Simulation and Capacity Evaluation of Refinery Flare System and Comparative Analysis of Carbon Capture Technologies

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ABSTRACT: *In a refinery flare system is the last defense line for controlling the over-pressurization of process vessels. Mostly power failure is the worst contingency in the refinery, and the flare capacity is evaluated for this case. The data of Pressure Safety Vessels (PSVs), header network, knockout drums, flare stack, and flare tip is to utilize for simulating the flare system of the Oil Refinery Complex (ORC-II). In power failure contingency out of fourteen PSVs, four were found to have higher back pressures than the allowable limits, those PSVs were resized and new models have been proposed. Carbon dioxide (CO_2) is a significant benefactor of global warming stances a severe hazard to the environment. The danger of natural contamination might be diminished by downstream usage of post-combustion vent gases which principally originate from power plants, gas, or oil fields, and the cement industry with the essential spotlight on CO_2 catch. Post-combustion is a broadly utilized system as a result of its similarity with the existing force plant framework. The procedure was conveyed using 30 wt. % monoethanolamine (MEA) dissolvable and Hollow-fiber cellulose acetic membrane framework. This research consists of two sections. In the initial segment, the capacity evaluation of the flare framework was finished utilizing Aspen Flare System Analyzer V8.4 and the rating of the flare framework was conveyed in which to break down the necessary parameters like Mach number and back weight in the system and the adjustments in the flare framework were made as per API 520. In the second part chemical absorption and membrane separation innovations were looked at for post-combustion carbon catch. The research focuses on conveying a relative investigation of the above-expressed methods for the flow rate of vent gas runs between 1 to 200 MMSCFD. The goal is to accomplish 90% recuperation of CO_2 with carbon decrease from 10.66 mole % to 2 mole %. The absorption technique is simulated by ASPEN HYSYS V8.4 and a program for membrane framework is created by connecting values from ASPEN HYSYS to Microsoft EXCEL. For membrane separation, the operating expense is seen as lower than the absorption process, yet from the results, it was concluded that the absorption technique is superior to the membrane technique until the problems concerning the degradation of the membrane and high capital expense would be settled.*

KEYWORDS: *ASPEN HYSYS, Flare system; Absorption process, Membrane; Monoethanolamine; Carbon dioxide.*

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INTRODUCTION

When industrial equipment is over-pressurized, the pressure relief system will automatically release gases and some liquids. Released gases are released through pipes named flare headers to a flare; gases are burned as they exit the stack. The Flare system serves as the final defense line in case of any emergency in a plant. Hydrocarbons released from different equipment are burned in a flare. Every combustion reaction results in the release of flue gases such as carbon monoxide, carbon dioxide, and nitrous oxides.

To ensure environmental safety, rules and regulations restrict the amount of these flue gases to be exhausted into the atmosphere; this can be accomplished by downstream treatment of the flue gases emitting from the flare. Carbon dioxide is also a constituent of the gases emitting from the flare. Carbon dioxide is a significant greenhouse gas. Recent industrial growth has resulted in a drastic increase in the emissions of carbon dioxide [1, 2].

In this research, besides the capacity evaluation of the flare system has also considered the above scenario, the downstream treatment of flue gases (recovery of carbon dioxide). Carbon dioxide Capture and Storage (CCS) is the path that allows the world to enjoy the benefits of rapid industrial growth. CCS technologies on a broader scope find their applications in coal-fired power plants as they are the largest source of CO_2 emissions.

A Flare system is used for the safe disposal of the relieved gases from different refinery equipment, but the flare must be reliable enough to operate safely in an emergency scenario. The problem statement of excessive relief loads may fail some PSVs. The reliability of the flare can be tested by capacity evaluation of the flare system for the worst contingency (power failure scenario). The flue gases from various sources such as flare systems, fired power plants and cement industries contain multiple gases like carbon dioxide and nitrous oxides. Carbon dioxide being a significant greenhouse gas poses a danger to the environment. These gases need to be treated for sake of environmental protection [3, 4].

The objective of the research is to a simulation of a complex refinery flare system using the Aspen Flare System Analyzer. Study of flare system for the worst contingency of power failure and rating of existing Flare system through Aspen Flare. Modification of order by API standards. The study of carbon capture techniques through chemical treatment and membrane separation techniques.

The scope of this research is to the capacity evaluation of the flare system will be useful in testing the reliability of our flare system for the power failure scenario, when the relief loads of the PSVs installed on different equipment is much higher as compared to normal operating conditions. So by capacity evaluation, those PSVs can be resized to ensure the safe operation of the flare system in a power failure scenario. Treatment of the flue gases by suitable techniques such as “Carbon Capture and Storage (CSS)” techniques will help in keeping greenhouse gases emission below prescribed limits. Further a comparative analysis between the “chemical treatment process” and “membrane separation technique” will help in selecting an economical method for the treatment of flue gases [5, 6].

Types of Flare System

In vertical flares, combustion reactions take place at an elevated position relative to the ground. They are oriented to fire upwards. Vertical flares can be supported in the following ways. A mechanically and structurally designed riser supports the flare burner. An elevated flare with the riser supported by cables is attached to the flare riser at one or more elevations to limit the structure deflection [7].

The flared fluids and gases are channeled to a level flare burner that releases into a pit or excavation. The smokeless flare sorts of flares are utilized to avoid smoke forming from smoke framing from a flare. This is cultivated by utilizing steam, compelling vitality, or different intends to entrain air or make disturbance inside the flared gas stream. Usually, the smoking tendency is a function of the gas calorific worth and the tendency is a function structure of the hydrocarbons. The non-smokeless flare sorts of flares may create smoke in some working conditions. It doesn't use any outside techniques (air, steam) to improve combustion.

A flare burner is an important component of the flare system; it mixes relief gases and air at turbulence to maintain proper and stable ignition. Whenever an emergency or plant disruption occurs, the vapors are discharged for process relief, flare burner ignites and combusts those vapors. The flare burner is a key component and must provide the desired combustion efficiency [7, 8]. The pilot is a device that ignites the released hydrocarbon vapors, if it fails then unburned hydrocarbons may be released into the atmosphere resulting in adverse health effects or a vapor cloud explosion. The pilot should be reliable enough

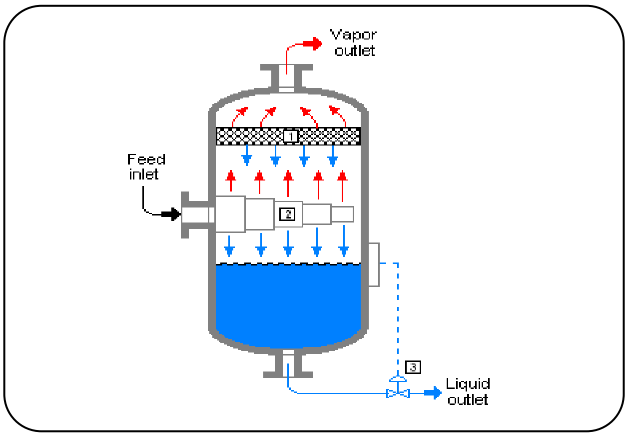


Fig. 1: Knockout drum

to be in service for years without the need for maintenance. The quantity of pilots required is an element of the flare burner diameter. As the flare burner diameter increases, the number of pilots required to dependably light the flare, paying little respect to wind heading increments.

Relief vapors from different types of equipment contain liquid droplets, the burning of the vapors with these droplets may cause problems such as incomplete combustion or chocking or plugging of the burner, to overcome this problem knock-out drum is used. A knockout drum separates liquid droplets from the vapors. Figure 1 shows the knockout drums, which are normally situated on the principal flare line upstream of the flare stack or any fluid seal. When there are specific bits of gear or procedure units inside a plant that give significant wellsprings of fluid to the flare, it is attractive to have knock-out drums inside as far as possible for those sources. Typically three types of knockout drums are used in flare systems horizontal separator, vertical separator, and vertical centrifugal separator. A wind fence is utilized to relieve the capability of wind to upset the wind stream or vent gas stream. A uniform wind stream to all sides of all burners is essential to accomplishing controlled combustion [9, 10].

An average closed and pressure relief incorporates valves and lines for the accumulation of releases from process units, knock-out drums to spate fluid from fumes, seals and cleanses gas for flashback protection and a flare and igniter framework which combusts fumes when released legitimately to the air is not allowed. Steam might be infused into a flare to decrease visible smoke.

Pressure relief devices must be given where the potential exists for overpressure in treatment facility forms because of the accompanying causes like; loss of cooling water, which may extraordinarily diminish warmth trade-in condensers and therefore increment the pressure in distillation columns. Loss of reflux stream, which may cause pressure to ascend in refining towers because the amount of reflux influences the volume of fumes leaving the refining tower. Fast vaporization and pressure increment by injection of lower boiling point fluid including water into a procedure vessel working at higher temperatures [11, 12].

Flare gases can have broadly changing compositions that will be assessed during the determination of recuperation frameworks. The potential for materials that are not good with the flare gas treating frameworks or extreme goals will be resolved such as, streams containing corrosive gases normally are steered straightforwardly to the flare, thus bypassing the recuperation framework.

A pressure relief framework and device intended to open and alleviate overabundance pressure and to reclose and forestall further flow of liquid after typical conditions have been reestablished. A relief valve is a spring-loaded valve activated by the static pressure upstream of the valve. The pressure increment over the opening pressure makes the valve open. The pressure relief frameworks are crucial in the CPI (chemical process industries) for dealing with a wide assortment of circumstances. They are utilized to avert pressurization over a framework's plan pressure; for venting during an irregular or emergency circumstance; and for typical depressurization during a shutdown, as models.

An over-pressurization may result from a solitary reason or a mix of events. Ordinarily, not all causes will happen at the same time. In the event of an outer fire in vessels that prevalently handle fumes, for example, knockout drums, there might be a fast temperature ascending in the metal that went with an ascent in pressure because of expansion. If there should be an occurrence of outside fire in vessels that contain fluids, there will be an ascent in pressure as the fluid disintegrates. Weight may likewise rise unexpectedly because of warm extension when a hindered in the pipeline or other hardware containing a fluid is warmed. Alleviating pressure under these circumstances is fundamental to preventing failure. It is additionally required in frameworks where a nonstop flow of fume or fluid is all of a sudden halted by a downstream blockage [12, 13].

Carbon capture and storage techniques

Carbon Capture and Storage (CSS) technologies on the recovery of carbon dioxide gas from flue gases of coal-fired power plants and different industrial processes. The captured carbon dioxide gas is transported to a storage site (geological formation) where it will not enter the atmosphere. Broadly, three different types of technologies for scrubbing exist post-combustion, pre-combustion, and oxyfuel combustion [14, 15].

Carbon Capture and Storage (CSS) innovations emphases on the recuperation of carbon dioxide gas from vent gases of coal-fired power plants and different industrial procedures. The captured carbon dioxide gas is shipped to a capacity site where it does not enter the weather. Extensively, three distinct kinds of innovations for cleaning exist pre-combustion, oxyfuel combustion, and post-combustion.

The pre-combustion technique is generally applied in dung, compound, vaporous fuel (H_2, CH_4), and power generation. In these cases, the petroleum derivative is somewhat oxidized, as in a gasifier. In oxy-fuel ignition, the fuel is singed in oxygen rather than air. The outcome is nearly pure CO_2 flow, moved to the possessing site, and put away.

In post-ignition catch, CO_2 is caught after the burning of the fuel. Then the gas is caught from pipe gases of a power plant or other huge point sources. The innovation is surely known and is right now utilized in other mechanical applications, even though not at a similar scale as may be required in a business scale power station. When contrasted with the other two systems of catching carbon dioxide, the post-catch strategy has a favorable position.

All catch procedures utilize an absorbent, adsorbent, and membranes. Adsorption alludes to the take-up of CO_2 molecules on to the outside of another material. Membranes can separate CO_2 from the pipe gas by specifically pervading it with the membrane material. If CO_2 has a higher permeability, chemical agents that respond specifically with CO_2 are increased to build membrane selectivity for CO_2. Comparable to adsorbents, membranes are asserted to possibly propose low vitality capture processes [16, 17].

EXPERIMENTAL SECTION

Capacity Evaluation of Flare System

Simulation can be used as a tool to acquire comprehensive information required for the design of a real plant, for the experiment, control, and optimization purposes. The benefits of the simulation include; precise design information to ensure the process feasibility, material and energy balances along with the process flow diagrams, multiple design cases, or options that save valuable cost, and the best retrofit option for the chemical plant. Optimization to get the process's highest performance point and sensitivity analysis, evaluating the process key control variables and degree of operating constancy.

Simulation Approach

In this study, simulation of the flare system is carried out using the Aspen flare analyzer version 8.4. Aspen flare system analyzer is specifically designed for simulation of the flare system. It can be used for capacity evaluation of the flare system. The major components in a refinery are typically hydrocarbons for which the appropriate fluid package is Peng-Robinson. The Flare system ensures the safe disposal of the hydrocarbon vapors generated from different process equipment.

One of the most significant parts of procedure simulation is the determination of an appropriate physical property strategy that will precisely calculate diverse physical properties. A plan for the choice of the fluid package has appeared in Fig. 2. It gives an extremely helpful plan that can be utilized for the brisk and simple determination of a suitable property model for any concoction framework.

The primary purpose of this simulation was to perform a capacity evaluation analysis of the flare system of the refinery. Capacity evaluation means checking the operating scenario of the flare system and network of headers and PSVs in case of different contingencies like power failure, plant failure, loss of cooling water, and loss of reflux. Since power failure is the mother of all other failures, therefore capacity evaluation was performed for power failure contingency. The required data (maximum relief load, temperatures, pressures, and molecular weights) for PSVs installed on different equipment were obtained by the refinery. The simulation flowsheet is shown in Figure 3. The required data such as PSVs relief loads for power failure, temperature, pressure, molecular weights of off-gases, header network connections, header lengths, and diameters, knock-out drum dimensions, and flare stack dimensions.

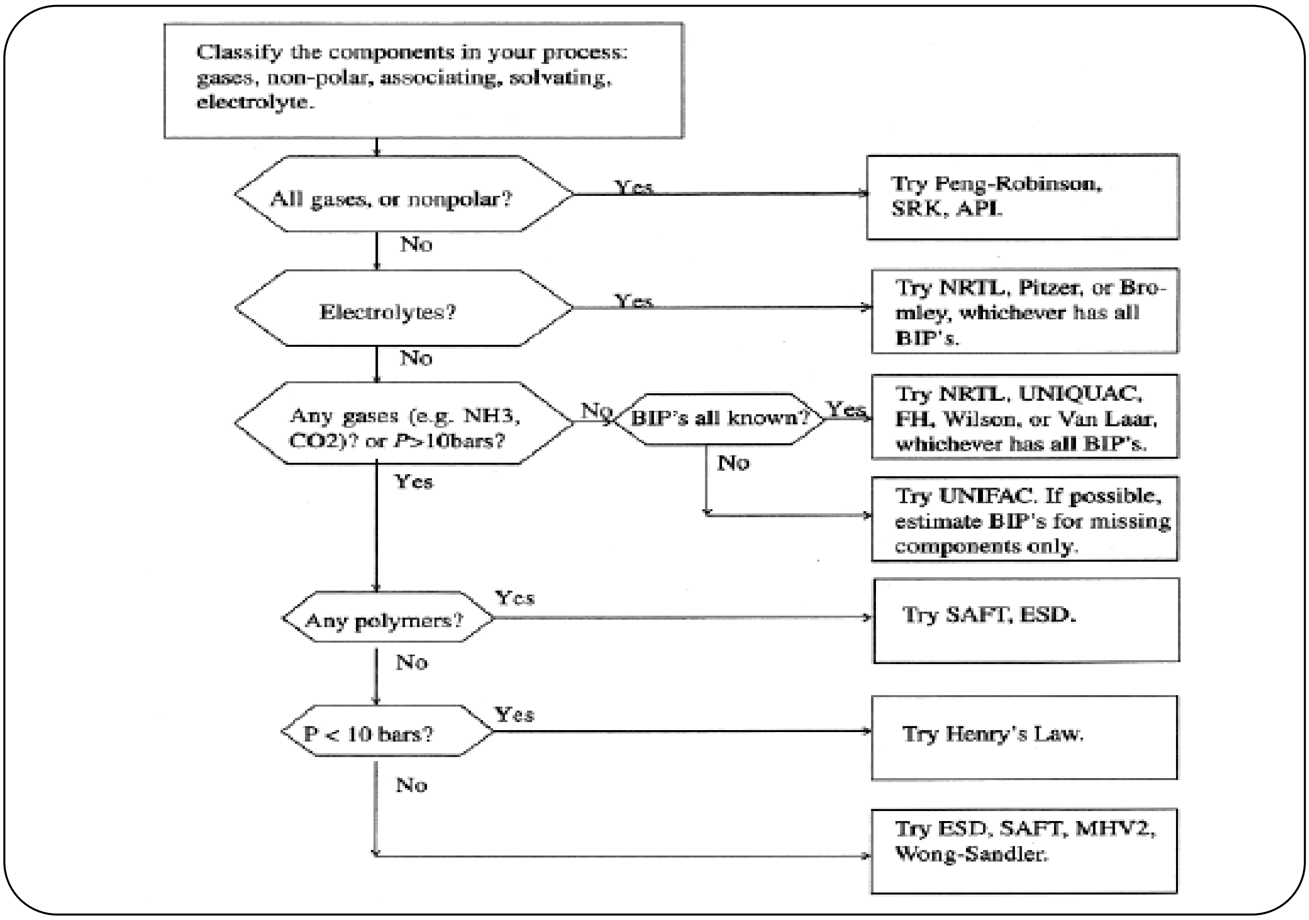


Fig. 2: Tree diagram for Fluid Package selection.

RESULTS AND DISCUSSION

The available data was utilized to perform the simulation of flare in power failure contingency. According to API standards, the match number in headers should not exceed 0.5. Further, the back pressures for conventional, balanced bellows PSVs should not exceed 10% and 50% of the set pressure respectively. After simulating the power failure scenario, some PSVs showed back pressures exceeding the prescribed limit. For example, the PSV 16C-25 of the isomerization unit (plant 16) has back pressure exceeding the prescribed limit.

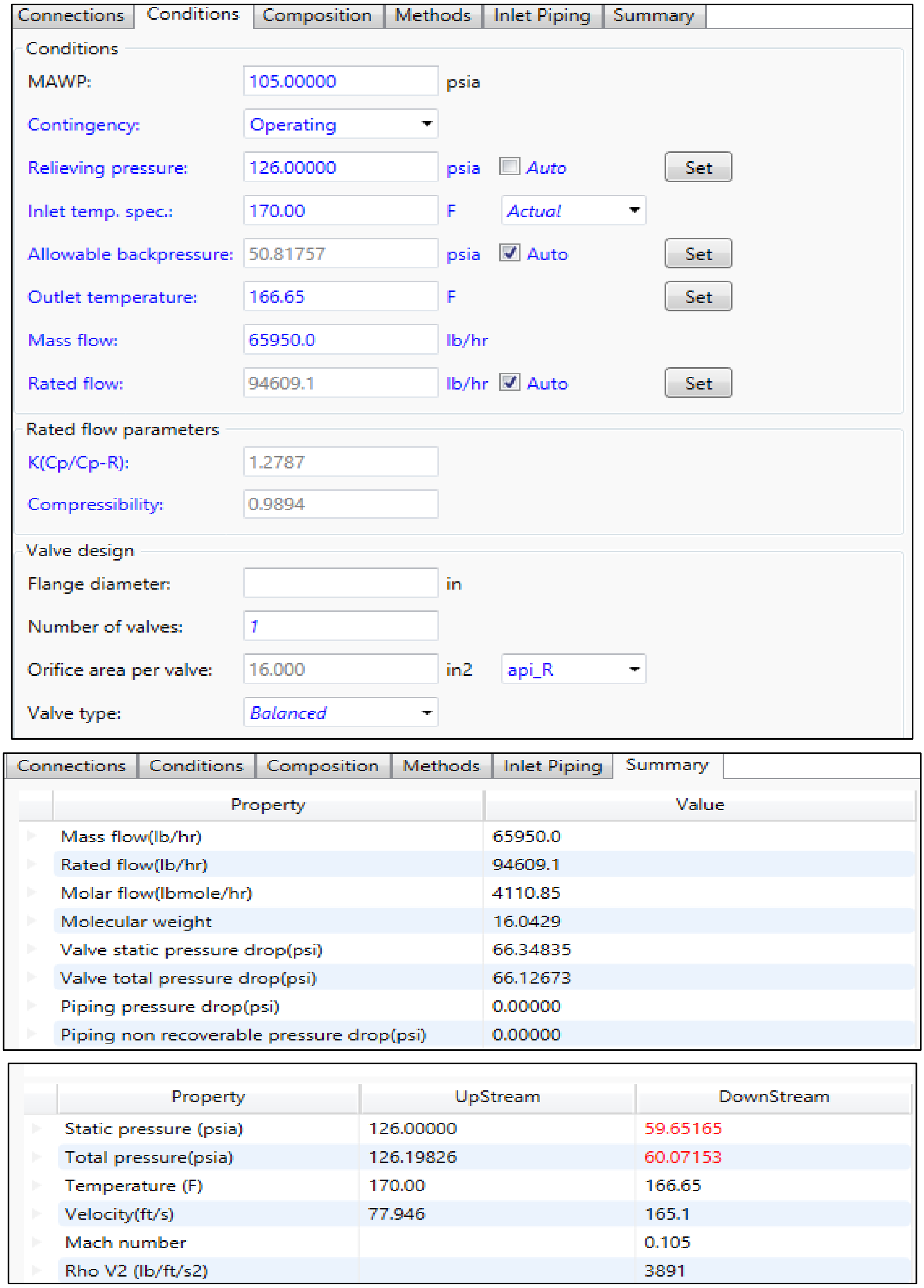
In a power failure, 15 PSVs are operated to relieve the excessive vapor build-up. Some of the PSVs experienced back pressure exceeding the limits. PSVs 16C-B, 16C-13, 16C-12, 8C-2, 8C-5, 4C-4, 4C-7, 4C-8, and 1C-2 operated safely according to API standards that have backpressure under allowable limits. For example, the operating profile of the PSV 1C-2 is shown in Fig. 4.

PSVs 16C-24, 16C-25, 16C-28, 11C-1, 15C-5 have backpressure exceeding the allowable limit. For example, the operating profile of the PSV 16C-25 is shown in Fig. 5.

The PSVs with backpressure exceeding the limits were resized using vendor-based software “Pentair PRV2SIZE” which uses design code “ASME Section VIII” and sizing standards of “API 520”. “Pentair PRV2 SIZE” sheets of PSVs 16C-25, 16C-24, 11C-1, 16C-28, are shown in Figures 6, 7, 8, and 9 respectively.

Post-Combustion Carbon Capture

The downstream treatment of flue gases involves flue gas treatment by absorption through an amine solution and by using membrane separation techniques. Flue gas mainly contains carbon dioxide and nitrogen; other components include oxygen and water vapors. First, the flue gas enters the absorption column from the bottom where it interacts with MEA solvent 30 wt%. CO_2 is absorbed in MEA solution whereas sweet gas with 2.5 mole% CO_2 leaves



Conditions

MAWP: 105.00000 psia

Contingency: Operating

Relieving pressure: 126.00000 psia ☐ *Auto*

Inlet temp. spec.: 170.00 F *Actual*

Allowable backpressure: 50.81757 psia ☑ Auto

Outlet temperature: 166.65 F

Mass flow: 65950.0 lb/hr

Rated flow: 94609.1 lb/hr ☑ Auto

Rated flow parameters

K(Cp/Cp-R): 1.2787

Compressibility: 0.9894

Valve design

Flange diameter: in

Number of valves: *1*

Orifice area per valve: 16.000 in2 api_R

Valve type: *Balanced*

Property	Value
Mass flow(lb/hr)	65950.0
Rated flow(lb/hr)	94609.1
Molar flow(lbmole/hr)	4110.85
Molecular weight	16.0429
Valve static pressure drop(psi)	66.34835
Valve total pressure drop(psi)	66.12673
Piping pressure drop(psi)	0.00000
Piping non recoverable pressure drop(psi)	0.00000

Property	UpStream	DownStream
Static pressure (psia)	126.00000	59.65165
Total pressure(psia)	126.19826	60.07153
Temperature (F)	170.00	166.65
Velocity(ft/s)	77.946	165.1
Mach number		0.105
Rho V2 (lb/ft/s2)		3891

Fig. 3: Simulation sheet of PSV 16C-25

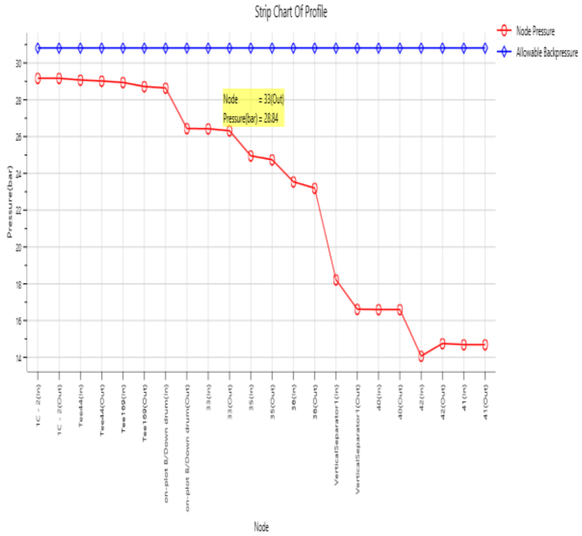


Fig. 4: Operating Profile of PSV 1C-2.

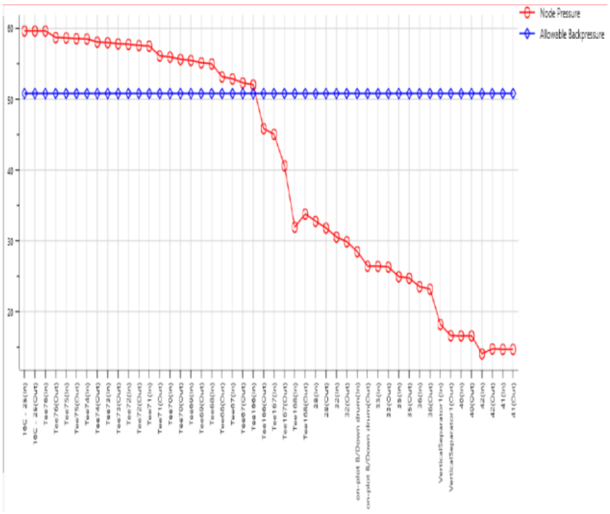
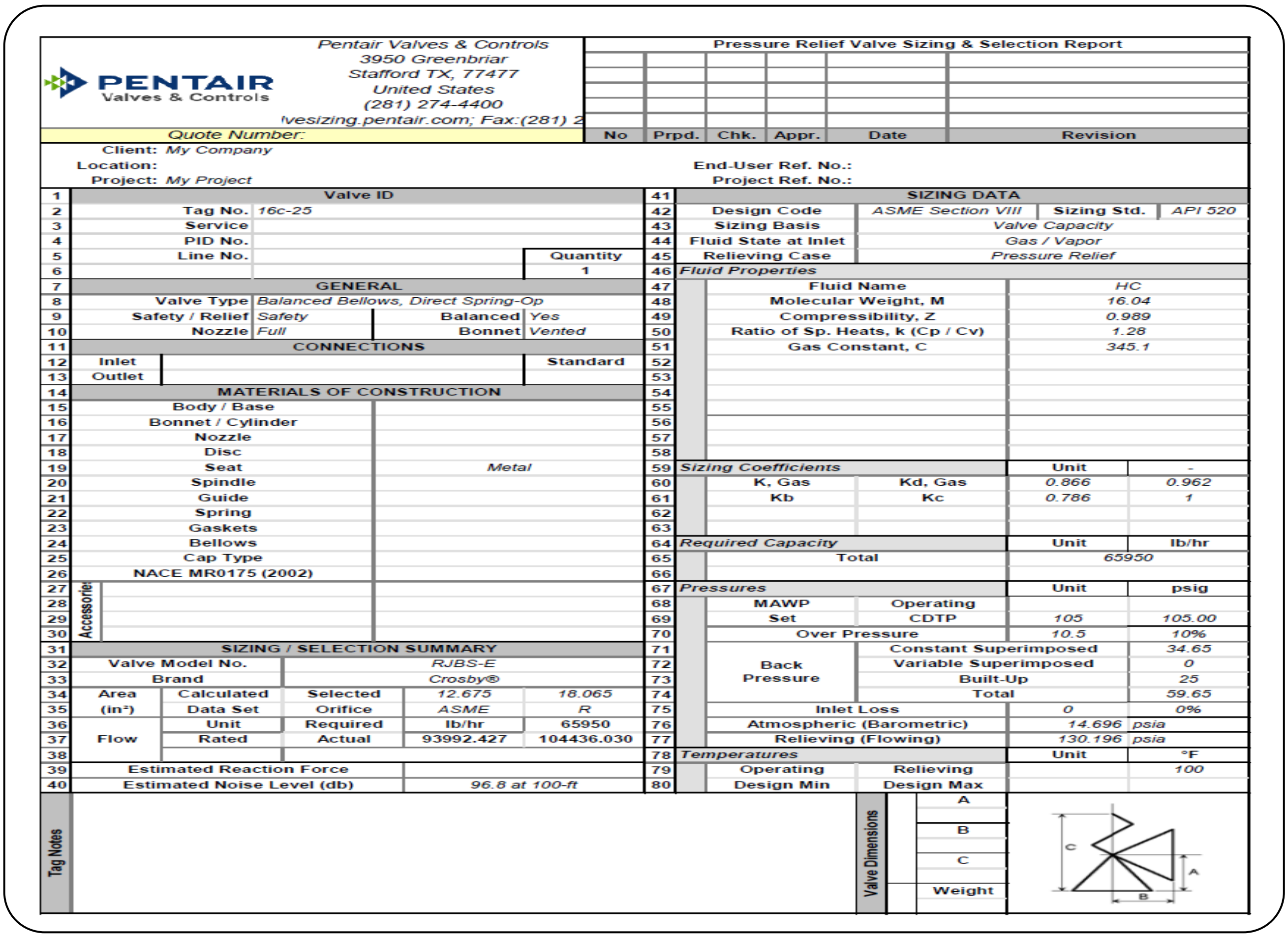


Fig. 5: Operating profile of the PSV 16C-25.



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3950 Greenbriar
Stafford TX, 77477
United States
(281) 274-4400
'vesizing.pentair.com; Fax:(281) 2

Pressure Relief Valve Sizing & Selection Report

No	Prpd.	Chk.	Appr.	Date	Revision

Quote Number:

Client: *My Company*
Location:
Project: *My Project*

End-User Ref. No.:
Project Ref. No.:

1	**Valve ID**			
2	**Tag No.**	*16c-25*		
3	**Service**			
4	**PID No.**			
5	**Line No.**		**Quantity**	
6			1	
7	**GENERAL**			
8	**Valve Type**	*Balanced Bellows, Direct Spring-Op*		
9	**Safety / Relief**	*Safety*	**Balanced**	*Yes*
10	**Nozzle**	*Full*	**Bonnet**	*Vented*
11	**CONNECTIONS**			
12	**Inlet**		**Standard**	
13	**Outlet**			
14	**MATERIALS OF CONSTRUCTION**			
15	**Body / Base**			
16	**Bonnet / Cylinder**			
17	**Nozzle**			
18	**Disc**			
19	**Seat**	*Metal*		
20	**Spindle**			
21	**Guide**			
22	**Spring**			
23	**Gaskets**			
24	**Bellows**			
25	**Cap Type**			
26	**NACE MR0175 (2002)**			
27	**Accessories**			
28				
29				
30				
31	**SIZING / SELECTION SUMMARY**			
32	**Valve Model No.**	*RJBS-E*		
33	**Brand**	*Crosby®*		

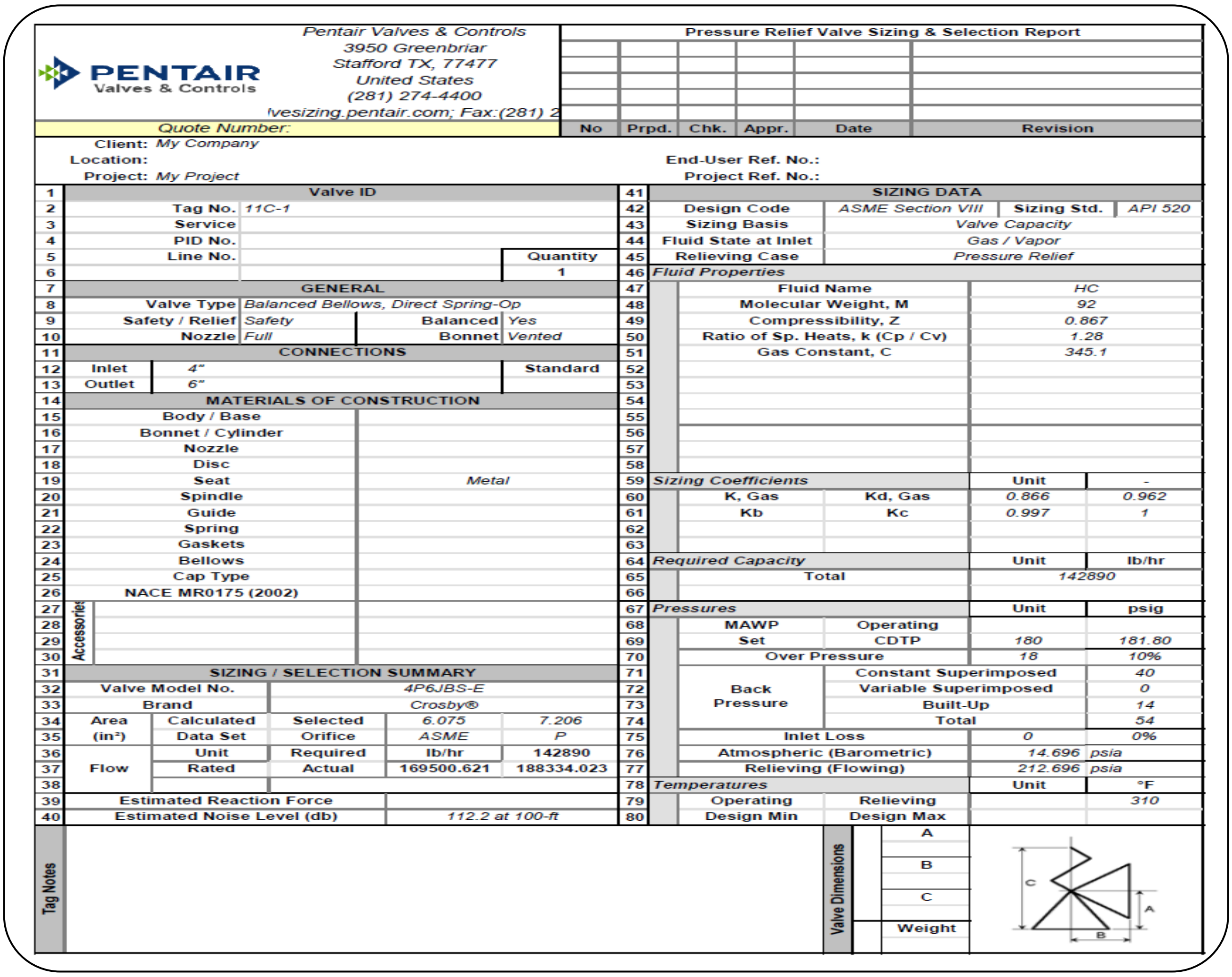
34	**Area**	**Calculated**	**Selected**	*12.675*	*18.065*
35	**(in²)**	**Data Set**	**Orifice**	*ASME*	*R*
36	**Flow**	**Unit**	**Required**	**lb/hr**	**65950**
37		**Rated**	**Actual**	**93992.427**	**104436.030**
38					
39	**Estimated Reaction Force**				
40	**Estimated Noise Level (db)**		*96.8 at 100-ft*		

41	**SIZING DATA**			
42	**Design Code**	*ASME Section VIII*	**Sizing Std.**	*API 520*
43	**Sizing Basis**	*Valve Capacity*		
44	**Fluid State at Inlet**	*Gas / Vapor*		
45	**Relieving Case**	*Pressure Relief*		
46	***Fluid Properties***			
47	**Fluid Name**		*HC*	
48	**Molecular Weight, M**		*16.04*	
49	**Compressibility, Z**		*0.989*	
50	**Ratio of Sp. Heats, k (Cp / Cv)**		*1.28*	
51	**Gas Constant, C**		*345.1*	
52				
53				
54				
55				
56				
57				
58				
59	***Sizing Coefficients***		**Unit**	-
60	**K, Gas**	**Kd, Gas**	*0.866*	*0.962*
61	**Kb**	**Kc**	*0.786*	*1*
62				
63				
64	***Required Capacity***		**Unit**	**lb/hr**
65	**Total**		*65950*	
66				
67	***Pressures***		**Unit**	**psig**
68	**MAWP**	**Operating**		
69	**Set**	**CDTP**	*105*	*105.00*
70	**Over Pressure**		*10.5*	*10%*
71	**Back Pressure**	**Constant Superimposed**		*34.65*
72		**Variable Superimposed**		*0*
73		**Built-Up**		*25*
74		**Total**		*59.65*
75	**Inlet Loss**		*0*	*0%*
76	**Atmospheric (Barometric)**		*14.696*	*psia*
77	**Relieving (Flowing)**		*130.196*	*psia*
78	***Temperatures***		**Unit**	**°F**
79	**Operating**	**Relieving**		*100*
80	**Design Min**	**Design Max**		

Tag Notes

Valve Dimensions	
A	
B	
C	
Weight	

Fig. 7: Pentair PRV² sheet of PSV 16C-24.



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Quote Number:

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No	Prpd.	Chk.	Appr.	Date	Revision

Client: My Company
Location:
Project: My Project
End-User Ref. No.:
Project Ref. No.:

1	**Valve ID**			
2	Tag No.	11C-1		
3	Service			
4	PID No.			
5	Line No.			Quantity
6				1
7	**GENERAL**			
8	Valve Type	Balanced Bellows, Direct Spring-Op		
9	Safety / Relief	Safety	Balanced	Yes
10	Nozzle	Full	Bonnet	Vented
11	**CONNECTIONS**			
12	Inlet	4"		Standard
13	Outlet	6"		
14	**MATERIALS OF CONSTRUCTION**			
15	Body / Base			
16	Bonnet / Cylinder			
17	Nozzle			
18	Disc			
19	Seat	Metal		
20	Spindle			
21	Guide			
22	Spring			
23	Gaskets			
24	Bellows			
25	Cap Type			
26	NACE MR0175 (2002)			
27	Accessories			
28				
29				
30				
31	**SIZING / SELECTION SUMMARY**			
32	Valve Model No.	4P6JBS-E		
33	Brand	Crosby®		
34	Area (in²)	Calculated	Selected	6.075	7.206
35		Data Set	Orifice	ASME	P
36	Flow	Unit	Required	lb/hr	142890
37		Rated	Actual	169500.621	188334.023
38					
39	Estimated Reaction Force				
40	Estimated Noise Level (db)	112.2 at 100-ft			

Tag Notes

41	**SIZING DATA**			
42	Design Code	ASME Section VIII	Sizing Std.	API 520
43	Sizing Basis	Valve Capacity		
44	Fluid State at Inlet	Gas / Vapor		
45	Relieving Case	Pressure Relief		
46	*Fluid Properties*			
47	Fluid Name	HC		
48	Molecular Weight, M	92		
49	Compressibility, Z	0.867		
50	Ratio of Sp. Heats, k (Cp / Cv)	1.28		
51	Gas Constant, C	345.1		
52				
53				
54				
55				
56				
57				
58				
59	*Sizing Coefficients*		Unit	-
60	K, Gas	Kd, Gas	0.866	0.962
61	Kb	Kc	0.997	1
62				
63				
64	*Required Capacity*		Unit	lb/hr
65	Total		142890	
66				
67	*Pressures*		Unit	psig
68	MAWP	Operating		
69	Set	CDTP	180	181.80
70	Over Pressure		18	10%
71	Back Pressure	Constant Superimposed		40
72		Variable Superimposed		0
73		Built-Up		14
74		Total		54
75	Inlet Loss		0	0%
76	Atmospheric (Barometric)		14.696	psia
77	Relieving (Flowing)		212.696	psia
78	*Temperatures*		Unit	°F
79	Operating	Relieving		310
80	Design Min	Design Max		

Valve Dimensions	
A	
B	
C	
Weight	

Fig. 8: Pentair PRV^2 sheet of PSV 11C-1.

Table 1: Flue gas composition

Components	Mole fractions
Carbon dioxide	0.0922
Nitrogen	0.7872
Water vapors	0.0545
Oxygen	0.0622

the column from the top and is vented to the atmosphere. Rich MEA solution containing CO_2 is then entering the stripping section where CO_2 is separated from the solution by warming it. The recovered MEA solution is again transported to the absorption section subsequently passing over the heat exchangers where the solution is cooled to 30°C. Since some of the MEA solutions is also lost; therefore make-up MEA solution is regularly added to the system. The simulation was run from 1 to 200 MMSCFD for flue gas, the composition was taken from the literature as given in Table 1 [18, 19].

Thermodynamic properties

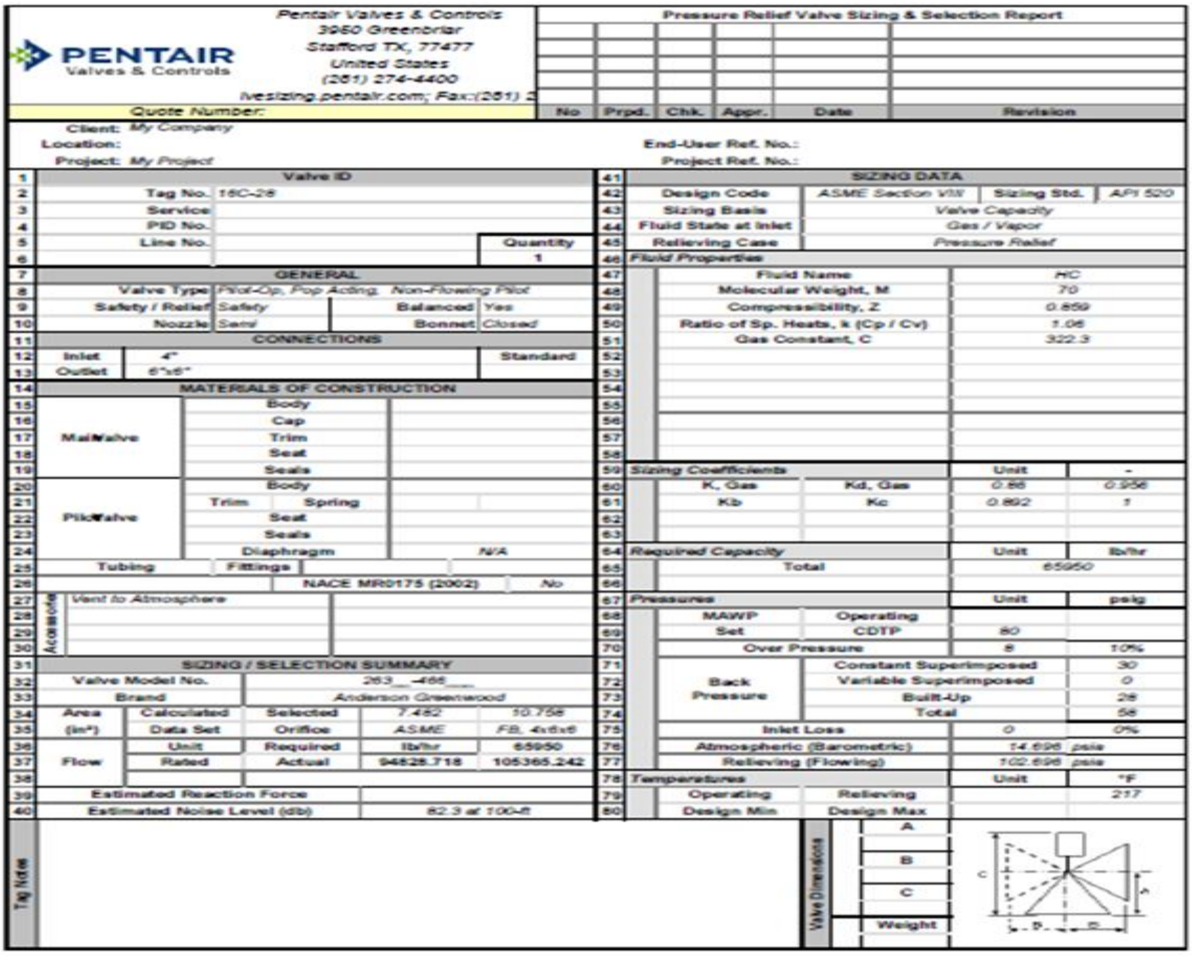
For the simulation of the CO_2 absorption unit, an anime package is utilized. Figure 10 shows the simulation accomplished on the Kent-Edinburg model. Typical equipment utilized in simulation absorber, regenerator, reboiler and condenser, siphons, pre radiator, cooler, and blender.

Overall mass balance is given in Table 2.

Overall energy balance is given in Table 3

Case Study 1

Controlled parameter: CO_2 fraction recovered by the regenerator, observed parameters: Reboiler and condenser



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No	Prpd.	Chk.	Appr.	Date	Revision

Client: My Company
Location:
Project: My Project

End-User Ref. No.:
Project Ref. No.:

1	Valve ID				
2	Tag No.	16C-28			
3	Service				
4	PID No.				
5	Line No.				Quantity
6					1
7	GENERAL				
8	Valve Type	Pilot-Op, Pop Acting, Non-Flowing Pilot			
9	Safety / Relief	Safety		Balanced	Yes
10	Nozzle	Semi		Bonnet	Closed
11	CONNECTIONS				
12	Inlet	4"			Standard
13	Outlet	6"x6"			
14	MATERIALS OF CONSTRUCTION				
15	Main Valve	Body			
16		Cap			
17		Trim			
18		Seat			
19		Seals			
20	Pilot Valve	Body			
21		Trim	Spring		
22		Seat			
23		Seals			
24		Diaphragm		N/A	
25	Tubing	Fittings			
26			NACE MR0175 (2002)		No
27	Accessories	Vent to Atmosphere			
28					
29					
30					
31	SIZING / SELECTION SUMMARY				
32	Valve Model No.	263__-466__			
33	Brand	Anderson Greenwood			
34	Area	Calculated	Selected	7.482	10.758
35	(in²)	Data Set	Orifice	ASME	FB, 4x6x6
36	Flow	Unit	Required	lb/hr	65950
37		Rated	Actual	94828.718	105365.242
38					
39	Estimated Reaction Force				
40	Estimated Noise Level (db)			82.3 at 100-ft	

41	SIZING DATA			
42	Design Code	ASME Section VIII	Sizing Std.	API 520
43	Sizing Basis	Valve Capacity		
44	Fluid State at Inlet	Gas / Vapor		
45	Relieving Case	Pressure Relief		
46	Fluid Properties			
47	Fluid Name		HC	
48	Molecular Weight, M		70	
49	Compressibility, Z		0.859	
50	Ratio of Sp. Heats, k (Cp / Cv)		1.06	
51	Gas Constant, C		322.3	
52				
53				
54				
55				
56				
57				
58				
59	Sizing Coefficients		Unit	-
60	K, Gas	Kd, Gas	0.86	0.956
61	Kb	Kc	0.892	1
62				
63				
64	Required Capacity		Unit	lb/hr
65	Total		65950	
66				
67	Pressures		Unit	psig
68	MAWP	Operating		
69	Set	CDTP	80	
70	Over Pressure		8	10%
71	Back Pressure	Constant Superimposed		30
72		Variable Superimposed		0
73		Built-Up		28
74		Total		58
75	Inlet Loss		0	0%
76	Atmospheric (Barometric)		14.696	psia
77	Relieving (Flowing)		102.696	psia
78	Temperatures		Unit	°F
79	Operating	Relieving		217
80	Design Min	Design Max		

Tag Notes

Valve Dimensions	
A	
B	
C	
Weight	

Fig. 9: Pentair PRV² sheet of PSV 16C-28.

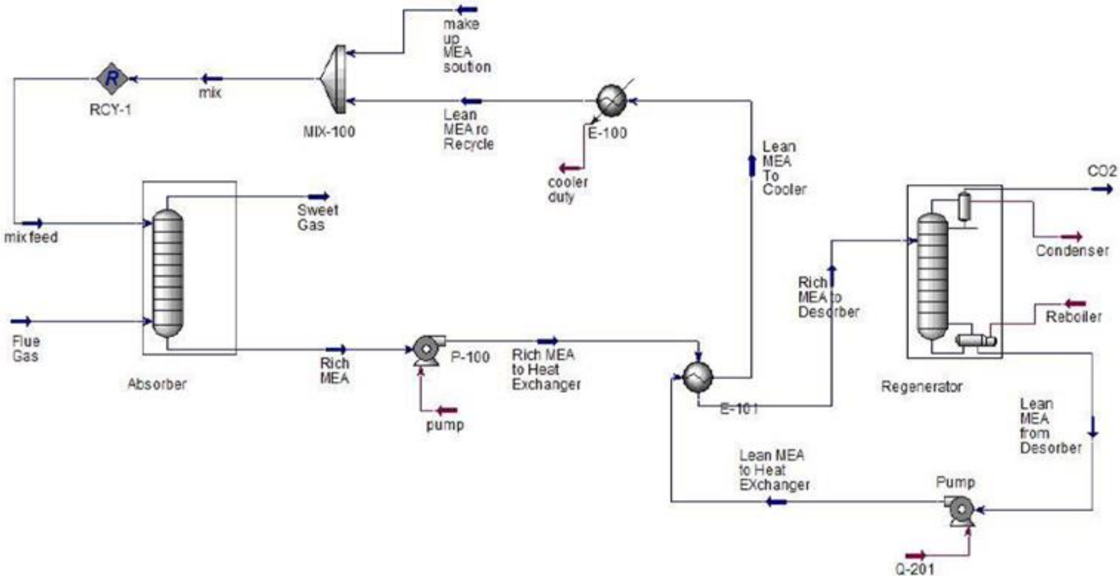


Fig. 10: Simulation flow sheet of absorption.

Table 2: Overall mass balance

In-Stream	Count Mass Flow (kg/h)	Out Stream	Count Mass Flow (kg/h)	In-Stream	Count Mass Flow (kg/h)
Flue gas	14550.00	Sweet gas	13720.00	Flue gas	14550.00
Makeup water	641.6	CO_2 out	1478	Makeup water	641.6
Total in mass flow (kg/h)	15190.00	Total out mass flow (kg/h)	15200.00	Total in mass flow (kg/h)	15190.00
Mass in balance (kg/h)	9.348	Mass in balance (%)	0.06	Mass in balance (kg/h)	9.348

Table 3: Overall energy balance.

Stream	Count Energy Flow (kW)	Out Stream	Count Energy Flow (kW)
Flue gas	1146.00	Sweet gas	1352.00
Reboiler	3293.00	Condenser	1842.00
Makeup water	-325.30	CO_2	89.48
Q-201	0.06	Cooler duty	829.70
Pump	0.82	-	-
In energy flow	4115.00	Total out the energy flow	4113.00
Energy in balance (%)	-2.02	Energy in balance (%)	-0.05

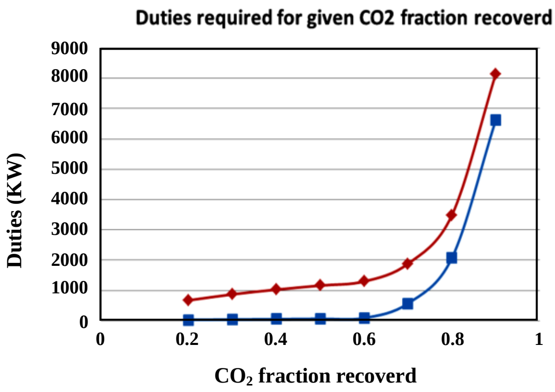


Fig. 11: Reboiler and condenser duties.

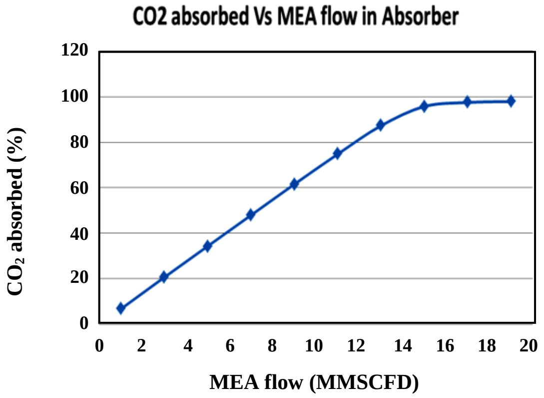


Fig. 12: Effect of MEA flow on CO_2 absorbed.

duties. A base case of flue gas of 10 MMSCFD with 13.5 MMSCFD MEA's solution is selected for comparative analysis with composition, 0.705 MMSCFD of makeup MEA solution is added to recycle stream. Simulation is done for various CO_2 recoveries in regeneration to measure condenser and reboiler duties as present in Fig. 11 [20, 21].

Case Study 2

Controlled Parameter: MEA flow rate, observed parameter: Carbon dioxide absorbed a percentage. With the increasing recovery of more than 80%, condenser and reboiler duties rise significantly. Hence recovery of 80% is designated for the base case. For a constant flow of Flue Gas (10 MMSCFD), simulation is performed on different flows of MEA Solution. The amount of MEA solution used affects the absorption of CO_2 as shown in Fig. 12.

By rising MEA flow afar 13.5 MMSCFD, the absorption comes continuously. Therefore it is chosen for the base case. Due to the limitations of the MEA solution, a 30-weight percent solution of MEA with water is used. The simulation was performed for different flow rates while maintaining a constant Recovery of CO_2 at 80 % in the regenerator column. At different flow rates of flue gas consumption of MEA solution, reboiler, and condenser

Table 4: Equipment's duties at different flow rates.

Flue gas (MMSCFD)	MEA Solution (GPM)	Reboiler Duty (KW)	Pumps Duty (KW)	Condenser Duty (KW)	Cooler Duty (KW)
1	6.58	297.67	0.111	158.95	78.31
5	33.91	1700.45	0.572	986.71	418.7
10	67.31	3468.3	1.1356	2053.3	833.27
20	134.63	7050.1	2.27	4223.1	1670
50	336.57	17636.2	5.68	10553.24	4145.5
75	503.61	25958.6	8.49	15372.9	6212
100	673.14	34668	11.36	20528	8384
150	1032.16	54125.8	17.44	32528.47	13206
200	1371.2	73677	23.184	44970	17652.58

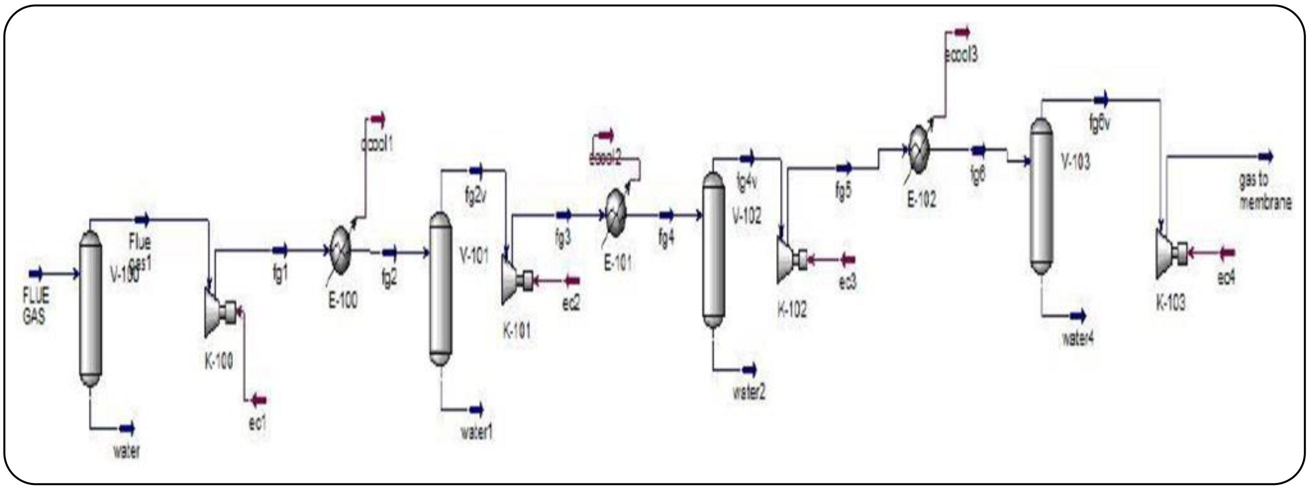


Fig. 13: Simulation sheet of water removal

duties, pump electrical consumption, and utility usage is measured and shown in Table 4. The amine treatment process was simulated and case studies show that the carbon dioxide absorbed percentage is increased as the flow rate of the amine process is increased, as want to increase the recovery of absorbed carbon dioxide from lean amine, and the reboiler duty also increases [16, 21].

Membrane Separation

The membrane separation procedure requires the gas to treat, free from any moistness. The vent gases from the flare holds water. Fig. 13 represents the simulation of the first stage of removal of the water and compressor framework.

The flue gas was initially sent to a separator where some amount of water was evacuated; the subsequently treated gas was passed to the cooler. A subsequent separator was utilized to accomplish moisture expulsion. In the membrane separation unit, the resultant gas was compressed utilizing two compressors to 20 bar and fed to the primary phase. The first stage permeate is then compressed to 20 bar afore entering the second stage. Likewise, in the second stage, in the third stage, permeate is also compressed to 20 bar. Fig. 14 is the compressor system simulation flow sheet of the 2nd and 3rd stage membrane skids.

Process Model

The equation used for membrane separation calculations is as follows:

$$(\Theta(1-\alpha) + R(1-\Theta)(1-\alpha))Yp2 + (1-(1-\alpha)(\Theta+Yf) - R(1-\Theta)(1-\alpha))Yp - \alpha(Yf) = 0$$

$$A = \Theta(1-\Theta)FfYp\,/Q(P1(Yf-\Theta Yp)-(P2Yp(1-\Theta))$$

where; $\alpha = CO_2/N_2$ selectivity, Yp =Mole fraction of CO_2 at permeate side, R=Pressure ratio (P_2/P_1), Yf =Mole

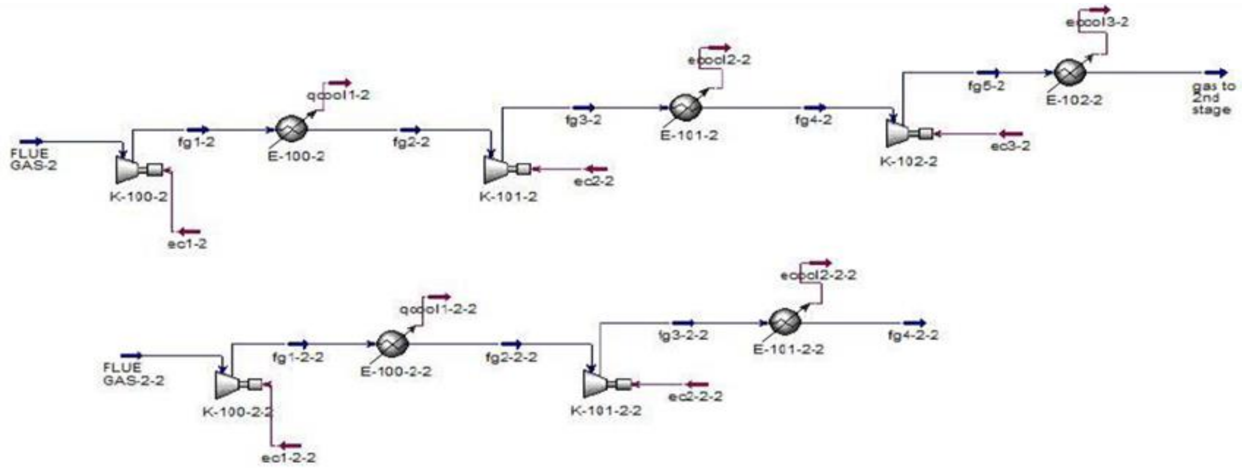


Fig. 14: Simulation sheet of 2nd and 3rd stage of membrane process

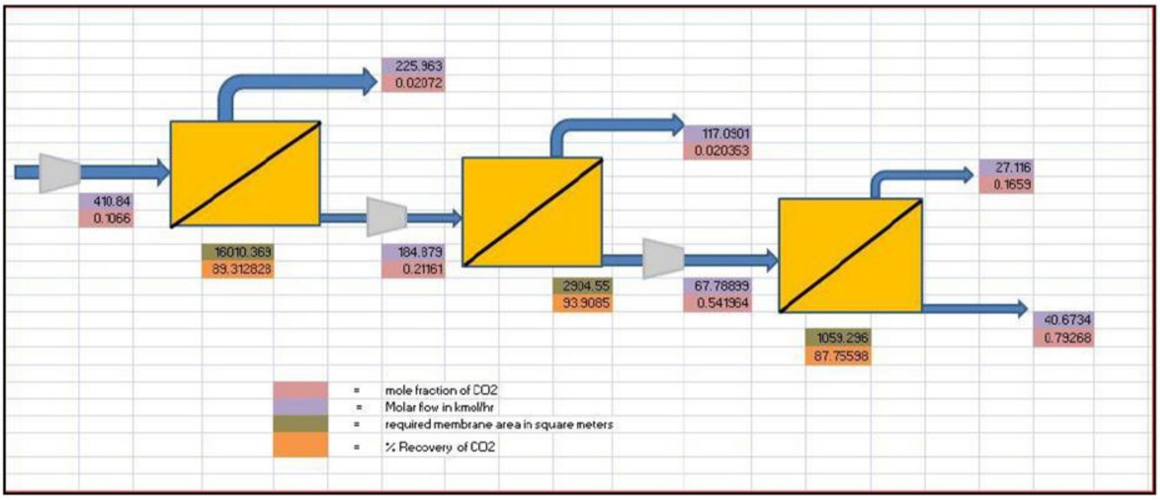


Fig. 15: Excel programming flow sheet.

fraction of CO_2 in the feed stream, A= Effective membrane area, V=Permeation rate, Q= CO_2 permeability, P1= Feed side pressure, P_2= Permeates side pressure and ϴ= Cut or fraction of permeate (ratio of the flow rate of permeate stream to flow rate of feed).

The process consists of three stages of membrane separation. Iterations were performed at different gas flow rates ranging from 1-200 MMSCFD. The power and membrane area required for each stage of the process was calculated [17, 20].

Typical Equipment

Typical equipment includes multistage compressors with inter-stage coolers, two-phase separators, and hollow-fiber cellulose acetate membrane skids. The membrane separation unit was simulated by linking some parameters from ASPEN HYSYS like flue gas flow rate, and compositions in the EXCEL sheet then the model equations of membrane separation were utilized to make a complete program for calculating and optimizing the process. Below is the excel sheet diagram in Fig. 15.

Case Studies

Controlled Parameter: ϴ (Fraction of permeate), observed parameters: Yp (Concentration of CO_2 in permeate stream), Required membrane area, Recovery percentage.

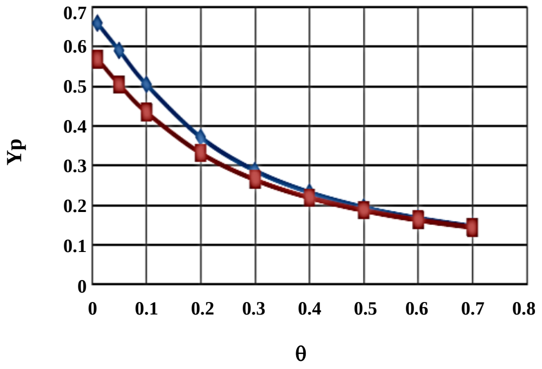


Fig. 16: First stage trend.

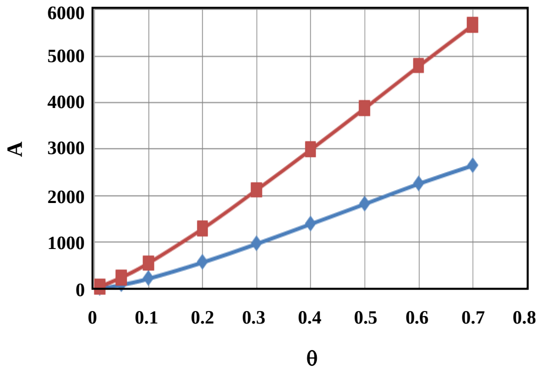


Fig. 17: First stage trend.

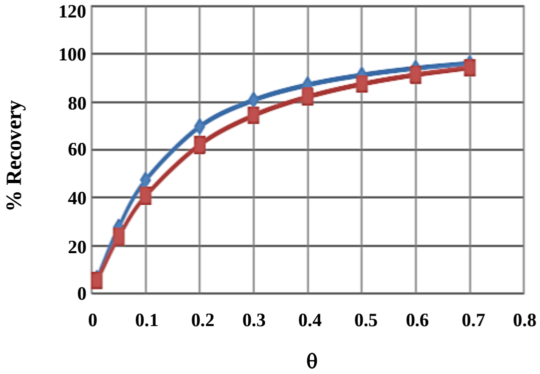


Fig. 18: First stage trend.

First stage

On plotting the mole fraction of carbon dioxide (Yp) versus ϴ, a declining curve was obtained as shown in Fig. 16. When the permeation rate is low, the concentration of carbon dioxide in the permeate stream is maximum. As more moles permeate, the concentration of carbon dioxide (Yp) is decreased in Fig. 16.

On plotting area (A) versus ϴ, an increasing curve was obtained as shown in Fig. 17. As the perimeter ϴ increases, the membrane area increases. This is due to the number of moles permeated increases, and gases other than carbon dioxide may permeate, thus decreasing the concentration of carbon dioxide [10, 11].

On plotting the perimeter ϴ versus percent recovery, an increasing curve is obtained in Fig. 18. The reason is that as perimeter "ϴ" increases, the number of carbon dioxide moles increases thus increasing the overall recovery.

Second Stage

For the second stage of the membrane separation unit, the results and plots obtained are as in Fig. 19.

Third Stage

For the third stage of the membrane separation unit, the results and plots obtained are as in Fig. 20.

After running case studies, the optimum parameters selected are given in Table 5.

The detailed result sheet for the membrane separation process is shown in Table 6.

Absorption and membrane separation comparison

The financial analysis of the membrane and absorption method is conveyed utilizing ASPEN Economic Analyzer V8.4.

Equipment cost comparison

The monetary investigation for the capital expense of hardware is conveyed for the flue gas rate of 10 MMSCFD. For the flue gas stream of 10 MMSCFD, the apparatus budget of the membrane procedure is significantly greater than the absorption process. For the membrane process, the apparatus cost is approximately 8.87 million USD whereas it is 4.69 million USD for the absorption process as appeared in Figure 21 [22, 23].

Operating cost comparison

The working cost is analyzed based on utility utilization by each procedure. The working examination is made for a flue gas flow rate running somewhere in the range of 1 and 200 MMSCFD. The working expense absorption process is higher in contrast with the membrane process as shown in Fig. 22. For 10 MMSCFD flow of vent

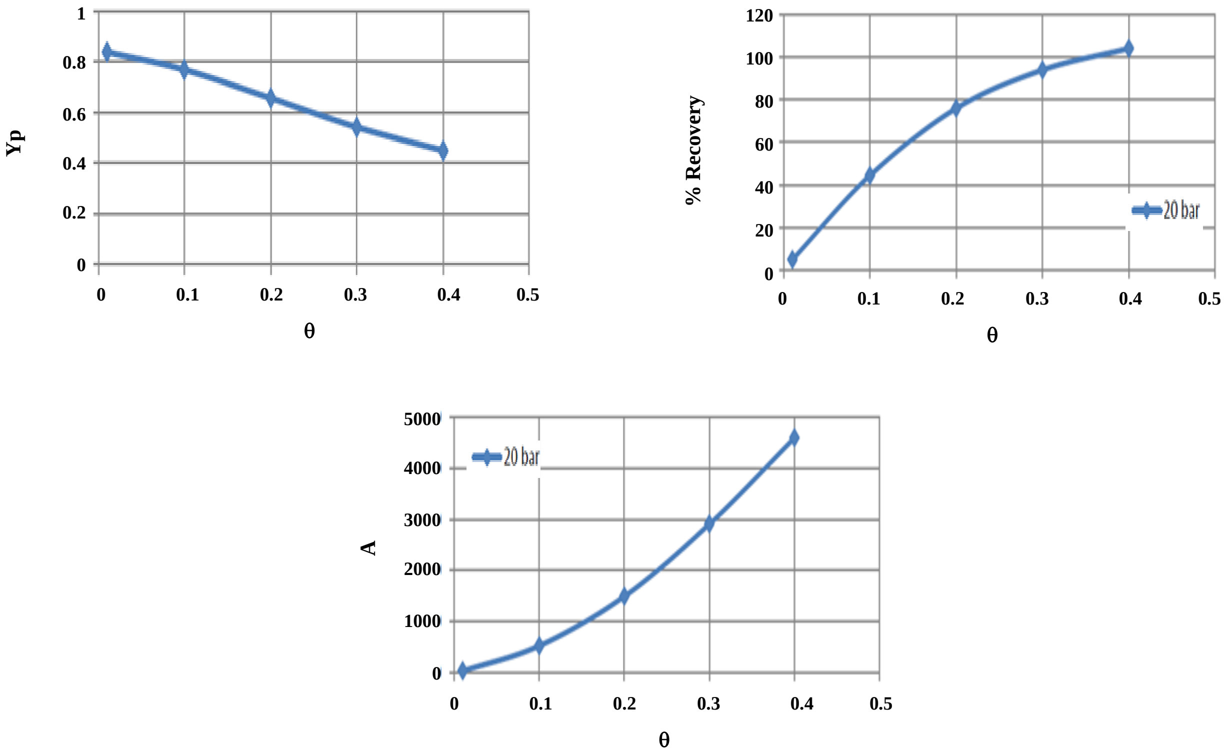


Fig. 19: Second stage trends.

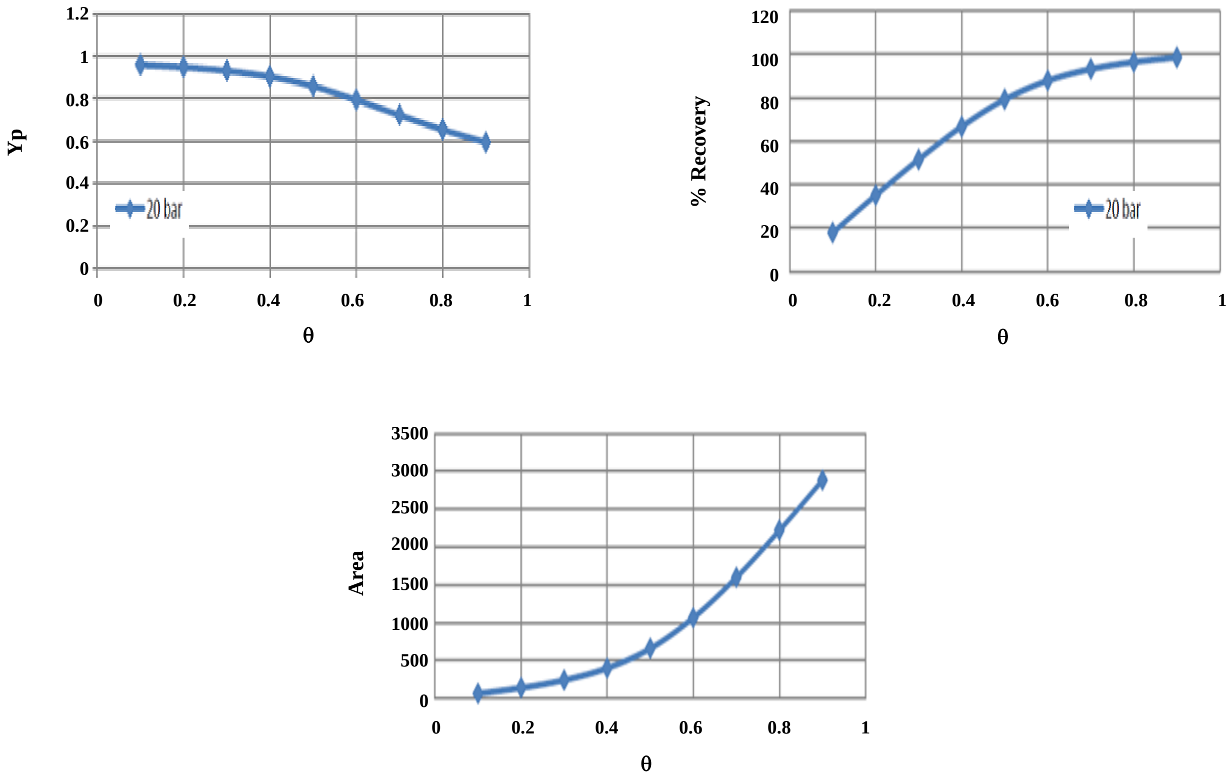


Fig. 20: Third stage trends.

Table 5: Process parameters.

Parameters	Value
Permeability of CO_2	10 barrier
The selectivity of CO_2/N_2 mixture	25
Permeability of N_2	0.4 barrier
ϴ (1st stage)	0.45
ϴ (2nd stage)	0.3
ϴ (3rd stage)	0.6
Permeate side pressure of each stage	1 bar
Inlet pressure of each stage	20 bar

Table 6: Result sheet for membrane separation process.

Flue gas (MMSCFD)	1st Stage Power (KW)	Membrane area (m^2)	2nd stage Power (KW)	Membrane area (m^2)	3rd stage Power (KW)	Membrane area (m^2)	Total power (KW)
1	126.3484	1601.037	59.2722	290.45	20.79604	105.93	206.41665
5	631.7375	8005	296.3508	1452.3	103.9802	529.64	1032.0684
10	1263.547	16011.18	592.722	2904.69	207.9604	1059.35	2064.2292
20	2526.97	32020	1185.24	5809	415.9373	2118.6	4128.1478
50	6317.426	80051	2963.498	14522.7	1039.802	5296.47	10320.725
75	9476.114	120077.8	4445.16	21784	1559.786	7944.72	15481.059
100	12634.85	160103	5927.016	29045	2079.604	10593	20641.472
150	18952.43	240155	8890.32	43568	3119.405	15889	30962.158
200	25268.88	320207	11853.42	58090	4159.39	21185	41281.692

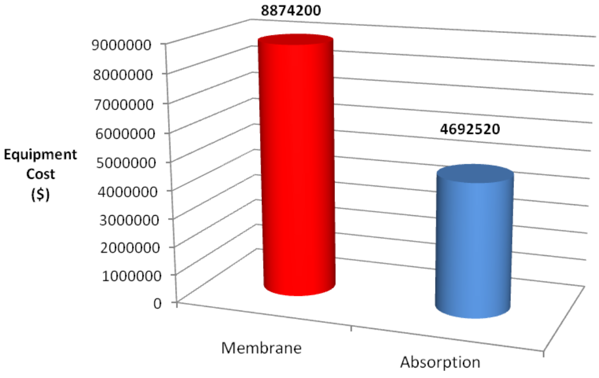


Fig. 21: An equipment cost comparison.

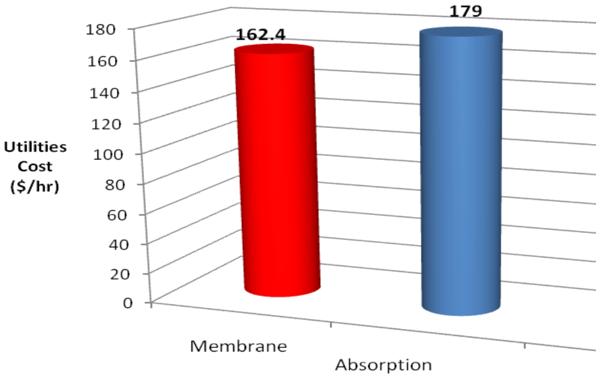
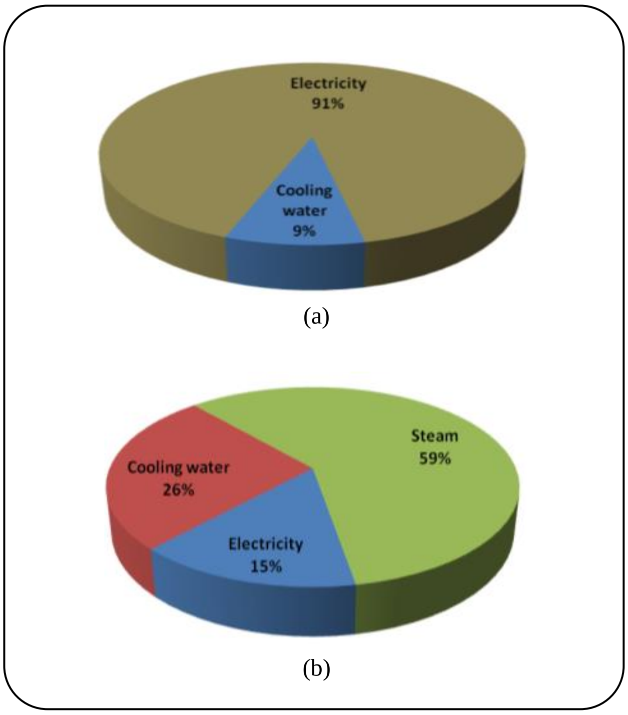


Fig. 22: Utilities cost comparison.

gas, the working or utility expense of the membrane procedure is 162.4 USD/h and 179 USD/h for the absorption process. This gap in working cost increments as the flow rate of pipe gas increments [4, 23].

Utility distribution comparison

As discussed above that the major utility for the absorption process is steam whereas for the membrane process the major utility is electricity. In the membrane process,



(a)

(b)

Fig. 23: Utility consumption for (a) membrane process and (b) absorption.

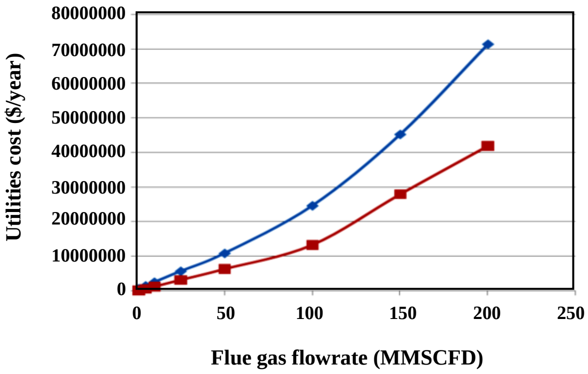


Fig. 24: Utility cost for different gas flow rates.

91% of the total operating cost came from electricity consumption and 9% from cooling water consumption. And for the absorption process steam constitute 59% of the total operating cost, cooling water 26%, and electricity 15%. The pie charts are shown in Fig. 23 [2].

Capacity and the Operating Cost

The case study is carried out for evaluating the operating cost of both absorption and membrane processes for the flue gas flow rate is ranges from 1 - 200 MMSCFD, the trend in Figure 25 shows that the operating rate of the absorption process is greater than that of the membrane process. But when the flow is greater the required membrane area increases largely and the other parameters of the membrane process become difficult to control, that is why the membrane process is only suitable for small to medium-scale processes [1, 7].

CONCLUSIONS

Capacity evaluation for the power failure scenario was carried out. The PSVs with backpressure exceeding the limits were resized using vendor-based software "Pentair PRV^{2}SIZE" which uses design code "ASME Section VIII" and sizing standards of "API 520". Absorption procedure is as yet a superior procedure since it is broadly concerned and creates reliable outcomes while membrane procedure is still under examination for commercialization. Factors like degradation of the membrane, permeability, selectivity, and life-cycle should be improved to supplant the absorption process with membrane separation. According to this research, the membrane process has a lower working expense than the absorption process however the outcome is for a new membrane as the membrane degradation factor is not considered. The absorption procedure can produce high purity of CO_2 capture up to 98 mole% as compared to the membrane process. Different parameters to consider include the maintenance cost that is higher for the absorption process, and performance decrease with time which is a significant worry in membrane separation. Finally, membrane separation is efficient for small to the medium flow of flue gases, and higher stream rate absorption is the favored procedure. In the future, if the problems concerning membrane degradation and its life cycle have improved, at precisely that point the membrane separation can supplant the absorption process.

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