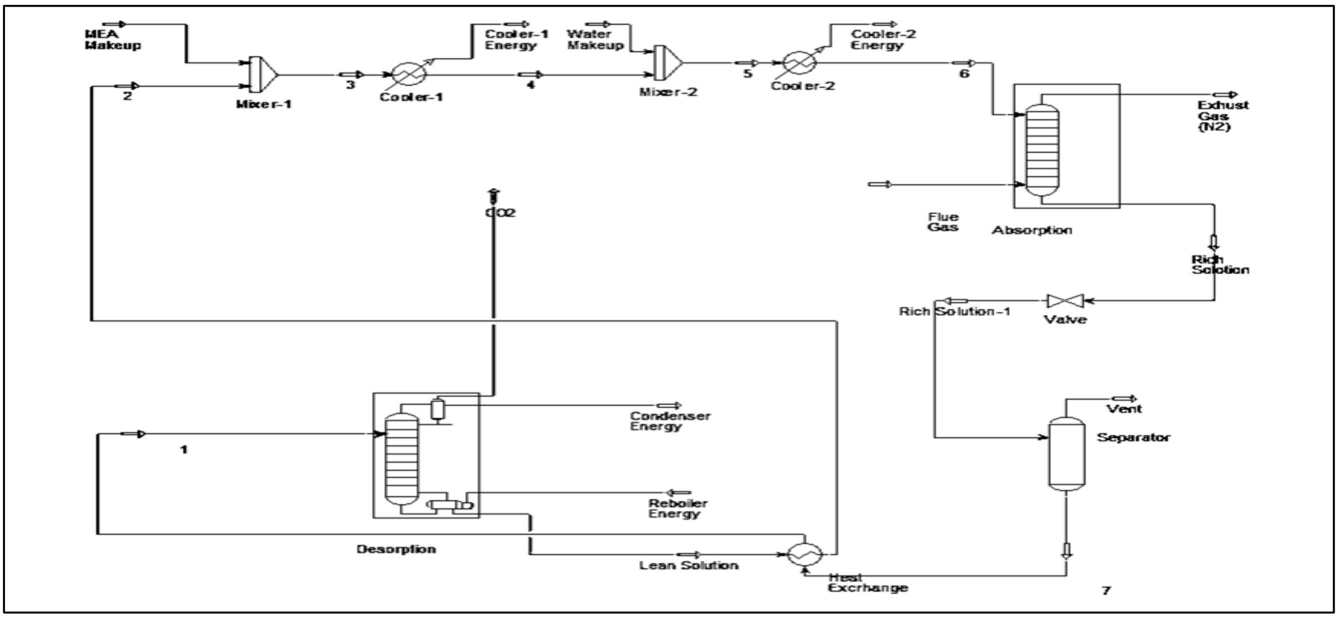


Fig. 4. PFD for chemical CO2 absorption system

It has the ability to achieve a high level of CO2 capture (more than 90%) of flue gas by rapid kinetics and strong chemical reactions. There are, however, some residual shortcomings that need to be discussed, including solvent deterioration, oxidation and solvent regeneration efficiency[33]. Amines are corrosive and susceptible to trace constituent degradation (in particular SOx) which severely restricts the application of this technology. According to the study of Rao and Rubin [34], solvent oxidation leads to about 10% of the total cost of CO2 capture. There are two main types of deterioration:

Thermal degradation which happens under situations of high temperature and strong partial CO2 concentration.

Oxidative oxidation, mostly due to the presence of a large amount of O2 in the flue gas.

Many impurity gasses (e.g. SOx and NOx) can also induce solvent oxidation. Volatile elements may be released into the air and are potentially harmful. In fact, the recovery of chemical solvents involves a significant amount of energy (approximately 4–6 MJ / kg of CO2) [35].

Adsorption

Figure. 5 indicate the standard configuration of the external adsorption of CO2. [14]

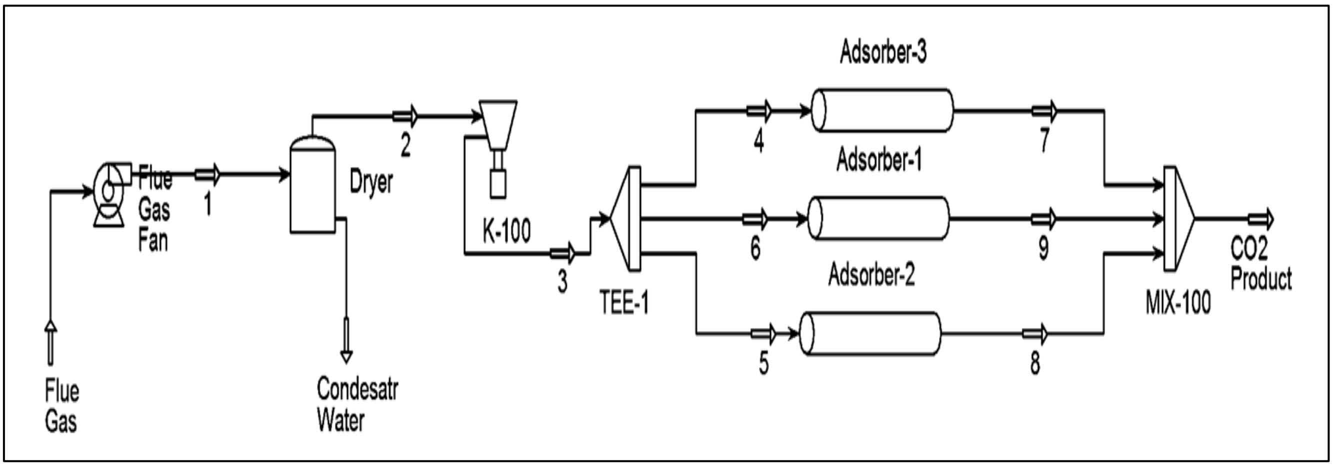


Fig. 5. PFD for the CO2 capture by adsorption proccsses

As shown in the graph, a pretreatment phase is required prior to the adsorption of CO2. Each of the adsorption chambers are filled with a strong adsorbent (i.e. activated charcoal, zeolites, or natural metal frames, etc.)[36, 37]. There are normally two or three adsorption chambers throughout the entire process, such that, during service, one chamber receives the feed for adsorption, the second chamber desorbs the CO2 collected, and the third chamber is on standby to receive the feed[38]. The device can therefore run continuously. To date, many CO2 adsorption systems are thought to be dry methods. Certain drawbacks that render this system less effective are [39-41]:

Low CO2 selectivity and efficiency in the usable adsorbents.

Poorer processing performance relative to other techniques such as absorption and cryogenics.

Recycling and reusability of adsorbents.

Membranes

Membranes are a relatively new separation technique and have been investigated for CO2 capture in recent years. As a viable option, membrane-based technology has become a competitive process for trapping CO2 due to its usability, energy efficiency and eco-friendliness [42-44]. Figure. 6 indicates a two-stage membrane separation technique utilizing most of the permeate as a sweep, where 70 per cent of the permeate from the first-stage membrane is fed to the second-stage membrane as a feed, and the remaining 30 per cent of the permeate is re-circulated as a sweep to the first-stage membrane[45], while 5 per cent of the permeate from the second-stage membrane is re-circulated as a sweep. This distribution corresponds to approximately 5% of the feed flow rate at each respective membrane stage[45].

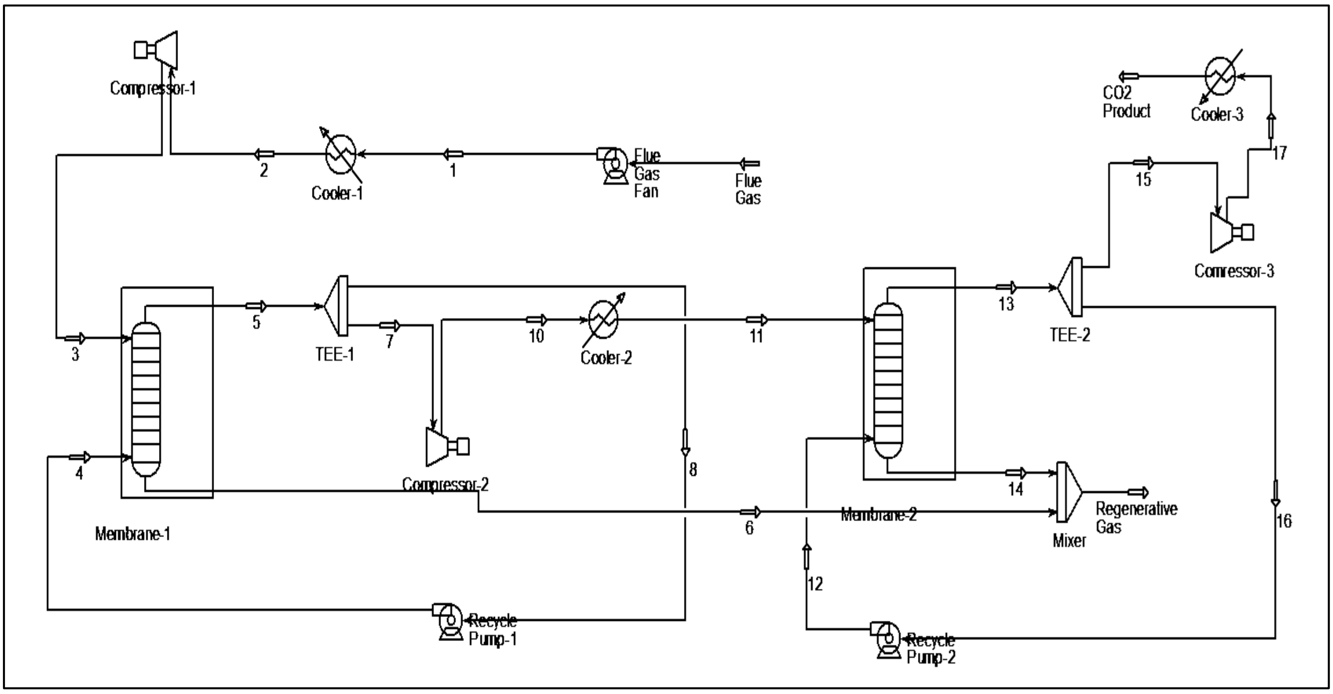


Fig. 6. PFD for the CO2 capture by membranes

Nevertheless, there are also some negative effects which hinder the final use of membranes [46-48]. First of all, membranes have specific temperature criteria. Their systems will be demolished easily as the temperature of the flue gas reaches 100 ° C [48]. In the meantime, membranes are prone to corrosive gases (e.g. SOx, NOx and H2S); thus, pre-treatment prior to membrane separation is important. Membrane performance over long-term service is difficult to maintain. Most membranes do not have longevity in the practical conditions of the industry and fail quickly, which is one of the greatest challenges for their potential application in industrial practice[49]. In addition, when the concentration of CO2 in the feed stream is diluted (below 20%), several steps and/or reuse of one of the feed streams are also needed

Chemical looping cycle

Chemical-looping combustion (CLC), suggested by Richter and Knoche [50], splits combustion into intermediate oxidation and reduction reactions, which are conducted simultaneously by a solid oxygen carrier flowing between the separate sections. Small metal oxide fragments, such as Fe2O3, NiO, CuO and Mn2O3[55,56], are ideal oxygen carriers. The simple CLC process with two reactors, one for air and gas, is shown in Figure. 7.

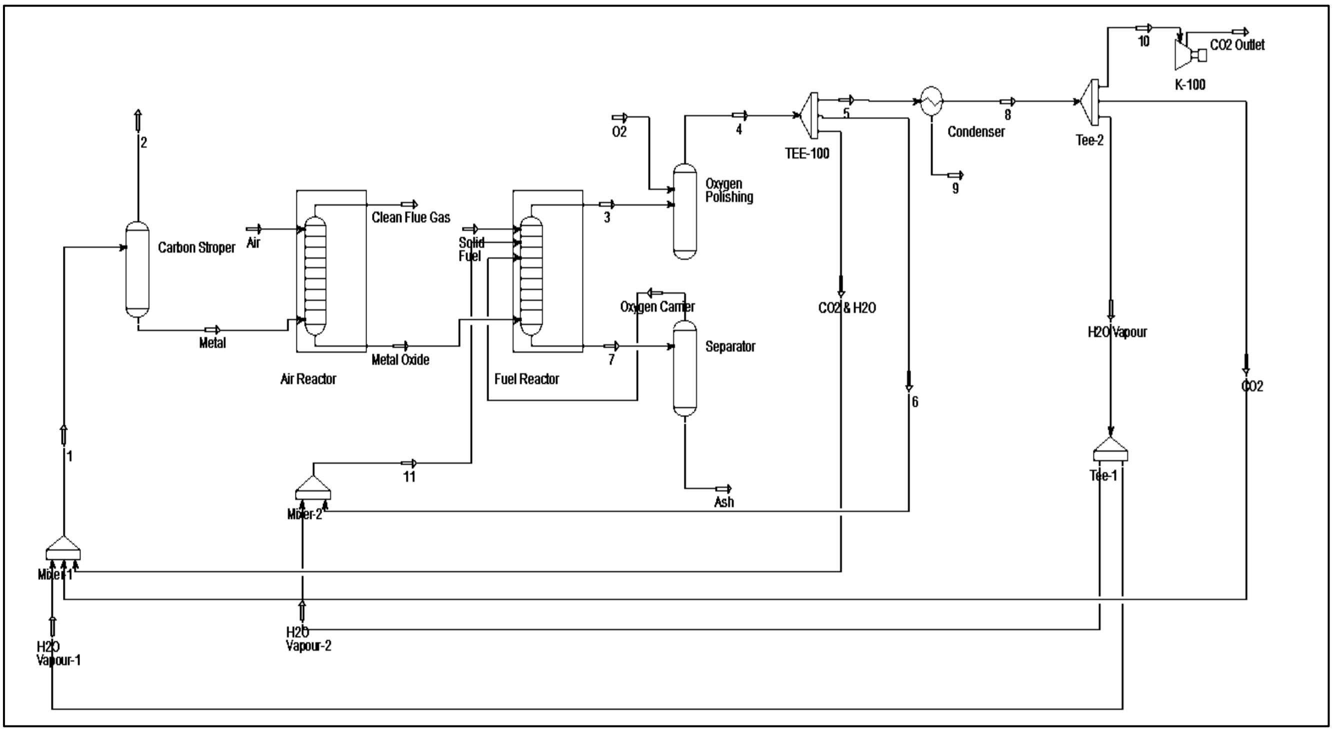


Fig. 7. PFD for the CO2 capture from by CLC process.

The oxygen carrier is circulating between the reactors. The carrier is oxidized by hydrogen in the water reactor. The metal oxide in the fuel reactor is reduced by the fuel that is oxidized to CO2 and H2O. The key benefits of CLC can be summed up as[13, 51]:

The exhaust gas from the air reactor is primarily N2 and is therefore innocuous.

The fuel reactor exhaust gas stream is composed of CO2 and H2O; thus, the CO2 can be easily separated by a condenser that avoids the energy penalty of the traditional absorption technology and reduces the capital cost.

Currently, the majority of CLC processes have been tested only on a laboratory scale, and there are few large-scale demonstrations of this technology. In the meantime, some significant problems persist throughout existing processes (e.g. loss of stabilization of the oxygen carrier and poor redox kinetics)[52]. In fact, desulfurization of the fuel is also necessary in order to stop the carrier from sulfating

Microalgae

At present, CO2 bio-fixation through microalgae has gained tremendous traction due to its high photosynthetic efficiency, which makes it possible to bio-fix CO2 more efficiently than in terrestrial plants[53, 54]. A description method for the fixation of CO2 microalgae and the processing of biodiesel is presented in Figure. 8. The microalgae capture system has the following benefits[55-57]:

It is an environmentally sustainable method;

This makes direct use of solar energy.

It co-produces high-value substances from biomass, such as human food and animal feed.

Due to a lack of awareness of the microalgae CO2 fixation cycle, many problems are usually ignored (such as the need for an inorganic nutrient supply and the intense resources used in the production, processing and drying of microalgae biomass)[58-60]. The implications of these limitations will contribute to a negative CO2 and energy balance for the life-cycle of the biodiesel output from microalgae. Apart from that, the poor CO2 solubility in water is another issue that needs more study.

CONCLUSION

There are many ways and strategies to get rid of atmospheric carbon dioxide such as absorption and adsorption, membranes and chemical rings, moisture and the use of enzymes. This paper aims to shed light on simulating the famous techniques used for CO2 Capturing from atmosphere using the HYSYS program by taking an overview of previous research that dealt with carbon dioxide disposal technologies in order to facilitate the required modifications of these technologies to reach them To the highest possible levels of performance.

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