Evaluating the Performance of Multiple Carbon Capture Technologies of Hot Potassium Carbonate (HPC) and Monoethanolamine (MEA)

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Abstract: *Carbon capture is a technology that captures CO_2 emissions from power generation and industrial activities to reduce global warming. Post-combustion absorption technologies stand out as some of the most commercially viable methods for CO_2 capture. The main objective of this study is to compare the two processes of carbon capture technologies for both Monoethanolamine (MEA) and Potassium carbonate (K_2CO_3) systems through comprehensive simulations using ASPEN HYSYS software. Results demonstrate significant CO_2 emission reductions for both technologies, with MEA outperforming HPC. While MEA exhibits higher CO_2 capture rates, HPC presents advantages in toxicity and regeneration energy requirements. The key results obtained from analyzing the two systems yield an annual capture of 944.9 ktone CO_2/year for MEA and 534.7 ktone CO_2/year for HPC. The findings offer valuable insights for policymakers and industry stakeholders in promoting sustainable energy transitions.*

Keywords: Carbon capture **;** Amine-based capture; Hot potassium carbonate ; Iraq

1. INTRODUCTION

1.1 Background

Ranked as the fifth most vulnerable country to climate change, Iraq confronts environmental and energy challenges that significantly affect its stability and prosperity [1]. The oil and gas sector activities in the southern region have significantly contributed to exacerbating pollution as a side effect of urbanization and industrialization in the country [2]. To achieve ambitious emission reduction targets, a comprehensive strategy is necessary. This should include energy efficiency measures, the adoption of renewable energy sources, the use of nuclear power, and the implementation of carbon capture, storage, and utilization technologies (CCUS). CCUS is essential for significantly reducing CO_2 emissions from major stationary sources like power plants, which are expected to continue relying on fossil fuels for the foreseeable future [3]. The basic process involves capturing the released carbon dioxide and compressing it into a dense liquid for more accessible storage and transportation [4]. This compressed CO_2 is then either injected into underground reservoirs or utilized in the production of various chemicals. In countries like Australia, where a large portion of electricity is generated from high CO_2 intensity fuels such as coal, natural gas, and oil, adopting CCUS is crucial for reducing emissions [5]. The primary barrier to the widespread adoption of carbon capture technology is its cost [6], [7]. Over the past few decades, carbon capture, utilization, and storage (CCUS) have regained attention in managing industrial flue gases [8]. Beyond cost, CO_2 capture technologies face challenges due to their potential adverse environmental impacts [9]. Integrating capture plants into power generation reduces the overall global warming potential [10]. However, some capture technologies may increase additional environmental impacts, such as eutrophication potential and acidification [11]. By retrofitting existing fossil fuel-based facilities with these technologies, we can significantly reduce emissions and contribute to the transition towards net-zero emissions [12].

1.2 Retrofitting of carbon capture technologies

There are several techniques for removing CO_2 from power plants. The three primary types of carbon capture systems are post-combustion capture, pre-combustion capture, and oxy-fuel combustion capture [13] methods for capturing CO_2 after combustion include membrane separation, adsorption, absorption, and cryogenic procedures. As of right now, absorption is the only commercially available technique; alternative approaches are still in the research and development stage [14]. Chemical solvent absorption is the most widely studied and feasible method for large-scale deployment [15]. The absorption of CO_2 using amines or carbonate-bicarbonate buffers has attracted a lot of interest among absorbents [16], [17]. Reducing carbon dioxide (CO_2) emissions in current industrial and power facilities is made possible by carbon capture using an amine-based solvent method [18]. The main and most well-known first-generation amine-based absorbent is monoethanolamine (MEA), which is distinguished by its low manufacturing costs and strong CO_2 reactivity [19]. By eliminating the emissions of MEA degradation and lowering the energy required for CO_2 removal, the hot potassium carbonate (HPC) process—which uses a comparatively safe capture solvent—was selected over the MEA process in terms of environmental impact [20]. In practical use, MEA technology can attain capture rates that surpass 90% when required, although at a little greater cost for individual captures [21]. The extra health and environmental advantages of low-carbon energy technology, such as fewer fatalities from air pollution and less damage to ecosystems, have been pivotal in advocating for CO_2 emission reduction policies [22].

1.3 Management of the Co-Pollutants

Managing co-pollutants is crucial for maintaining the efficiency, integrity, and longevity of capture systems. The impact of co-pollutants on amine-based capture systems is significant, affecting both the efficacy of the capture process and the overall operation of the system. Co-pollutants, including NOx, SO2, and PM2.5, necessitate exhaust gas pretreatment to prevent reduced capture efficacy, system contamination, and the formation of harmful compounds like nitrosamines [23]. Conventional amine-based solvents like monoethanolamine (MEA) can deteriorate when exposed to impurities present in flue gases, such as (O_2, SO_x, and NO_x). This degradation process can lead to the formation of harmful compounds like nitrosamines, which may be released into the environment [9]. Co-pollutants can also physically clog and contaminate the system, challenging compliance with regulatory standards. When compared to benchmark amine-based solvents like MEA, HPC offers several advantages. These include lower heat of absorption, affordability, reduced toxicity, minimal solvent losses, absence of thermal and oxidative deprivation, and no development of heat-stable salts [24]. During the regeneration phase of an amine-based absorption system, introducing a cold stream into the top section of the stripper column helps lower the condenser duty by cooling the upward vapor. This heat exchange process reduces the energy needed for regeneration overall. The cold stream benefits from the heat of the ascending hot vapor, thereby decreasing the demand on the reboiler system. Unlike amine-based systems, Hot Potassium carbonate-based capture technology doesn't employ a lean/rich cross-heat exchanger. Instead of temperature swing, desorption in Hot Potassium Carbonate-based systems relies on pressure swing. Consequently, the split stream is introduced to the stripper column at the same temperature but at a different stage pressure. As this split portion enters a lower section of the column, its residence time decreases, leading to a lower level of decarbonization and adversely affecting the overall carbon capture effectiveness [23].

2. METHODOLOGY

A detailed simulation of two carbon capture processes from a natural gas combined cycle (NGCC) power plant is performed, using the plant as a case study for the CO2 source. The technologies examined are the amine-based capture technology (MEA) and the hot potassium carbonate capture technology (HPC), with simulations conducted using ASPEN HYSYS [25] software to show the differences in the emission reduction applied to the Al-Hartha power plant in southern Iraq. Fig. 1 Shows the methodological framework.

3. RESULTS

Both the MEA and HPC processes rely on the absorption of CO_2 from flue gases. Within the absorber column, a solvent (either MEA or HPC) captures the CO_2, allowing CO_2-lean flue gas to exit the system. Subsequently, in the stripper column, the solvent undergoes regeneration, leading to CO_2 desorption. Carbon dioxide desorbed from the stripper column exits with an elevated purity and goes through compression and liquefaction before being transported to a permanent storage site. In the monoethanolamine process, absorption and desorption

occur due to temperature variations, known as temperature swings. During absorption, low temperatures prevail, whereas heat is introduced during the desorption phase. This is typically achieved by utilizing condensing steam at temperatures ranging from 120 to 130°C to facilitate solvent regeneration.
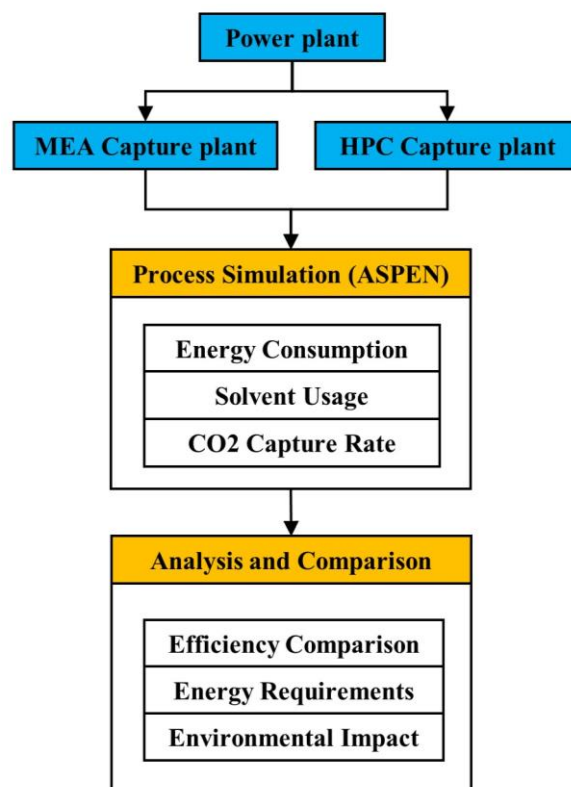

Fig. 1. Methodological framework.

Conversely, the Hot Potassium Carbonate method utilizes a pressure-swing system to aid in absorption and desorption. Absorption happens under increased pressure, while desorption occurs at a reduced pressure level. As a result, compressing the flue gas is necessary for absorption, leading to an electricity requirement. While heat is also needed for solvent regeneration in the Hot Potassium Carbonate technique, it generally requires slightly lesser amounts compared to the monoethanolamine process. An internal heat recuperation system, utilizing flashy boxes, can be integrated to meet the heat requirement of the HPC method without depending on external steam sources [26]. Both processes are based on similar equipment, including desorption and absorption columns, as well as a Carbon dioxide conditioning plant. Consequently, they can be expected to have nearly equivalent cost of investment [27]. Both processes utilize similar equipment, such as desorption and absorption columns, along with a Carbon dioxide conditioning plant. Therefore, it can be inferred that they possess roughly equivalent investment costs. The primary equipment distinctions lie in the Hot potassium carbonate flue gas compressor and the marginally larger reboiler heat exchanger in the monoethanolamine (MEA) method. A comprehensive assessment reveals significant reductions in CO_2 emissions for the MEA and HPC of (944.9, 534.7) kt/year for the two technologies, respectively, due to the adoption of carbon capture technologies in the Hartha

power plant. Applying the two capture designs, the annual avoided carbon capture quantities are shown in Table 1. The primary drawback of capture technology using an aqueous solution of potassium carbonate (K_2CO_3) is its lower rate of CO_2 absorption compared to amine solutions like MEA and MDEA [28], [29]. However, potassium carbonate is deemed more appealing as a wet chemical absorbent due to its lower toxicity and corrosion potential compared to amines. Additionally, it requires fewer energy inputs for regeneration, enhancing its feasibility [30].

Table .1 Avoided emissions table (t/y).

Capture technology	CO_2
MEA	944,900
HPC	534,700

3.1 Retrofitting of HPC carbon capture technology

The process of Hot Potassium Carbonate (HPC) capture technology begins with cooling and compressing the flue gases, enhancing the efficiency of CO_2 absorption in the absorber. In this stage, the HPC solvent captures CO_2 from the flue gases. Subsequently, the solvent undergoes regeneration in the desorber through the reversible reaction:

$$K_2CO_3 + CO_2 + H_2O \leftrightarrow 2KHCO_3$$

The CO2-rich solvent (KHCO3) is then pumped into a desorber (or stripper) column. Here, through the application of heat, the reverse reaction occurs:

$$KHCO_3 \rightarrow K_2CO_3 + CO_2 + H_2O$$
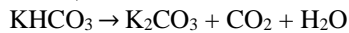
This step regenerates the potassium carbonate solvent and releases CO2 in a concentrated form. The regenerated solvent is then recycled back to the absorber for reuse. Fig. 2. Shows the simulation diagram of the suggested capture plants in Aspen HYSYS ver.14.
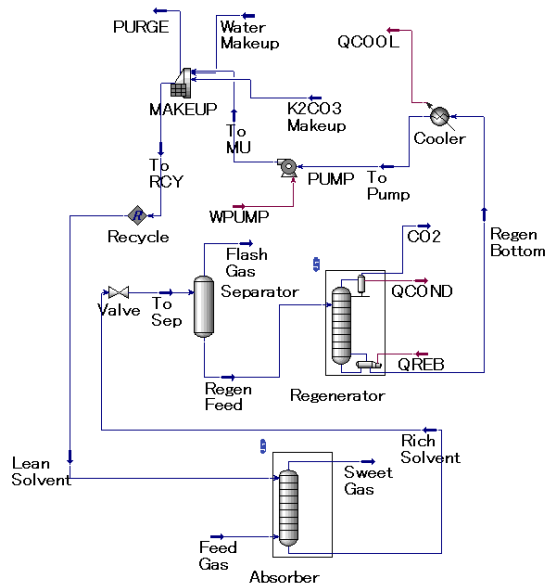

Fig. 2. Shows the simulation diagram of the HPC capture process in Aspen HYSYS ver.14.

Expanding the CO2-depleted flue gases through an expander allows for the recovery of a significant portion of the compression energy. The heat extracted from both the flue gas and the product CO_2 streams is internally utilized within the capture system. The presence of water and CO_2 can lead to the formation of corrosive species. Appropriate materials and corrosion inhibitors are necessary to ensure the longevity of the equipment[31]. Effective heat management is crucial to maintain the energy efficiency of the process. This requires careful design of heat exchangers and integration systems[32]. The HPC process involves multiple stages of gas-liquid contact, heat exchange, and pressure manipulation, necessitating sophisticated control systems for optimal operation [32]. Hot Potassium Carbonate (HPC) capture technology is a robust and efficient method for CO2 removal from industrial flue gases. Its advantages in terms of absorption efficiency, solvent regeneration ability, and energy recovery make it a promising option for reducing greenhouse gas emissions in various sectors. However, careful attention to material selection, heat management, and operational control is essential to fully realize its potential benefits. Table 2. shows the key simulation HPC assumptions and results of the stripper and absorber columns.

Table 2. Simulation assumptions of HPC and results of the stripper and absorber columns

Absorber Column Parameter	Lean solvent	Feed Gas	Sweet Gas	Rich solvent
Mass Flow [Mt/y]	7.008	1.752	0.876	7.884
Pressure [bar]	21.7	21.7	21.7	21.7
Temperature [C]	93.4	130	126.3	139.4
Composition [mole %]				
CO_2	0.046	0.259	0.134	0.102
K_2CO_3	0.146	0	0	0.140
Packing vendor	GENERIC			
Diameter, m	3.658			
Packing type	PALL			
Packing dimension	1.5 in or 38 MM			
Tray spacing,m	12.19			
Start stage	1			
End Stage	10			

Regenerator Column Parameter	Regen Feed	CO_2
Mass Flow [Mt/y]	7.008	0.39
Pressure [kPa]	1.84	1.7
Temperature [C]	115.48	50
Composition [mole %]		
CO_2	0.0856	0.9263
K_2CO_3	0.144	0
Packing vendor	GENERIC	
Diameter, m	3.658	
Packing type	PALL	
Packing dimension	2-IN OR 50-MM	
Tray spacing,m	9.144	
Start stage	1	
End Stage	10	
CO_2 removal efficiency (%)	98.65	
Reboiler duty kJ/hr	1E+8	

a Aspen HYSYS process simulation [25]

3.2 Retrofitting of MEA carbon capture technology

In the MEA (Monoethanolamine) process, the treated gas, which contains CO_2, is directed into the absorber unit. Within the absorber, the CO_2 undergoes a chemical reaction with the MEA solvent, leading to its absorption. As a result, the solvent becomes CO_2-rich. The solvent enriched with CO_2, exiting the absorber, is subsequently pumped into an internal heat exchanger, where it undergoes preheating before being introduced into the regeneration column. Preheating the solvent ensures optimal conditions for the subsequent regeneration process. Within the regeneration column, heat is applied to the CO_2-rich solvent. This heat causes the CO_2 to be released from the solvent, a process known as desorption or stripping. The CO_2 exits from the regeneration column's top in a concentrated form. Following desorption, the CO_2 undergoes compression in a series of units to achieve the required conditions for utilization, storage, or transportation. To maintain the efficiency of the process, makeup streams containing water and monoethanolamine are added to the reutilized stream[33]. These streams replace any losses of solvent and ensure consistent performance of the MEA absorption and regeneration cycles. Fig. 3. Shows the simulation diagram of the suggested capture plants in Aspen HYSYS ver.14. Table 3. shows the key simulation assumptions and results of the absorber and stripper columns.

Table 3. Simulation assumptions of MEA and results of the stripper and absorber columns

| Absorber Column Variable	Flue Gas	Lean solvent	Rich solvent	Clean gas
Mass Flow [Mt/y]	26.28	17.52	17.52	17.52
Pressure [bar]	1.08	1.08	1.05	1
Temperature [C]	40	37	66.68	35
Composition [mole %]				
CO_2	0.023	0.013	0.036	0.001
MEA	0	0.114	0.096	0
Section Height, m	**Section 1** = 5 **Section2** =20			
Diameter, m	**Section 1** = 15 **Section2** =20			
Packing type	Mellapak250Y			
Start stage - End Stage	1-5, 6 - 25			
Stripper Column Variable	Rich Solvent	Outflow	Distilled water	Bottom
Mass Flow [Mt/y]	17.52	0.944	1.752	17.52
Pressure [bar]	1.08	1	1	1.5
Temperature [C]	70	35	35	104
Composition [mole %]				
CO_2	0.036	0.942	0.002	0.013
MEA	0.096	0	0.001	0.114
Section Height, m	25			
Diameter, m	12			
Packing type	Mellapak250Y			
Start stage - End Stage	1 - 25			
Reboiler duty kJ/hr	2.614 E+07			
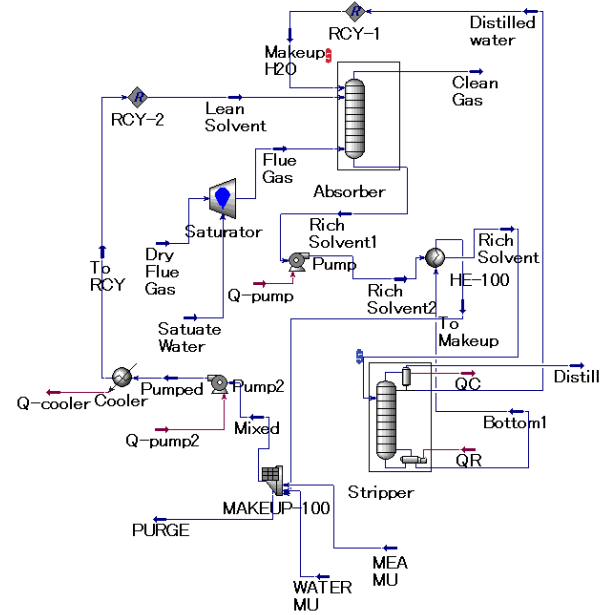
Fig. 3. Shows the simulation diagram of the MEA capture process in Aspen HYSYS ver.14.

4. CONCLUSION

In conclusion, this study has provided a comprehensive evaluation of carbon capture, utilization, and storage (CCUS) technologies in southern Iraq, focusing on the comparison between amine-based capture (MEA) and hot potassium carbonate (HPC) processes. By utilizing Aspen HYSYS for simulations and the Hartha power plant as a case study, significant insights have been gained regarding the performance and potential adoption of these technologies.

The results demonstrate substantial CO_2 emission reductions achievable through both MEA and HPC technologies, with MEA exhibiting higher capture rates compared to HPC. Nevertheless, it's essential to recognize that each technology comes with its distinct array of benefits and obstacles. MEA, while offering superior capture rates, comes with concerns regarding toxicity and regeneration energy requirements. According to the results, the MEA capture technology is able to avoid 410.2 kt CO_2/y more emission than HPC technology from the power plant. On the other hand, HPC shows promise in terms of reduced environmental impact and energy consumption during regeneration.

The findings of this study carry implications for policymakers and industry stakeholders aiming to promote sustainable energy transitions in the region. By understanding the nuances of each technology and their respective performance metrics, informed decisions can be made regarding the implementation of CCUS strategies in southern Iraq.

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