DESIGN SIMULATION ANALYSIS OF MULTIPLE COMPONENT MIXTURE OF CO$_2$ CAPTURE AND PURIFICATION MECHANISMS

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ABSTRACT

Oil recovery may be increased by reusing and reinjecting collected and purified CO$_2$ from the generated gas of CO$_2$ flooding, which can also be used for geological storage of CO$_2$. One single CO$_2$ capture and purification system cannot handle the annual growth and large-scale fluctuation in CO$_2$ content in the generated gas with the operation and progress of the CO$_2$ flooding development mode. This research proposes four methods for capturing and purifying CO$_2$ from oil and gas fields in order to help the development of CO$_2$-EOR technology. One-stage membrane separation one-stage hydramine technique, two-stage membrane separation one-stage hydramine method, and one-stage membrane separation two-stage hydramine method are all included in this procedure. And HYSYS software was used to do simulations based on CO$_2$ flooding operating condition data from one particular oilfield. Aside from these factors, the enrichment degree of the CO$_2$ gathered and purified by various methods, as well as its energy consumption and economics, were examined in detail. The following are the findings of the study. Because of the need to achieve the needed purity for reinjected gas when the gas's CO$_2$ content is low, the two-stage alcohol-amine circulation mechanisms must first be put into production before the deacidification of natural gas can be completed. Membrane separation technology is preferable to two-stage alcohol amine circulation methods as CO$_2$ concentrations rise, so that the purified and enriched gas may meet CO$_2$ purity requirements for re-injection. As a consequence of the study findings, engineers may use them to create a strategy for enriching and purifying CO$_2$ from CO$_2$ flooding gas.

Keywords: Membrane separation; Hydramine absorption; CO$_2$ capture; CO$_2$ flooding; Deacidification; Reinjection; Geological storage; HYSYS software

0. INTRODUCTION

Carbon capture and storage (CCS) technology has been increasingly contributing to global cumulative CO$_2$ emissions reduction [1]. As one of the CCS technologies, CO$_2$ flooding of medium-to low-permeability reservoirs can not only enhance oil recovery (EOR), but also realize the geological storage of CO$_2$, so it is a winewin technology with good economic benefit [2,3]. CO$_2$-EOR technology emerged in the 1950s and was commercially promoted in the United States and Australia in the 1980s [1e4]. In the CO$_2$-EOR mechanisms of oil and gas fields, CO$_2$ content in the produced gas increases. So, capturing and purifying CO$_2$ in the

produced gas sufficiently to realize its recycling and reinjection can yet be regarded as an economic and efficient development mode suitable for medium-to low-permeability reservoirs [4].

Globally, a key measure to deal with the great variation of CO_2 content in the gas produced during CO_2-EOR is the membrane separation technology [5,6]. The Honeywell UOPSeparex™ membrane mechanisms is reported to have a daily natural gas mechanisms capacity of 700 $10^4 m^3$ [7]. The membrane separation technology is superior in purifying acid gas containing CO_2 with a large range of variation and at moderate and high value, so it is called the most potential gas separation technology developed in the 1970s [8]. It doesn't involve phase change, and is low energy consumption, easily maintainable, and highly automatic, with no moving devices, making it simple and reliable to operate [9e11]. It is commonly used for rough mechanisms of high-concentration acid gas. However, the hollow fiber membrane of permeable membrane module may be contaminated easily by impurities, so the premechanisms cost is high. The membrane module should be replaced periodically after the equipment is put into operation. Kentish [8] stated that most academic researches currently focus on the research and development of new membrane materials [1_2,13], but the key to reduce the application cost of this technology is to design a reasonable technical mechanisms.

During CO_2-EOR of oil and gas fields in China, hydramine liquid absorption and generation method (referred to as the "hydramine method") and hydramine liquid absorptione regeneration þ pressure swing adsorption (PSA) þ low-temperature separation method are adopted to deal with a great variation of CO_2 content in the produced gas [14,15]. Hydramine method, which has the advantages of high removal efficiency, simple operation and high economic adaptability, is applicable to the mixed gas with lower CO_2 content [$16e_2$1] and is widely applied in petroleum and petrochemical fields at home and abroad, but its regeneration heat load is higher [16]. PSA is considered as a new cost-effective separation method, and it is widely applied in flue gas capture [$2$1,22], but regeneration of its adsorption medium needs large energy consumption. Low-temperature separation is to realize gas separation according to the principle that gases have different condensate phase behaviors, but it is energy-consuming and costly, so it has been rarely applied in the industry [$2$3,$2$4].

Ma et al. [15] compared the produced gas disposal schemes and CO_2 capture and reinjection mechanismses in oil and gas fields with CO_2 flooding. They proposed that the hydramine method is used when the CO_2 content of produced gas is lower than 40%, the membrane separation or low-temperature separation method is used or, for the sake of cost saving, direct reinjection or rejection after mixing with high-purity CO_2 is adopted when the CO_2 content is higher than 70%, and the PSA method is recommended when the CO_2 content fluctuates greatly. However, it is still uncertain that which scheme above mentioned is acceptable for CO_2 flooding with huge injection size, where the produced gas contains a great varying CO_2 content and a certain amount of H_2S. Ling et al. [$2$5] set up a test bench for CO_2eCH_4 separation by arranging the membrane separation technology (hollow fiber membrane) and traditional chemical hydramine method in series. The test results prove that this combined method is applicable to the mechanisms with high disposal rate and low decarbonization efficiency. Limited by test conditions, however, Ling's study did not analyze the application of two-stage membrane or two stage hydramine technology [$2$5].

This paper puts forward four schemes of Multiple Component CO_2 capture and purification mechanisms and simulates the mechanisms at a CO_2 content of 11.9% and 60.01% by using the HYSYS software. In addition, the enrichment degree of CO_2 captured and purified and the energy consumption and economics under four schemes are analyzed. The study results can provide technical support for the promotion of CO_2-EOR in oil and gas fields.

1. CAPTURING AND PURIFYING CO_2 USING MANY COMPONENTS

Membrane separation uses pressure to separate gases based on their varying permeability to a hollow fiber separation membrane. Rough separation of input gas with CO_2 concentration more than 40% may be achieved using this method. Hydrogen sulfide (H_2S) and high levels of carbon dioxide (CO_2) make the hydramine technique unsuitable in most cases, although it may be used in low-CO_2 settings. We suggest four strategies of CO_2 capture and purification based on the research of Ling [$2$5], as well as the membrane separation technology and the hydramine technique, for an oil and gas field that produces more than $_2$83.$_2$ 104 m3/d and includes CO_2 (3.7 percent e60 percent) and stable H_2S.

When the CO_2 level is minimal, the hydramine procedure is not necessary since the generated gas from this oil and gas field has a certain quantity of H_2S. Membrane separation is paired with hydramine in a series, which is preferable in the case of high mechanical rates [$2$5], to accommodate the increasing production of gas and CO_2 with time.. In other words, the decarbonization efficiency may be improved by increasing the mechanistic phases of the hydramine technique or membrane separation. Analysis should be used to establish the number of membrane separation and hydramine stages that should be used in the process. As shown in Table 1 (Scheme 1), there are four options: two-stage hydramine technique (Scheme 1), one stage membrane separation (Scheme $_2$), two stages membrane separation (Scheme 3), and one stage one-stage membrane separation hydramine method (Scheme 4). (Scheme 4). Through one-stage or two-stage membranes, input gas with a greater concentration of CO_2 is approximately separated in Schemes $_2$, 3 and 4.

Table 1 Four CO_2 capture and purification techniques.

No.	Scheme	Characteristics
1	Two-stage hydramine method	Two stages of hydramine circulation are used to circulate the pre-mechanized feed gas. The acid gas (H_2S and CO_2) in the input gas is partially eliminated in stage 1 hydramine circulation. It's at this point when H_2S is reduced even more, and CO_2 levels are elevated.
2	One-stage membrane separation þ one-stage hydramine method	One stage hydramine circulation unit is used to remove acid gases from the high-pressure side of the hollow fiber membrane module, where the pre-mechanismized input gas flows into the module and CO_2 enriches the permeation side. On the permeation side of membrane separation, acid gas exiting the regeneration tower combines with CO_2 to produce rejected CO_2.
3	Two-stage membrane separation þ one-stage hydramine method	The pre-mechanized input gas enters the two-stage membrane unit, where CO_2 is enhanced on the permeation side and residual generated gas goes into stage 2 membrane separation on the high-pressure side. In the second step of membrane penetration, enhanced CO_2 is combined for reinjection. A one-stage hydramine unit processes the acid content of natural gas after it exits the high-pressure side of the two-stage membrane unit.
4	One-stage membrane separation þ two-stage hydramine method	Carbon dioxide (CO_2) is enriched on the permeation side of the one-stage membrane unit, and residual generated gas is sent to a two-stage hydramine unit for separation. The first-stage regeneration tower's acid gas flows into the stage 2 hydramine circulation unit, and the absorption tower's CO_2 gas is combined with the permeation side's CO_2 from the top. Thus, CO_2 is reinjected.

Under four different scenarios, simulations were run using HYSYS (V10.0) to examine the CO_2 enrichment degree, energy consumption, and economics of capturing and purifying low and high concentrations of CO_2 (61.01 percent). Table 2 shows the gas compositions in two examples. The gas generated has a temperature of 64.9_2 C and a pressure of 6_279 kPa. The reinjected gas must have a CO_2 concentration of at least 95%. In Figs. 1e4 four strategies are shown as simplified mechanics.

2. SETTING PARAMETERS FOR THE SIMULATION AND TESTING THE MODULES

In order to accurately compare mechanisms schemes, HYSYS mechanisms simulation requires specifying parameters and testing modules. Hydramine mechanisms and the membrane module are among the modules to be tested in the simulation, which includes setting the equation of state, the kind of hydramine solution, the parameters of the adsorption and regeneration towers, and the parameters of the membrane module.

Table 2 Compositions of produced gas by CO_2 flooding.

Composition	Case 1	Case 2
C_1	55.15%	$_23.33\%$
C_2	11.48%	4.86%
C_3	9.95%	$4._21\%$
iC_4	1.88%	0.80%
nC_4	3.41%	1.44%
iC_5	0.99%	$0.4_2\%$
nC_5	0.98%	0.39%
C_6	0.63%	$0._27\%$

H$_2$S	3.00%	3.00%
CO$_2$	11.90%	61.01%
N$_2$	0.63%	0.$_2$7%
Total	100.00%	100.00%

2.1.   Equation of state

Soave-RedilichKwong (SRK) equation of state and PengRobinson (PR) equation of state are commonly employed in oil and gas mechanisms and refineries. Hydramine processes, on the other hand, include non-ideal solutions, such as acid gases, hydrocarbon molecules, and alcohols, which constitute a non-ideal chemical system under high pressure. It was decided to simulate processes using the Acid Gas-Chemical Solvent equation of state from HYSYS (V10.0) [27]. PR equation of state and electrolyte nonrandom double solution activity coefficient model are used to construct acid gas-chemical solvent equation of state. Considering the amine solution's chemical characteristics, the hydramine process may be accurately simulated.... Note that HYSYS may automatically propose the Acid Gas-Chemical Solvent equation of state if the composition list contains any kind of amine solution when the fluid package is constructed in the early stages of simulation. In addition, it is clear that the penetration processes of acid and hydrocarbon gases in the membrane module may be described by this equation of state.

2.2.   Type of hydramine solution

Acid gas reacts with hydramine solution, and the process may be stopped by adding a little amount of acid. Hydramine processes may be improved by altering the flow of absorption and regeneration. Decarbonization efficiency can only be improved with the use of the correct hydramine solution. As a result of their high volatility, primary and secondary amine solution concentrations in common hydramine solutions may be as low as 15% and 30%, respectively, and their selective recovery is challenging since they both react with H$_2$S and CO$_2$. While the tertiary amine solution has a concentration range of 45 to 60 percent, its circulation and regeneration energy consumption is lower. The reaction rate of CO$_2$ is much lower than that of H$_2$S, making it more selective to H$_2$S than CO$_2$. In order to lower the cost of equipment, the concentration of tertiary amine solution may be raised, but the suggested maximum limit corresponding to the solvent type must not be exceeded for equipment corrosion. There are two types of solutions that may be used as absorbents: the mixture of MEDA and DEA, both of which are tertiary ammonia solutions. Low corrosion, minimal regeneration energy consumption, low solvent loss, and strong thermal and chemical stability are only some of the benefits of using MDEA. Furthermore, it may selectively eliminate H$_2$S when a considerable quantity of CO$_2$ is not absorbed, allowing for effective CO$_2$ enrichment [28].
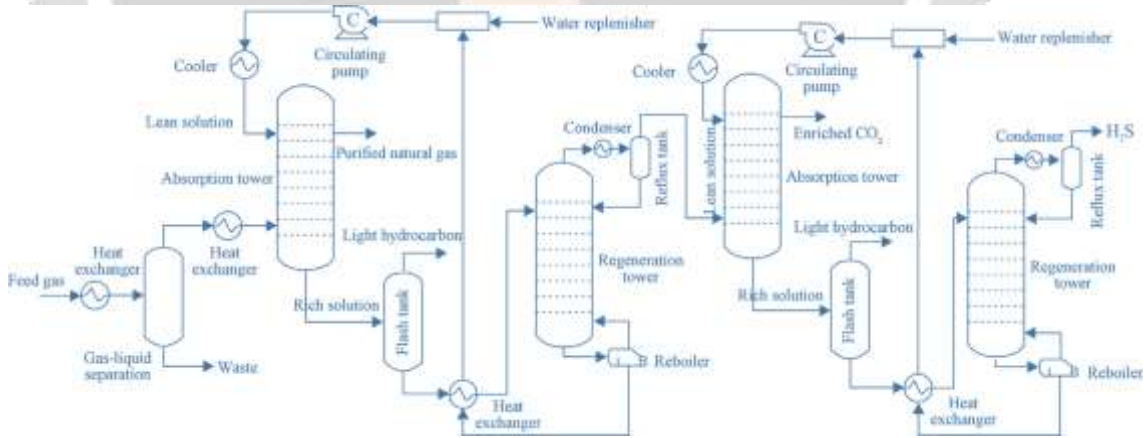

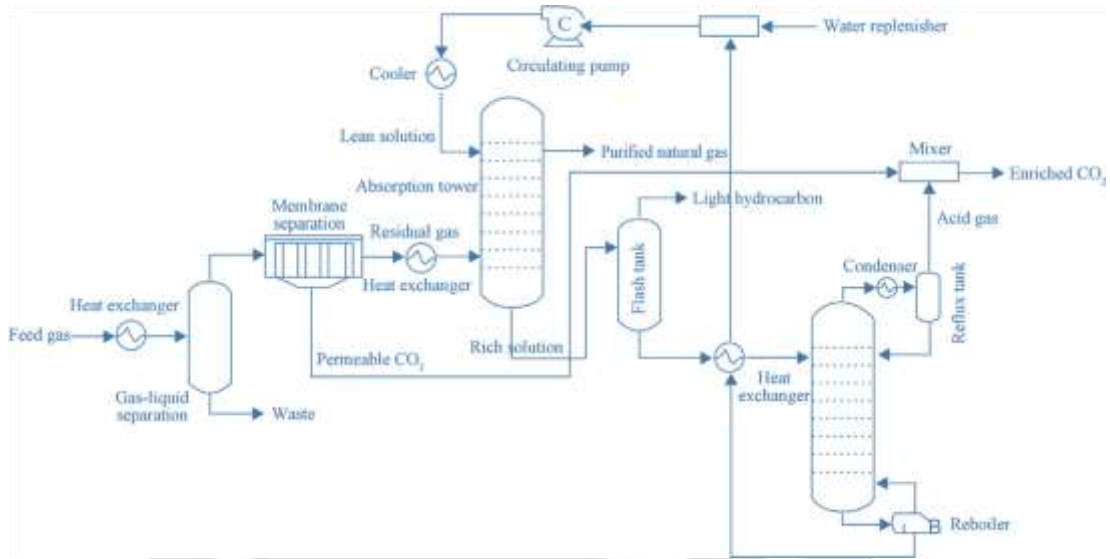**Fig. 1**. Scheme 1 e Simplified mechanisms flow of two-stage hydramine method.

Fig. 2. Scheme $_2$ e Simplified mechanisms flow of one-stage membrane separation þ one-stage hydramine method.
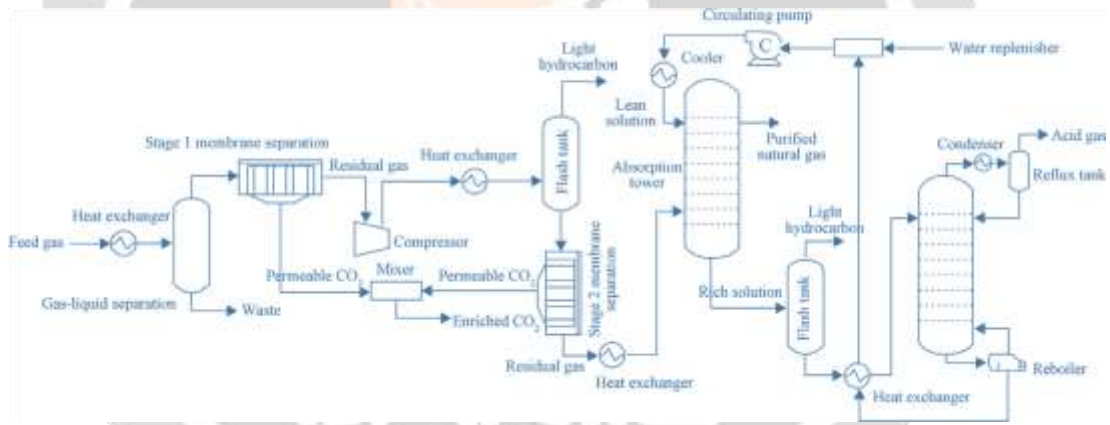

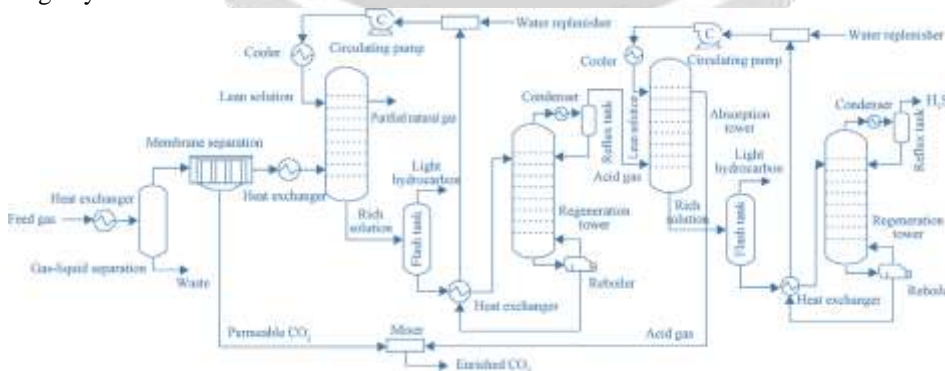**Fig. 3**. Scheme 3 e Simplified mechanisms flow of two-stage membrane separation þ one-stage hydramine method.

Fig. 4. Scheme 4 e Simplified mechanisms flow of one-stage membrane separation þ two-stage hydramine method.

Regenerating a hydramine-rich solution into a hydramine-lean solution may be accomplished using either temperature or pressure, or even both.

There are two-stage hydramine mechanisms as well as one-stage hydramine mechanisms developed in this work (Table 1). Acid gases are removed via hydramine processes with just one step. The first step of the hydramine processes still removes acid gases, but the second stage removes H_2S preferentially. To increase the amine solution's ability to absorb CO_2 and H_2S, MDEA solution with a specified amount of DEA (the mass fraction of MDEA and DEA are 40% and 10%, respectively) is added to the stage 1 hydramine processes. H_2S may be removed from high-concentration CO_2 using MEDA (a mass fraction of roughly 50 percent), which is applied to the stage 2 mechanisms.

2.3. Absorption and regeneration tower parameters

Hydramine mechanisms can only be accurately simulated if the characteristics of the absorption and regeneration towers can be accurately determined. Working pressure, tower top temperature and number of trays are the most important characteristics for both absorption and regeneration towers (Table 3). Table 3's stage 1 hydramine mechanisms apply to both the one-stage hydramine mechanisms in Schemes 2 and 3 and the two-stage hydramine mechanisms in Schemes 1 and 4. Table 3 especially relates to the stage 2 hydramine processes in Schemes 1 and 4 (hydramine mechanisms). Accordingly, keeping the characteristics of hydramine mechanisms' absorption tower and regeneration towers in accordance is a key foundation for comparing and selecting schemes.

According to the CO_2 and H_2S content of the input gas and the purity of the reinjected CO_2, the number of trays in the absorption tower may be estimated. However, the absorption tower typically has 14 to 20 trays. The greater the absorption, the more trays there are. Stage 2 hydramine mechanisms, on the other hand, are employed primarily to remove H_2S from acid gases, thus it is required to restrict the number of trays in the tower, which implies limiting the amount of time MDEA spends in the tower. Therefore, MDEA preferentially absorbs H_2S and excessive trays may enhance CO_2 absorption, which is negative for enhancing the purity of reinjected CO_2 to increase. The number of trays in the absorption tower should be lowered accordingly in stage 2 hydramine mechanisms. Hydramine stage 1 and stage 2 absorption towers have 20 and 5 trays, respectively. When it comes to regeneration, there are two options: stage 1 hydramine and stage 1 hydramine mechanisms have 10 and 8 trays in the tower, respectively. As illustrated in Table 3, the standard design range is used to establish the pressure, temperature, and other absorption and regeneration tower characteristics. It should be highlighted that the rate-based calculation approach must be properly followed while simulating the tower body. Table 3 shows the kinds of condensers and reboilers used in the mechanical simulation. Hydramine and water loss are also calculated using compensatory units. The hydramine solution circulation rate, hydramine concentration, and condenser temperature are the primary variables in the four schemes indicated in Table 3..

Table 3 Hydramine systems' absorption and regeneration tower parameters.

Parameter	Stage 1 hydramine mechanisms	Regeneration tower	Stage $_2$ hydramine mechanisms	
			Absorption tower	Regeneration tower
	Absorption tower			
Number of trays	$_2$0	10	5	8
Tower top pressure/kPa	5950	180	4100	170
Tower top temperature/C	$_2$9.44	$_2$5.00	35.91	$_2$5.00
Tray diameter/m	0.61	0.61	0.61	0.61
Tray space/m^3	0.88	0.97	0.88	0.97
Type of condenser	e	Total reflux	e	Total reflux
Reflux ratio	e	1.5	e	0.5
Type of reboiler	e	Conventional	e	Conventional

2.4. Membrane module

Membrane modules are found in all but one of the designs described in Table 1. To simulate and evaluate the membrane modules, HYSYS was utilized in combination with AspenTech-created membrane modules. According to Table 4, the hollow fiber membrane has an overall gas permeability coefficient of about $_2$9. The simulation was run using the settings listed in Table 4. Permeability coefficients for both input and output flows must be specified in the module's calculations. The mass flow rate of the input and output flows via the membrane module and the compositions of the flows may be derived after successful simulation debugging.

Total area of hollow fiber membrane in Schemes $_2$ and 4 is 135 m$_2$ when 3 membrane units are used, and the unit area is 45 m$_2$. Premechanisms unit adjustments before the membrane can keep the temperature and pressure of the high-pressure residual gas side of the membrane module in accordance with CO_2 concentration, which means that after a large amount of carbon dioxide is removed, the CO_2 content on the permeation side can be up to 91 percent. Although Scheme 3 has the same number of two-stage membrane modules and unit area as Schemes $_2$, 4 and 5, its high-pressure residual gas composition is different. The installation of a circulation compressor and cooler in the stage $_2$ membrane module is required to ensure that the gas pressure entering the module is adequate..

Table 4 Coefficient of gas permeability relative to a hollow fiber membrane.

Composition	C_1	C_2	C_3	iC_4	nC_4	iC_5	nC_5	nC_6	H_2O	H_2S	CO_2	N_2	DEA	MDEA
Relative permeability coefficient	0.$_2$	0.1	0.1	0.1	0.1	0.1	0.1	0.1	100	10	6	0.18	0.1	0.1

2.5. Module checking

The simulation findings of the Multiple Component CO_2 collection and purification systems cannot be compared to real-world data. On the basis of literature data and technical characteristics from membrane plants, it is important to verify the one-stage hydramine mechanisms and the one-stage membrane module.

Scheme 4 for natural gas deacidification methods provided by Wang et al. [17] was used to test the one-stage hydramine mechanisms. Its flow rate is $_2$200 kmol/h, and it is a mixed amine solution (40 percent MDEA and 10 percent DEA). The absorption tower's pressure and temperature are 4600 kPa and 35 C, respectively. The feed gas has a carbon dioxide concentration of 14.77 percent. One-stage hydramine mechanism simulations show that the CO_2 concentration of the sweet gas (7.046 percent) is very similar to the literature data (7.051 percent), with a relative difference of less than 0.08 percent.

The Dalian Eurofilm Industrial Ltd. Co. offered the membrane mechanisms parameters for the one-stage membrane module. There is a mass flow rate of 176040.98 kg/h, 6350 kPa and 65 C on the gas input side of the membrane module. The permeable gas side of the membrane module has a pressure and temperature of $_2$00 kPa and 58 degrees Celsius, while the high-pressure residual gas side has a pressure and temperature of 6180 kPa and 55 degrees Celsius. The gas entering the membrane module has a CO_2 concentration of 50.87 percent. In the simulation, we found a 4.87 percent relative deviation between the permeable gas production rate and the producer's data (85348.4$_2$ kg/h); a 0.95 percent relative deviation between the simulation's CO_2 content (89.54 percent) and the producer's data (86.7 percent); and an 8.6539.6 percent relative deviation between the high-pressure residual gas production rate and the producer's data (86.539.6 percent). These findings support the newly constructed simulation unit for a one-stage membrane module's dependability.

No significant discrepancies were found between the simulation results and the data supplied in the literature and by the manufacturer (less than 5%) for the one-stage hydramine mechanisms and one-stage membrane module. A reliable simulation of CO_2 capture and purification processes schemes based on the above-mentioned one-stage hydramine mechanisms and the one-stage membrane module has thus been shown.

3.   RESULTS AND DISCUSSION

As a result of the comparison of four CO_2 enrichment and purification strategies, an ideal scheme can be determined when the CO_2 concentration of input gas is different from that of the CO_2 caught and purified.

3.1. Purity and production rate of CO_2 enriched and purified

Analysis of the CO_2 content and total output of enriched and purified gas following enrichment and purification of CO_2 was carried out using four different methods (Tables 5, 6). As a result, four different CO_2 enrichment and purification strategies are examined. Table 5 shows the following for the feed gas with a low CO_2 level (Case 1, 11.9%):

✓ It's not possible to achieve CO_2 purity requirements for reinjected gas under any of the four methods since the CO_2 content of the input gas is low. Scheme 4 has the greatest CO_2 content, at 89.6 percent, in the enriched and filtered gas.

✓ 73.6 percent of the enhanced and purified gas in Scheme $_2$ has CO_2 concentration and 19.6 percent has H_2S content. Using this method, H_2S is not eliminated, hence the production rate is the greatest.

✓ Schema 3 has the lowest rate of generation of enriched and purified gas because the high-pressure residual gas discharged via two-stage membrane retains some acid gas.

✓ This shows that the addition of new mechanisms method can lead to the loss of the production rate of enriched and purified gas and in particular the leakage of partial CO_2 into the high-pressure residual gas in membrane separation mechanisms. The production rate in Scheme 4 is slightly lower than that in Scheme 1. As a result, when the feed gas contains a particular quantity of H_2S, it is essential to remove H_2S from the acid gas.

CO_2 purity and production rate cannot be met if CO_2 concentration in the input gas is low, which is why none of the four methods can be used. CO_2-EOR requires that a particular volume of pure CO_2 be procured and mixed with the enriched gas in order to ensure that the requisite CO_2 purity is met in the early stages.

Table 6 shows that for the gas with a high CO_2 level (Case $_2$, 61.01%), the following may be inferred:

✓ Scheme 1 has the poorest enrichment and purification impact with just 85.6 percent CO_2 concentration.

✓ 93.4%, 96.9%, and 97.6%, respectively, of the enriched and purified gas produced in Schemes 2, 3, and 4, indicate an increasing order of CO_2 content.

✓ Table 5 Composition and production rate of enriched and purified gas in Case 1.

Item		Scheme 1	Scheme 2	Scheme 3	Scheme 4
Composition	C_1	0.95%	2.90%	6.10%	3.60%
	C_2	0.40%	0.80%	1.30%	0.90%
	C_3	0.23%	0.60%	1.10%	1.50%
	iC_4	0.08%	0.10%	0.20%	0.20%
	nC_4	0.05%	0.20%	0.40%	0.30%
	iC_5	1.65%	1.20%	0.10%	1.50%
	nC_5	0.02%	0.10%	0.10%	0.10%
	C_6	0.01%	0	0.10%	0.10%
	H_2O	3.65%	0.90%	0	0.90%
	H_2S	5.99%	19.60%	1.60%	1.30%
	CO_2	86.96%	73.60%	88.90%	89.60%
Production rate/ (kgmolh^1)		855.11	1051.60	762.90	847.00

Table 6 Composition and production rate of enriched and purified gas in Case 2.

Item		Scheme 1	Scheme 2	Scheme 3	Scheme 4
Composition	C_1	6.82%	0.70%	1.40%	0.80%
	C_2	2.14%	0.20%	0.30%	0.20%
	C_3	1.41%	0.10%	0.30%	0.10%
	iC_4	0.35%	0	0	0
	nC_4	0.37%	0	0.10%	0
	iC_5	0.61%	0.30%	0	0.30%
	nC_5	0.12%	0	0	0
	C_6	0.08%	0	0	0
	H_2O	1.98%	0.30%	0	0.40%
	H_2S	0.50%	4.90%	0.90%	0.60%
	CO_2	85.60%	93.40%	96.90%	97.60%
Production rate/ (kgmolh^1)		3706.10	3544.90	3403.20	3375.50

✓ Re-injection quality may be affected by the lack of removal of H_2S from acid gas in Scheme 2. The elimination of H_2S from the in-depth enriched acid gas is now much more necessary as a result of this.

✓ It is significantly more enriched and purified than schemes 2, 3 and 3, which use membrane devices that may readily leak gas into the high-pressure residual gas when the related gas production rate is quite high.

✓ Scheme 2 has a greater production rate than Schemes 3 and 4 because of a little quantity of unremoved H_2S.

✓ The production rate for Scheme 4 is the lowest of the four. When H_2S is removed, Scheme 2's mole production rate drops by 8.9%, however Scheme 2's enriched and purified gas may be reinjected without any further purification, unlike Scheme 1's.

It's important to acquire pure CO_2 and mix it with the enhanced and purified gas in a specified proportion to produce an injection mixture that meets the requisite CO_2 purity of reinjected gas when the CO_2 concentration of the input gas is low. Scheme 4 shows the lowest production rate when the input gas CO_2 level is large, but it can achieve the requisite CO_2 purity of reinjected gas to the maximum extent possible. Indeed, Scheme 4's ability to absorb and purify CO_2 at a high level of enrichment is ideal.

3.2. Hydramine circulation rate

Hydramine circulates in all four schemes through a single-stage process. The circulation rate of hydramine solution differs in four schemes, despite the same fundamental composition and tower inlet temperature of hydramine solution (MDEA DEA), owing to varied preceding processes of stage 1 hydramine circulation mechanisms. Hydramine circulation rate in stage 1 correlates to the CO_2 and H_2S content of the acid gas at the top of the stage 1 regeneration tower, which serves as the basis for analyzing the energy consumption in the four schemes (Fig. 5). hydramine circulation is utilized to dispose of input gas in Scheme 1, high-pressure residual gas after membrane separation in Schemes 2 and 4, and high-pressure residual gas after membrane separation in Scheme 3 in four schemes. In addition, the purity and production rate of the enriched and purified gas corresponding to the total hydramine circulation rate under four schemes may be compared by linking with Schemes 1 and 4, which feature two-stage hydramine circulation mechanisms (Fig. 6).

Comparing the results in Figs. 5 and 6 for the feed gas with a low CO_2 level (Case 1,11.9%) reveals that:

✓ First, the hydramine circulation rate (394 m3/h), the CO_2 content of gas at the top of the regeneration tower, and H_2S content are lower in Scheme 1 than in Scheme 2. (20 percent).

✓ Scheme 2 and Scheme 4 both have a hydramine circulation rate of 411.9 m3/h and 413.9 m3/h, respectively. When the supply gas has a low CO_2 component, this shows that membrane processes aren't better for rough separation. There are 54 percent and 53 percent CO_2 and 39 percent and 39 percent H_2S in this gas at the top of the regeneration tower accordingly. As a result, H_2S separation is an absolute need.

✓ Scheme 3 has the lowest hydramine circulation rate, the lowest CO_2 content in the regeneration gas, and the highest concentration of H_2S.

✓ The hydramine circulation processes in Schemes 1 and 4 are also two-staged. Even after selectively removing H_2S from the enhanced gas and purified gas, the needed CO_2 concentration (>95 percent) remained lower than the CO_2 content of reinjected gas.

✓ Scheme 4 has a slightly greater total hydramine solution circulation rate and a CO_2 content that is enriched and purified than Scheme 1, but a lower production rate. This is because Scheme 4 incorporates the stage 2 hydramine circulation rate. Membrane separation does not perform well with low CO_2 content input gas, whereas two-stage hydramine processes are preferred.
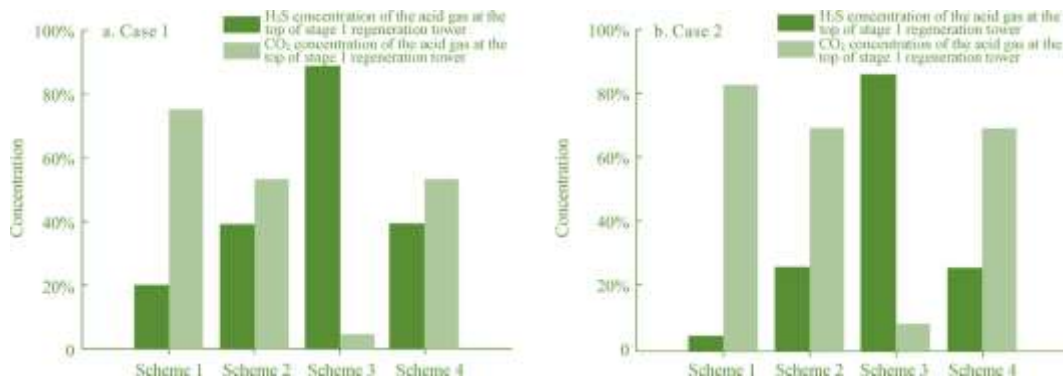
Fig. 5. H_2S and CO_2 concentrations of the gas at the top of stage 1 regeneration tower under four schemes in Case 1 and Case 2.
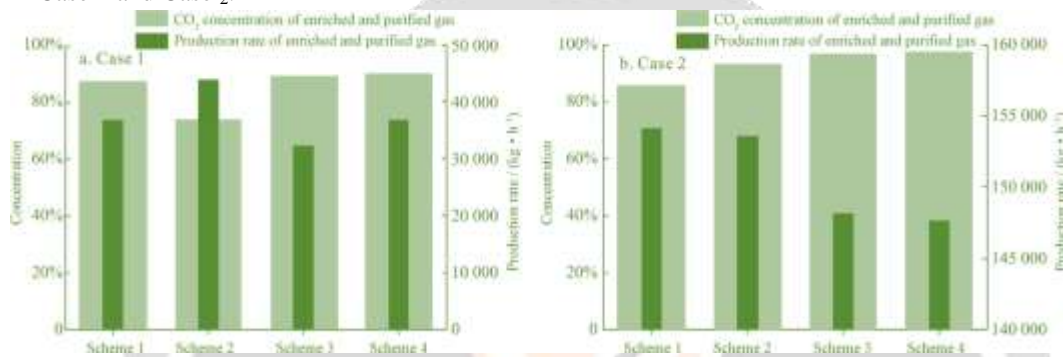

Fig. 6. Simulated CO_2 concentration and production rate of captured and purified gas under four schemes in Case 1 and Case 2.

Figures 5 and 6 illustrate that for a feed gas with a high CO_2 concentration (Case 2, 61.01 percent):

✓ Scheme 1 had the greatest hydramine solution circulation rate (10735.7 m3/h), the highest CO_2 concentration in the gas at the top of the regeneration tower (83 percent), and the lowest H_2S content of any of the other three schemes (4 percent). If there is no rough separation via membrane mechanisms, this implies that for greater CO_2 content feed gas, the circulation rate of stage 1 hydramine solution is very high and energy consumption in the mechanisms of lean solution regeneration is substantially increased.

✓ Scheme 1's circulation rate of hydramine, which is 282.3 m3/h, was substantially higher than that of Scheme 2, which was just 282.3 m3/h. That the membrane mechanisms unit is more effective at treating feed gas with a high CO_2 level is inferred from the data above. Gases near the apex of the regeneration tower have a CO_2 level of around 70%. The H_2S concentration is still approximately 26%, thus the removal of H_2S is critical.

✓ Hydrogen recirculation rate of 54.9 m3/h, CO_2 content of gas at top of regeneration tower lowest, H_2S content is relatively high in Scheme 3, and CO_2 purity of reinjected gas on low-pressure permeable gas side of stage 2 membrane separation is 96.9 percent, which meets the CO_2 purity of reinjected gas requirements.

✓ The enriched and purified gas in Schemes 1 and 4 has a CO_2 level of 93.40 percent and 97.60 percent, respectively, after the H_2S is selectively removed using stage 2 hydramine circulation. Scheme 1 fails miserably to achieve the requisite reinjected CO_2 purity.

✓ Although the overall circulation rate in Scheme 1 is substantially greater than that in Scheme 4, the enriched and purified gas does not satisfy the requisite CO_2 purity of reinjected gas.

✓ Increased the hydramine circulation rate in Scheme 4 to 375.6 m3/h, which ensures CO_2 purity requirements for enhanced and purified CO_2.

Again, it's been shown that when the input gas's CO_2 level is low, purchasing CO_2 is essential to match the purity requirements for reinjected CO_2. Scheme 1's total hydramine circulation rate is superior to that of Scheme 4's, even with the same purity of CO_2 and generation rate of enriched and purified gas. Scheme 4 is, nevertheless, the optimum option for feed gas with a high concentration of CO_2 when it comes to CO_2 purity and production rate. Though its output is smaller than that of Scheme 3, which fulfills the purity requirements for reinjected gas, Scheme 4 is more technologically viable. Even while multi-stage membrane separation mechanisms are technically feasible, they have not yet reached a point where they can be widely deployed, hence Scheme 3 is only useful as a theoretical study in which additional research into the technology is required.

3.3. Economics of energy use and production

The Energy Analysis module of HYSYS was used to examine four schemes in terms of energy consumption of equipment (e.g., incorporating heating and cooling equipment) and economics.

In the case of low-CO_2 input gas (Case 1, 11.9%), the findings in Fig. 7 reveal that:

✓ Scheme 3 has the lowest energy use. Scheme 3 has fewer stages of hydramine circulation and enriches reinjected CO_2 simply by membrane enrichment, therefore its equipment is simple enough to minimize excessive energy consumption. Scheme 3's economics, on the other hand, are low since the multi-stage membrane separation mechanisms are underdeveloped, and the inclusion of compressors and heat equipment increases investment.

✓ There is no difference in energy consumption between Scheme 2 and Scheme 4, which both use hydramine solution circulation, while Scheme 4 consumes a little more than Scheme 2, which uses hydramine solution circulation just once.

✓ Scheme 1 has a significant energy usage. In general, the cooling industry consumes more energy. However, the hydramine mechanisms
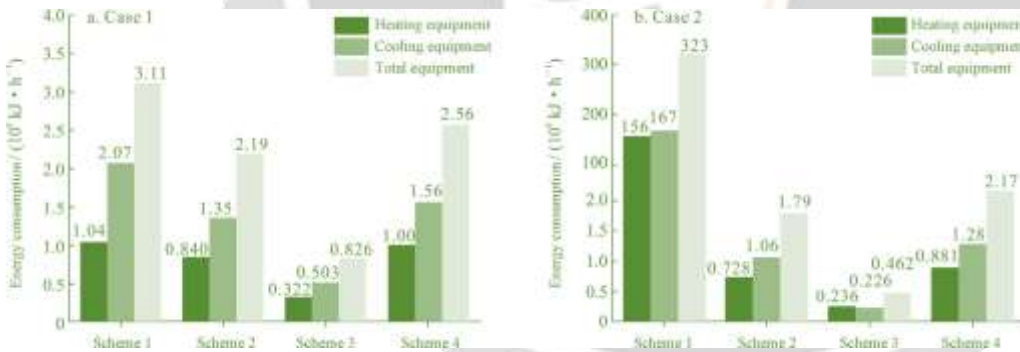
Fig. 7. Simulated equipment energy consumption under four schemes in Case 1 and Case 2.

outperform the membrane mechanisms in terms of economics when dealing with the differential pressure of lowemoderate acid gas.

As shown in Fig. 7 (case 2), the higher the CO_2 level of the feed gas, the more volatile it becomes:

✓ Scheme 1's total hydramine demand is substantially larger than that of the other three schemes, which means that its total equipment energy consumption is much higher than that of the other three schemes. Absorbent circulation rate is not only influenced by the volume of circulation, but also by the concentration of the solution. Increasing the concentration of the solution can, in general, reduce the circulation rate and, as a result, the equipment cost. An amine solvent's recommended upper limit should not be exceeded to prevent equipment corrosion. Due to high CO_2 concentration in the feed gas, the two-stage hydramine method cannot be used.

✓ Scheme 3 has the lowest equipment energy consumption when compared to the other schemes, but it has disadvantages when it comes to promoting and applying new technologies.

✓ Scheme $_2$ and Scheme 4 both use membrane mechanisms to lower the energy consumption of amine solution circulation, which in turn reduces the operating costs and the economics of the whole equipment. Low-concentration feed gas leads in somewhat greater energy consumption in Scheme 4 than in Scheme $_2$. As Scheme 4 has a two-stage amine solution circulation unit, the enriched and purified gas produced by Scheme 4 can be reinjected directly into the amine solution circulation unit.

Finally, the two-stage amine circulation under Scheme 1 should be used when CO_2 content in the feed gas is low and large amounts of gas must be disposed, whereas the one-stage membrane separation two-stage hydroamine mechanisms under Scheme 4 are more appropriate when CO_2 content in feed gas is high. The feed gas with different CO_2 content and specified H_2S concentrations, on the other hand, means that Scheme 4 is technologically and energy-wise superior to the other options.

4. CONCLUSIONS

There will be a need to acquire and mix pure CO_2 with enriched and purified gas in order to fulfill the requirements for CO_2 purity of reinjected gas for the input gas with low CO_2. With a low CO_2 level in the input gas, Scheme 1 with two stage hydramine mechanisms is more economical than Scheme 4 with two stage hydramine mechanisms – membrane mechanisms. Scheme 1 represents an apparent greater overall circulation rate of hydramine solution and operating costs, Scheme 3 is weak for promotion, and Scheme 4 is completely superior than Scheme $_2$ for the input gas with high CO_2 content.

The CO_2-EOR oilfield surface engineering is intended to be coupled with Scheme 4. Only the two-stage amine circulation is used when the supply gas has a low CO_2 component. One-stage membrane separation is used in conjunction with the two-stage hydramine technique when CO_2 levels rise. Technology and economics will be better able to handle the entire mechanisms. Based on the actual working circumstances, the crucial CO_2 concentration in staged operation must be studied and established.

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