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Design Alternatives for High Ratio Compressor Stations

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ABSTRACT

While the transmission compressor stations in pipelines normally operate at relatively low pressure ratios in the order of 1.2 to 1, there are applications that require significantly higher pressure ratios. This paper presents the results of a study conducted for a compressor station design where multiple pipelines feed into one new pipeline. One of the feeder pipelines is designed for significantly lower pressures than the other feeder and the transmission line. As a result, some operating conditions require a very high compression ratio, in some instances as high as 2.8 to 1. The purpose of the study is to select the best feasible turbocompressor unit for the project between two technical available options with different technologies: single compartment and dual compartment compressors. The methodology adopted is designing a (i) compressor station configuration for single compartment compressor technology with aftercooler and for (ii) dual compartment compressor technology with intercooler and aftercooler, pre-selecting the compressor units to address all operating conditions, perform thermohydraulic simulations, evaluate the gas fuel demand for each year of operation and then evaluate the economics for each alternative. The paper can serve as a guide line for compressor station designers to make decisions not only based on technical aspects – that could lead to higher project life cycle cost – but rather on overall technical and economic aspects that produces lower project life cycle cost.

INTRODUCTION

The design philosophy for choosing a turbocompressor unit should includes the following items:

(a) Good efficiency over a wide range of operating conditions
(b) Maximum flexibility of configuration
(c) Low maintenance cost
(d) Low lifecycle cost
(e) Acceptable capital cost
(f) High availability

METHODOLOGY

The methodology adopted for this case study considers the following steps:

1. Identify the ambient temperatures to be adopted for the project based on Summer, Winter and Average weather conditions;
2. Define technical assumptions for the project such as gas supply curves, gas compositions, capacity ramp up curve, suction and discharge pressures, suction temperatures, pressure drops at suction and discharge headers of the compressor station, coolers downstream controlled temperature, etc.;
3. Identify possible alternatives for the compressor station turbocompressor configuration;
4. Acquire from manufacturers the performance maps for centrifugal compressor and gas turbine;
5. Model the turbocompressor units to be simulated by using a simulation software;
6. Evaluate operation conditions for compressor and gas turbine;
7. Obtain the equipment, maintenance and operation costs;
8. Identify the economic assumptions for the feasibility study;

9. Project's final decision selecting the most feasible project configuration.

CASE STUDY

This case study is based on a header compressor station that feeds a pipeline with natural gas up to 10 BNCMY *(373 BSCFY)* with two different gas supplies. Each gas supply has its characteristics supply curve. The compressor station is shown in figure-1 and the centrifugal compressor units has been evaluated in two alternatives as described below and shown in figure-2:

Alternative I:

Centrifugal compressor type:	Single compartment
Gas supply:	Source A + Source B

Alternative II:

Centrifugal compressor type:	Dual compartment with intercooler
Gas Supply:	Source A + Source B

TECHNICAL ASSUMPTIONS

Gas specific gravity:	0.59 and 0.61
Compressor Station	
Suction Pressure:	
Pipeline A:	3.50 MPag *(508 Psig)*
Pipeline B:	5.00 to 7.00 MPag *(725 to 1015 Psig)*
Compressor Units	
Discharge pressure (flange):	9.81 MPag *(1423 Psig)*
Compressor Driver	
Gas turbine:	15000 kW ISO *(20115 hp ISO)*
Intercooler pressure drop:	70 KPa *(10.2 Psi)*
Intercooler downstream temperature:	53 C *(127.4 F)*
Site elevation	0 meter *(feet)*
Site ambient temperature:	25.0 C *(77 F)*
Quantity of standby compressor units: *	1

* Note: As Santos (2009) the best definition of the quantity of standby compressor units takes into account operation conditions and makes use of Monte Carlo simulation.

THERMOHYDRAULIC SIMULATION

The thermohydraulic simulation studies have been performed using the software *PipelineStudio* 3.3.1.0 from Energy-Solutions Inc. with Peng-78 (Peng and Robinson equation of state published in 1978) and in steady state mode. The thermohydraulic results for Alternatives I and II and for different capacities and average weather condition are presented in tables 1 and 2. Installation of required compressor station units is presented in tables 3 and 4. Fuel gas consumption is presented in table 5.

ECONOMIC EVALUATION

The economic evaluation for the compressor station configurations (alternative I and II) takes into account only what is different between the alternatives such as CAPEX and OPEX for the turbocompressor units including intercoolers. All that is the same, for both alternatives, e.g. compressor housing, gas turbine drivers, facilities, suction and discharge headers with scrubbers, piping, valves and also operation personnel, was not accounted for in the analysis.

To support the economic evaluation the following assumptions were considered:

Economic Assumptions

• Construction schedule:	1 year
• Single Compartment Compressor Unit:	2.450 MMUS$
• Dual Compartment Compressor Unit with valves, piping and fittings:	2.854 MMUS$
• Installed Intercooler (Dual Comp.) with valves, piping and fittings:	1.540 MMUS$
• Compressor station operating units:	4
• Standby compressor unit:	1
• Compressor station Incremental CAPEX for Dual Compartment Compressors (Atl. II) due to larger footprint area:	0.120 MMUS$
• O&M (without Fuel):	5% of CAPEX
• Depreciation:	30 years
• Taxes:	40%
• Fuel price, US$/1000 SCM:	170
• Discount rate:	12% a year
• Economic life:	30 years

Note: Investments on required equipment assumed to be done 1 year before they come into operation.

Economic Results

The economic results based on the CAPEX, OPEX and Fuel Gas Expenses schedule (tables 6 and 7) for Alternatives I (Single Compartment Compressors) and II (Dual Compartment Compressors) are measure based on the Present Value (PV) of each alternative.

To support selecting the best alternative we have adopted the following criteria based on the lowest Present Value based on the economic assumptions previously defined and the CAPEX, OPEX and Fuel Gas expenses presented in table 7:

$$PV = \sum_{t=0}^{n} \frac{C_t}{(1+R)}$$

$$C_t = Cash\ flow(costs)\ at\ period\ t$$

$$R = Discount\ rate$$

$$t = period\ of\ time$$

1. The lowest Present Value of CAPEX + OPEX + Fuel Gas (from table 7):
   Alternative I (Single): PV = -145.26
   Alternative II (Dual): PV = -157.50
2. The lowest Present Value for CAPEX only (from table 7):
   Alternative I (Single): PV = -10.41
   Alternative II (Dual): PV = -18.46

Based on the results of items (1) and (2) above we select Alternative I (Single Compartment Compressors) as the optimum alternative with a saving of 12.24 MMUS$ in Present Value of CAPEX + OPEX + Fuel Gas and with a saving of 8.05 MMUS$ in Present Value of CAPEX only.

BEST CRITERIA SELECTION

Whenever Compressor Station designer needs to select compressor units he should keep in mind this rule of thumb that will – most of the time – favor single compartment compressor selection for gas pipeline compressor station:

- Simplicity of installation: lower CAPEX;
- Simplicity of operation and maintenance: lower OPEX;
- High efficiencies: lower OPEX;
- Wide range of operation: increased operation flexibility;

When Dual Compartment May Be Required

Dual compartment centrifugal compressor may be required whenever discharge temperature is higher than the practical value of 135 C *(275 F)* as established by Gas Processors Suppliers Association – GPSA. Above this value it would cause carbonization, risk of fire and/or packing life reduction. A limit of 148.8 C *(300 F)* or 176.7 C *(350 F)* is suggested by GPSA when there is no oxygen in the gas stream. Use of intercooler will guarantee that the compressor unit discharge temperature will be lower than maximum allowed.

ASME B16.5 – Pipe Flanges and Flanged Fittings specifies that at operating temperature range from -29 up to 150 C the working pressure is up to 100.3 barg (10.03 MPag) under Class 600# and above 150 up to 200 C class 900# should be adopted for flanges, accessories and auxiliary equipment such as intercoolers and aftercoolers with negative impact in CAPEX.

If operation conditions (gas composition, suction temperature and compression ratio) will not cause compressor unit discharge temperature go above 135 or 150 C there is no reason to justify selecting dual compartment compressor but single compressor will be a much better technical and economical selection.

Dual Compartment Disadvantages in comparison to Single Compartment:

- Incremental CAPEX due to more complex compressor;
- Incremental CAPEX due to additional required equipment such as intercooler, valves, fittings, piping and instrumentation;
- Larger footprint area due to bigger and heavier compressors and consequently bigger and costly concrete base and compressor housing, increasing CAPEX;
- Higher probability of unscheduled outages due to more components e.g. intercooler, valves, piping and instrumentation and control, negatively affecting compressor station availability exposing Operation Company to potential losses of revenue and to contractual penalties for not delivering the agreed upon gas volumes;
- More items to maintain, increasing OPEX;
- More costly commissioning, increasing OPEX;
- More complex operation, increasing OPEX;

Higher probability of gas leakage due to more flanged connections, increasing operation risks and OPEX.

Sensitivity Analysis

In order to verify the advantages of the single compressor design (figure 3) versus dual compressor design (figure 4), where both equipment can fulfill operation requirements for a projet, we ran design set of operation conditions to quantify such advantages using two approaches.

(i) First approach: Single compartment compressor operating at 100% duty and dual compartment compressor with exactly the same stages as the single compartment split up evenly between two compartments. Dual compartment compressor, performing the same service duty, required 1.3% more power. This power requirement increase is a cconsequence of one more exit conection (first compartment) and one more inlet connection (second compartment) that produces pressure drops as compressor gas leaves on compartment and enters into the other.

(ii) Second approach: Same as approach (i) but adding intercooler with downstream temperature set up at 10 Celcius degrees above ambient temperature. Compression power requirement in comparison to approach (i) was reduced down to 97.9%, providing only just over 2.1% power reduction compare to the single compartment design.

Since feasibility analysis for equipment selection takes into account technical and economical aspects – as developed in this paper – this small power reduction do not overcome the overall benefit from single compartment compressor with much lower CAPEX requirements as quantified previously in the Economic Evaluation paragraph and justified at Best Criteria Selection paragraph.

CONCLUSION

The technical and economical evaluation performed on this case study identifies Single Compartment Compressor (Alternative I) as the optimum technical and economical alternative for projects where discharge temperature is lower than 135 C *(275 F)*.

This result is supported by some important advantages of Single Compartment Compressor against Dual Compartment compressor as listed below.

Advantages of Single Compartment Compressor:

- Simple design;
- Easy to install, commission, operate and maintain;
- Lower CAPEX and OPEX;
- High efficiency and flexible range of operation.

Disadvantages of Dual Compartment Compressor:

- Complex design
- More complex and costly installation since requires the installation of intercooler, two surge control systems, more valves, piping and fittings per compressor unit;
- Compressor station commissioning and start up take more time, are more expensive and require more qualified professionals;
- Higher CAPEX and OPEX for the compressor station;
- Operation of Dual Compartment Compressors in parallel requires more qualified professionals, more accurate controls and more attention from operators with a narrower margin of operation (lower flexibility) in comparison with Single Compartment Compressors;
- Higher probability of unscheduled outages due to more components e.g. intercooler, valves, piping and instrumentation and control, negatively affecting compressor station availability exposing Operation Company to potential losses of revenue and to contractual penalties (if applied) for not delivering the committed gas volumes;
- More power demanding because the required intercooler with consequent negative impact on fuel gas demand;
- More complex and expensive maintenance

The methodology presented in this paper serves as a guideline to compressor station designer to identify and quantify the most important equipment that affects compressor station projects – the compressor unit – and to provide reliable information to support the decision making process for an optimum compressor unit selection.

REFERENCES

1. SANTOS, S. P., "Monte Carlo Simulation – A Key for a Feasible Gas Pipeline Design" In: Pipeline Simulation Interest Group, 2009, Galveston, Texas, USA.

ABOUT THE AUTHOR

Sidney Pereira dos Santos is Executive director of At Work Rio Engineering and Consulting. Has a B.S. in Mechanical Engineering at FTESM in Rio de Janeiro, 1983; MBA at UFRJ-COOPEAD in Rio de Janeiro, 2002; Master in Logistics at PUC-RJ, 2008. Twenty five years experience in gas pipeline design including thermohydraulic simulation, economic studies and quantitative risk analysis. Has authored and presented papers in ASME-IPC and PSIG Seminars and has some articles published in international technical magazines as *Pipeline & Gas Journal*, *Pipeline & Gas Technology* and *Elsevier Energy Policy Journal*. He is a former Petrobras Senior Consultant.

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TABLES

Table 1 – Thermohydraulic Results for Single Compartment Compressor (Alternative I)

YEAR	Supply	Comp. Units	Gas Specific Gravity	Station Flow		Temperatures at Comp. Flange				Pressures at Comp. Flange				Actual Flow		Head		Required PWR		Speed	Isentropic Efficiency	Total Fuel Gas	
				10^3*NCMH	(MMSCFD)	C		(F)		kPa		Psig		10^3 x m3/h	(10^3 x cf/h)	J/kg	(lbf-ft/lb)	kW	(hp)	RPM	%	Nm3/h	(SCFH)
1	A	2	0.614	485.2	434.53	25.0	118.9	77.0	246.1	3290	9810	477.2	1422.8	7,243	255,794	154,594	51,720	10,709	14,361	8,246	78.0	7,220	269,426
2 - 3	A	2	0.614	606.6	543.25	25.0	125.6	77.0	258.1	3290	9810	477.2	1422.8	9,056	319,795	154,961	51,843	14,447	19,374	8,855	72.5	7,984	297,914
4 - 6	A	3	0.614	727.8	651.80	25.0	118.9	77.0	246.1	3290	9810	477.2	1422.8	7,244	255,825	154,594	51,720	10,711	14,363	8,247	78.0	10,832	404,208
	B	1	0.593	485.2	434.53	25.0	54.0	77.0	129.3	6800	9810	986.3	1422.8	6,671	235,595	47,053	15,742	5,800	7,778	6,574	84.6	2,355	87,867
7 - 11	A	2	0.614	606.6	543.25	25.0	125.6	77.0	258.1	3290	9810	477.2	1422.8	9,056	319,795	154,961	51,843	14,447	19,374	8,855	72.5	7,981	297,813
	B	1	0.593	606.6	543.25	25.0	57.4	77.0	135.3	6600	9810	957.2	1422.8	8,622	304,500	51,287	17,158	8,146	10,923	7,233	82.1	3,349	124,987
12 - 14	A	2	0.614	485.2	434.53	25.0	118.9	77.0	246.1	3290	9810	477.2	1422.8	7,243	255,794	154,594	51,720	10,709	14,361	8,246	78.0	7,220	269,425
	B	1	0.593	727.9	651.89	25.0	62.6	77.0	144.7	6350	9810	921.0	1422.8	10,800	381,405	56,881	19,030	11,449	15,353	8,098	77.7	3,800	141,813
15 - 20	A	2	0.614	363.9	325.90	25.0	116.1	77.0	241.0	3290	9810	477.2	1422.8	5,432	191,845	154,429	51,665	7,766	10,414	7,740	80.6	6,598	246,191
	B	2	0.593	849.2	760.52	25.0	63.9	77.0	147.1	6040	9810	876.0	1422.8	6,659	235,157	64,011	21,415	6,949	9,319	7,456	84.1	6,857	255,872
21 - 26	A	1	0.614	242.6	217.27	25.0	118.9	77.0	246.1	3290	9810	477.2	1422.8	7,243	255,794	154,594	51,720	10,709	14,361	8,246	78.0	3,610	134,713
	B	2	0.593	970.5	869.15	25.0	69.0	77.0	156.2	5660	9810	820.9	1422.8	8,175	288,692	73,619	24,629	9,072	12,165	8,190	84.6	7,867	293,564
27 - 30	A	1*	0.614	121.3	108.63	25.0	116.2	77.0	241.1	3290	9810	477.2	1422.8	5,856	206,809	157,278	52,618	8,409	11,277	7,914	80.5	3,299	123,104
	B	3	0.593	1091.8	977.79	25.0	77.6	77.0	171.7	5190	9810	752.7	1422.8	6,873	242,731	88,882	29,736	8,452	11,334	8,609	82.2	10,532	393,012

(*) Operating in recycling

Table 2 – Thermohydraulic Results for Dual Compartment Compressor (Alternative II)

YEAR	Supply	Comp. Units	Gas Specific Gravity	Station Flow		Temperatures at Comp. Flange				Pressures at Comp. Flange				Actual Flow		Head		Required PWR		Speed	Isentropic Efficiency	Total Fuel Gas	
				10^3*NCMH	(MMSCFD)	C		(F)		kPa		Psig		10^3 x m3/h	(10^3 x cf/h)	J/kg	(lbf-ft/lb)	kW	(hp)	RPM	%	Nm3/h	(SCFH)
1	A	2	0.614	485.2	434.53	25.0	72.5	77.0	162.5	3290	5843	477.2	847.5	7,243	255,794	76,177	25,485	5,215	6,993	7,697	78.9	7,217	269,313
						53.0	100.1	127.4	212.2	5818	9810	843.8	1422.8	4,462	157,587	75,280	25,185	5,312	7,124		76.6		
2 - 3	A	2	0.614	606.6	543.25	25.0	76.7	77.0	170.1	3290	5832	477.2	845.9	9,056	319,795	76,062	25,447	7,142	9,577	8,425	71.9	7,931	295,951
						53.0	104.6	127.4	220.2	5793	9810	840.2	1422.8	5,605	197,932	76,118	25,466	7,303	9,793		70.4		
4 - 6	A	3	0.614	727.8	651.80	25.0	72.5	77.0	162.4	3290	5843	477.2	847.5	7,243	255,794	76,177	25,485	5,215	6,994	7,697	78.9	10,826	403,970
						53.0	100.2	127.4	212.3	5818	9810	843.8	1422.8	4,462	157,587	75,280	25,185	5,312	7,123		76.6		
	B	1*	0.593	485.2	434.53	25.0	54.5	77.0	130.2	6800	9810	986.3	1422.8	4,196	148,192	47,073	15,749	3,713	4,979	5,620	83.2	2,419	90,276
						25.0	55.8	77.0	132.5	6800	9810	986.3	1422.8	2,475	87,403	47,127	15,766	2,291	3,073		71.1		
7 - 11	A	2	0.614	606.6	543.25	25.0	76.7	77.0	170.1	3290	5832	477.2	845.9	9,056	319,795	76,062	25,447	7,142	9,577	8,425	71.9	7,931	295,952
						53.0	104.6	127.4	220.2	5793	9810	840.2	1422.8	5,605	197,932	76,118	25,466	7,303	9,793		70.4		
	B	1*	0.593	606.6	543.25	25.0	57.8	77.0	136.0	6600	9810	957.2	1422.8	5,382	190,072	51,303	17,164	5,145	6,899	6,135	81.2	3,454	128,898
						25.0	58.7	77.0	137.7	6600	9810	957.2	1422.8	3,240	114,428	51,343	17,177	3,192	4,280		78.8		
12 - 14	A	2	0.614	485.2	434.53	25.0	72.5	77.0	162.4	3290	5843	477.2	847.5	7,243	255,794	76,177	25,485	5,215	6,994	7,697	78.9	7,217	269,313
						53.0	100.1	127.4	212.3	5818	9810	843.8	1422.8	4,462	157,587	75,280	25,185	5,312	7,123		76.6		
	B	1*	0.593	727.9	651.89	25.0	62.9	77.0	145.3	6350	9810	921.0	1422.8	6,705	236,768	56,897	19,035	7,177	9,624	6,813	77.0	3,912	145,984
						25.0	63.8	77.0	146.8	6350	9810	921.0	1422.8	4,096	144,637	56,932	19,047	4,486	6,015		75.3		
15 - 20	A	2	0.614	363.9	325.90	25.0	70.1	77.0	158.2	3290	5842	477.2	847.3	5,432	191,845	76,069	25,449	3,708	4,972	7,169	83.1	6,387	238,332
						53.0	98.2	127.4	208.7	5828	9810	845.3	1422.8	3,341	117,975	74,940	25,071	3,806	5,104		79.8		
	B	2	0.593	849.2	760.52	25.0	56.6	77.0	133.9	6040	8563	876.0	1242.0	6,659	235,157	45,342	15,169	5,623	7,540	6,357	73.6	7,287	271,908
						53.0	71.8	127.4	161.3	8511	9810	1234.4	1422.8	5,259	185,709	20,040	6,705	3,479	4,666		52.6		
21 - 26	A	1	0.614	242.6	217.27	25.0	72.5	77.0	162.4	3290	5843	477.2	847.5	7,243	255,794	76,177	25,485	5,215	6,994	7,697	78.9	3,609	134,657
						53.0	100.1	127.4	212.3	5818	9810	843.8	1422.8	4,462	157,587	75,280	25,185	5,312	7,123		76.6		
	B	2	0.593	970.5	869.15	25.0	63.3	77.0	146.0	5660	8411	820.9	1219.9	8,175	288,692	52,174	17,455	7,887	10,577	7,301	69.0	8,388	312,998
						53.0	75.3	127.4	167.5	8341	9810	1209.8	1422.8	6,141	216,879	22,995	7,693	4,723	6,334		50.8		
27 - 30	A	1**	0.614	121.3	108.63	25.0	69.6	77.0	157.2	3290	5848	477.2	848.2	5,017	177,185	76,014	25,431	3,435	4,607	7,068	83.0	3,113	116,181
						53.0	98.2	127.4	208.7	5836	9810	846.4	1422.8	3,089	109,093	74,729	25,001	3,527	4,730		79.5		
	B	3	0.593	1091.8	977.79	25.0	60.1	77.0	140.2	5190	7726	752.7	1120.6	6,741	238,065	52,659	17,617	5,446	7,303	6,668	75.6	10,986	409,931
						53.0	80.9	127.4	177.6	7683	9810	1114.4	1422.8	5,032	177,690	35,180	11,770	4,486	6,016		61.3		

(*) Operating the two compartments in parallel
(**) Operating in recycling

Table 3 – Installation Schedule of Required Compressor Units for Alternative I

		Alternative I - Single Compartment Compressor				
Operation Year	Compressor Station Capacity, BCMY	Supply A		Supply B		Total Required Compressor Units
		BCMY	Compressor Units	BCMY	Compressor Units	
1	4	4	2 (7st)	-	-	2 (7st)
2 -3	5	5	2 (7st)	-	-	2 (7st)
4 - 6	10	6	3 (7st)	4	1 (3st)	3(7st)+1(3st)
7 - 11	10	5	2 (7st)	5	1 (3st)	2 (7st)+1(3st)
12 - 14	10	4	2 (7st)	6	1 (3st)	2(7st)+1(3st)
15 - 20	10	3	2 (7st)	7	2 (7st)	2(7st)+2(7st) (1unit restaged)
21 - 26	10	2	1 (7st)	8	2 (7st)	1(7st)+2(7st)
27 - 30	10	1	1 (7st)	9	3(7st)	1(7st)+3(7st)

Table 4 – Installation Schedule of Required Compressor Units for Alternative II

		Alternative II - Dual Compartment Compressor				
Operation Year	Compressor Station Capacity, BCMY	Supply A		Supply B		Total Required Compressor Units
		BCMY	Compressor Units	BCMY	Compressor Units	
1	4	4	2 (8st)	-	-	2 (8st)
2 -3	5	5	2 (8st)	-	-	2 (8st)
4 - 6	10	6	3 (8st)	4	1 (8st)*	4(8st)
7 - 11	10	5	2 (8st)	5	1 (8st)*	3(8st)
12 - 14	10	4	2 (8st)	6	1 (8st)*	3(8st)
15 - 20	10	3	2 (8st)	7	2 (8st)	4(8st)
21 - 26	10	2	1 (8st)	8	2(8st)	3(8st)
27 - 30	10	1	1 (8st)	9	3(8st)	4(8st)

(*) Operating in parallel

Table 5 – **Fuel Gas Consumption for Single and Dual Compartments Compressors**

	Single Compartment Compressor - Average Weather Condition Fuel Demand						Dual Compartment Compressor - Average Weather Condition Fuel Demand						Total Fuel Difference per Year (Single - Dual)	
	Supply A		Supply B		Total per Year		Supply A		Supply B		Total per Year			
Year	Nm3/h	*(SCFH)*	Nm3/h	*(SCFH)*	NMMCM	BSCF	Nm3/h	*(SCFH)*	Nm3/h	*(SCFH)*	NMMCM	BSCF	MMCM	BSCF
1	7,220	269,426	-	-	63.25	2.36	7217	269,313	-	-	63.22	2.36	0.0264	0.0010
2	7,984	297,914	-	-	69.94	2.61	7931	295,952	-	-	69.48	2.59	0.4607	0.0172
3	7,984	297,914	-	-	69.94	2.61	7931	295,952	-	-	69.48	2.59	0.4607	0.0172
4	10,832	404,208	2,355	87,867	115.52	4.31	10826	403,970	2419	90,276	116.03	4.33	-0.5097	-0.0190
5	10,832	404,208	2,355	87,867	115.52	4.31	10826	403,970	2419	90,276	116.03	4.33	-0.5097	-0.0190
6	10,832	404,208	2,355	87,867	115.52	4.31	10826	403,970	2419	90,276	116.03	4.33	-0.5097	-0.0190
7	7,981	297,813	3,349	124,987	99.25	3.70	7931	295,952	3454	128,898	99.74	3.72	-0.4811	-0.0180
8	7,981	297,813	3,349	124,987	99.25	3.70	7931	295,952	3454	128,898	99.74	3.72	-0.4811	-0.0180
9	7,981	297,813	3,349	124,987	99.25	3.70	7931	295,952	3454	128,898	99.74	3.72	-0.4811	-0.0180
10	7,981	297,813	3,349	124,987	99.25	3.70	7931	295,952	3454	128,898	99.74	3.72	-0.4811	-0.0180
11	7,981	297,813	3,349	124,987	99.25	3.70	7931	295,952	3454	128,898	99.74	3.72	-0.4811	-0.0180
12	7,220	269,425	3,800	141,813	96.54	3.60	7217	269,313	3912	145,983	97.49	3.64	-0.9528	-0.0356
13	7,220	269,425	3,800	141,813	96.54	3.60	7217	269,313	3912	145,983	97.49	3.64	-0.9528	-0.0356
14	7,220	269,425	3,800	141,813	96.54	3.60	7217	269,313	3912	145,983	97.49	3.64	-0.9528	-0.0356
15	6,598	246,191	6,857	255,872	117.86	4.40	6387	238,332	7287	271,908	119.78	4.47	-1.9196	-0.0716
16	6,598	246,191	6,857	255,872	117.86	4.40	6387	238,332	7287	271,908	119.78	4.47	-1.9196	-0.0716
17	6,598	246,191	6,857	255,872	117.86	4.40	6387	238,332	7287	271,908	119.78	4.47	-1.9196	-0.0716
18	6,598	246,191	6,857	255,872	117.86	4.40	6387	238,332	7287	271,908	119.78	4.47	-1.9196	-0.0716
19	6,598	246,191	6,857	255,872	117.86	4.40	6387	238,332	7287	271,908	119.78	4.47	-1.9196	-0.0716
20	6,598	246,191	6,857	255,872	117.86	4.40	6387	238,332	7287	271,908	119.78	4.47	-1.9196	-0.0716
21	3,610	134,713	7,867	293,564	100.54	3.75	3609	134,657	8388	312,998	105.09	3.92	-4.5491	-0.1698
22	3,610	134,713	7,867	293,564	100.54	3.75	3609	134,657	8388	312,998	105.09	3.92	-4.5491	-0.1698
23	3,610	134,713	7,867	293,564	100.54	3.75	3609	134,657	8388	312,998	105.09	3.92	-4.5491	-0.1698
24	3,610	134,713	7,867	293,564	100.54	3.75	3609	134,657	8388	312,998	105.09	3.92	-4.5491	-0.1698
25	3,610	134,713	7,867	293,564	100.54	3.75	3609	134,657	8388	312,998	105.09	3.92	-4.5491	-0.1698
26	3,610	134,713	7,867	293,564	100.54	3.75	3609	134,657	8388	312,998	105.09	3.92	-4.5491	-0.1698
27	3,299	123,104	10,532	393,012	121.16	4.52	3113	116,181	10986	409,931	123.51	4.61	-2.3467	-0.0876
28	3,299	123,104	10,532	393,012	121.16	4.52	3113	116,181	10986	409,931	123.51	4.61	-2.3467	-0.0876
29	3,299	123,104	10,532	393,012	121.16	4.52	3113	116,181	10986	409,931	123.51	4.61	-2.3467	-0.0876
30	3,299	123,104	10,532	393,012	121.16	4.52	3113	116,181	10986	409,931	123.51	4.61	-2.3467	-0.0876

Table 6 - CAPEX Schedule for Single and Dual Compartment Compressors

Alterantive I - Single Compartment Compressor	Year 0	Year 1	Year 3	Year 14	Total CAPEX MMUS$
4 Single compartment compressor	4.90	-	4.05	-	8.95
1 Restage	-	-	-	0.85	0.85
1 Standby Single compartment compressor	2.45	-	-	-	2.45
Total CAPEX, MMUS$	7.35	-	4.05	0.85	12.25

Alterantive II - Dual Compartment Compressor	Year 0	Year 1	Year 3	Year 14	Total CAPEX MMUS$
4 Dual compartment compressor	5.71	-	5.71	-	11.416
5 Installed Intercoolers w/valves	4.62	-	1.54	-	6.16
1 Standby Dual compartment compressor	2.85	-	-	-	2.854
Compressor station incremental CAPEX due to compressor larger footprint area	0.12	-	-	-	0.12
Total CAPEX, MMUS$	13.30	-	7.25	-	20.55
CAPEX difference (Single - Dual)	(5.95)	-	(3.20)	0.85	(8.30)

Number between brackets are negative.

Table 7 - **Cash Flow, in MMUS$, for CAPEX, OPEX and Fuel Gas Expences**

Alternative I - Single Compartment Compressor				Alternative II - Dual Compartment Compressor			
Year	CAPEX	OPEX	Fuel Gas	Year	CAPEX	OPEX	Fuel Gas
0	(7.35)	-	-	0	(13.30)	-	-
1	-	(0.37)	(10.75)	1	-	(0.67)	(10.75)
2	-	(0.37)	(11.89)	2	-	(0.67)	(11.81)
3	(4.05)	(0.37)	(11.89)	3	(7.25)	(0.67)	(11.81)
4	-	(0.57)	(19.64)	4	-	(1.03)	(19.72)
5	-	(0.57)	(19.64)	5	-	(1.03)	(19.72)
6	-	(0.57)	(19.64)	6	-	(1.03)	(19.72)
7	-	(0.57)	(16.87)	7	-	(1.03)	(16.95)
8	-	(0.57)	(16.87)	8	-	(1.03)	(16.95)
9	-	(0.57)	(16.87)	9	-	(1.03)	(16.95)
10	-	(0.57)	(16.87)	10	-	(1.03)	(16.95)
11	-	(0.57)	(16.87)	11	-	(1.03)	(16.95)
12	-	(0.57)	(16.41)	12	-	(1.03)	(16.57)
13	-	(0.57)	(16.41)	13	-	(1.03)	(16.57)
14	(0.85)	(0.57)	(16.41)	14	-	(1.03)	(16.57)
15	-	(0.61)	(20.04)	15	-	(1.03)	(20.36)
16	-	(0.61)	(20.04)	16	-	(1.03)	(20.36)
17	-	(0.61)	(20.04)	17	-	(1.03)	(20.36)
18	-	(0.61)	(20.04)	18	-	(1.03)	(20.36)
19	-	(0.61)	(20.04)	19	-	(1.03)	(20.36)
20	-	(0.61)	(20.04)	20	-	(1.03)	(20.36)
21	-	(0.61)	(17.09)	21	-	(1.03)	(17.86)
22	-	(0.61)	(17.09)	22	-	(1.03)	(17.86)
23	-	(0.61)	(17.09)	23	-	(1.03)	(17.86)
24	-	(0.61)	(17.09)	24	-	(1.03)	(17.86)
25	-	(0.61)	(17.09)	25	-	(1.03)	(17.86)
26	-	(0.61)	(17.09)	26	-	(1.03)	(17.86)
27	-	(0.61)	(20.60)	27	-	(1.03)	(20.99)
28	-	(0.61)	(20.60)	28	-	(1.03)	(20.99)
29	-	(0.61)	(20.60)	29	-	(1.03)	(20.99)
30	-	(0.61)	(20.60)	30	-	(1.03)	(20.99)
Present Value @12% RR	(10.41)	(4.17)	(130.69)		(18.46)	(7.41)	(131.63)
Total Present Value, MMUS$		(145.26)				(157.50)	

Values between brackets mean negative.

FIGURES

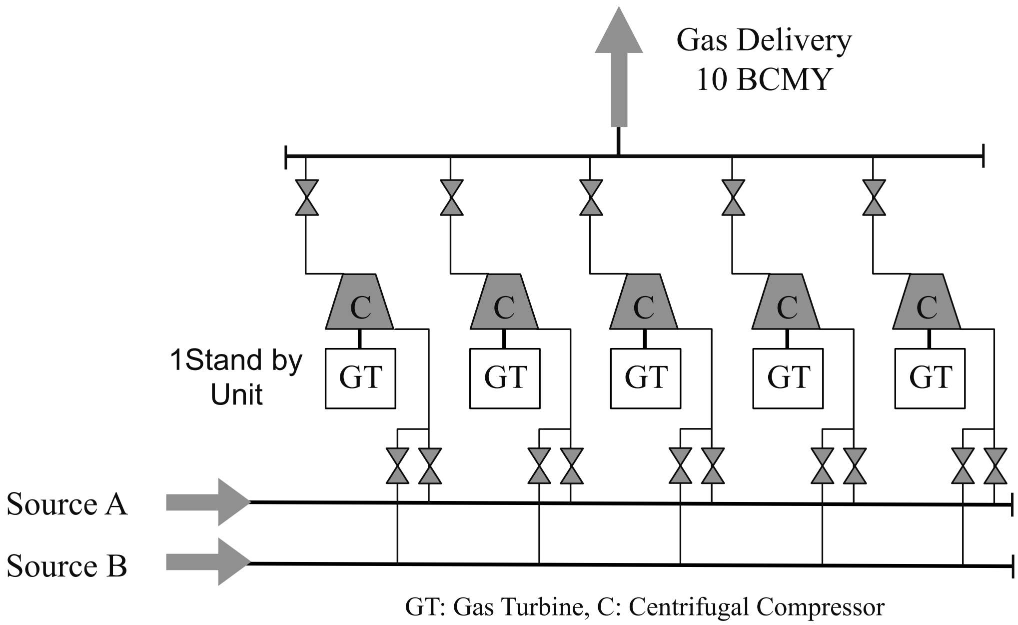

Figure 1 – Compressor Station Configuration

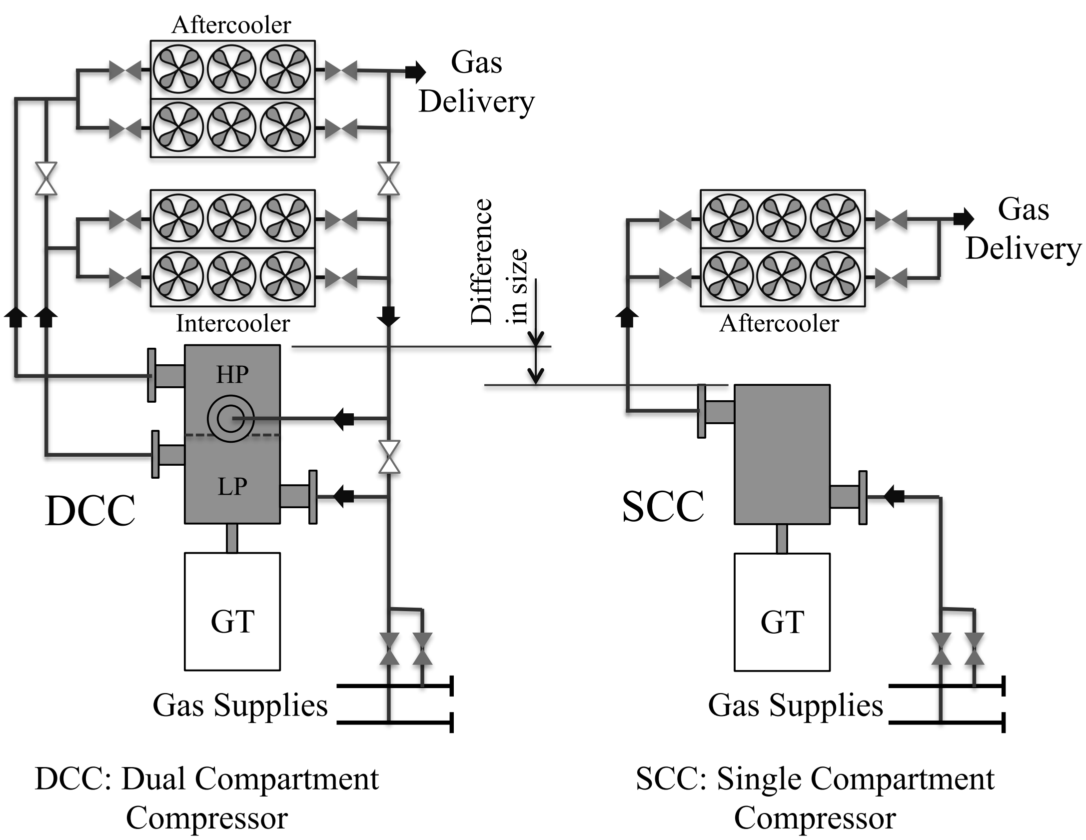

Figure 2 – Alternative I (Single Compartment) and Alternative II (Dual Compartment)

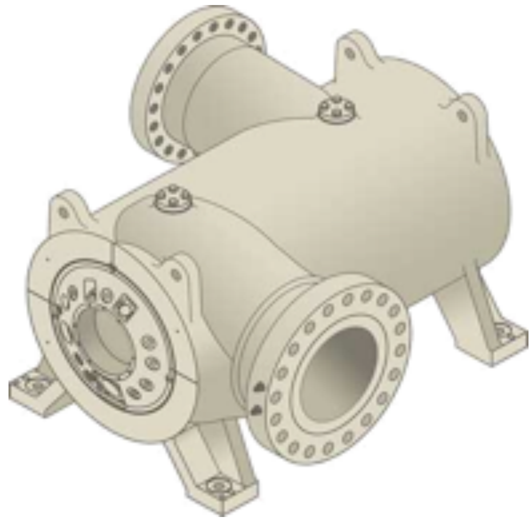

Figure 3 – Single Compartment Compressor

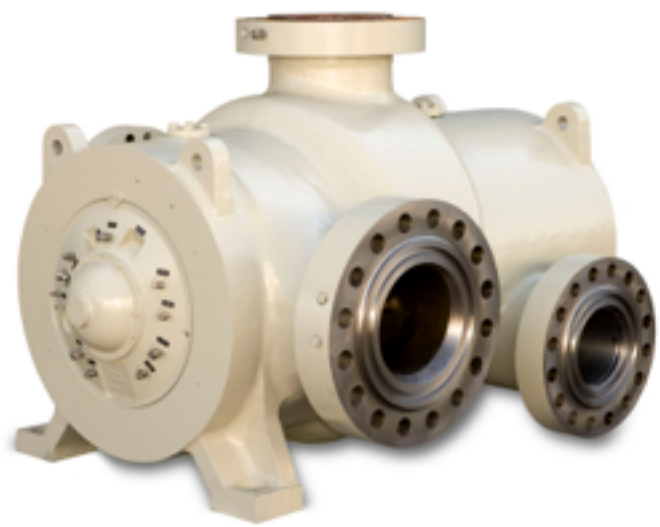

Figure 4 – Single Compartment Compressor