

Development of a Computer Program to Assess Gas Compressor Performance

by

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Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
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CERTIFICATION OF APPROVAL

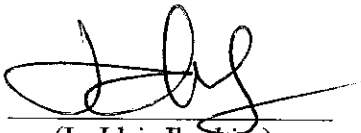
**Development of a Computer Program to Assess
Gas Compressor Performance**

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Ahmad Nadiyah Mohd Ghazali

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the referenced and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.



(AHMAD NADIY B MOHD GHAZALI)

ABSTRACT

This report discusses the preliminary research done and basic understanding of the chosen topic, which is Development of a Computer Program to Assess Gas Compressor Performance. The author has compiled all the materials related to the topic and utilizes them as the main source to start the project. The main objective of the project is to develop a computer program for the usage of evaluating the performance of gas compressor specifically centrifugal compressor performance. There are two (2) phases in the development of the computer program. The first phase is the development of the basic spreadsheet which has a very limited function but still able to perform the calculations to assess gas compressor performance. The second phase is the critical improvement of the program which more user-friendly and has modern-look. This project enhanced the assessment of gas compressor performance by eliminating the usage of manual calculations on a basic spreadsheet to evaluate the gas compressor performance. By using this computer program, gas compressor operators will be able to perform calculations by giving inputs to this program and get specific outputs in order for them to use for assessment. The outputs of this program which are in a graph plots can be assessed to evaluate the performance of the gas compressor. Recommendations were given to improve the design and features of the computer program for any future works.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Gas compressors are widely used in mechanical related industries in compressing the air / gas to increase the pressure of the Gas. Applications of compressed gas vary from consumer products, such as the home refrigerator, to large complex petrochemical plant installations. Mainly, there are two types of Compressor; Dynamic Compressor and Positive-Displacement Compressor. A widely used gas compressor is the centrifugal compressor, one of the dynamic compressors which exhibit a contrary behaviour to the positive displacement-type compressors. For example, in a reciprocating compressor (positive-displacement compressor) a quantity of gas is drawn into the cylinder and trapped by the action of the valves and motion of a piston. As the piston moves in the cylinder, compression is achieved by direct volume reduction. By comparison, centrifugal compressor achieve compression by applying inertial forces to the gas (acceleration, deceleration, turning) by means of rotating impellers at high speed (Figure 1.1), that continuously impact and perform work on the gas during operation.

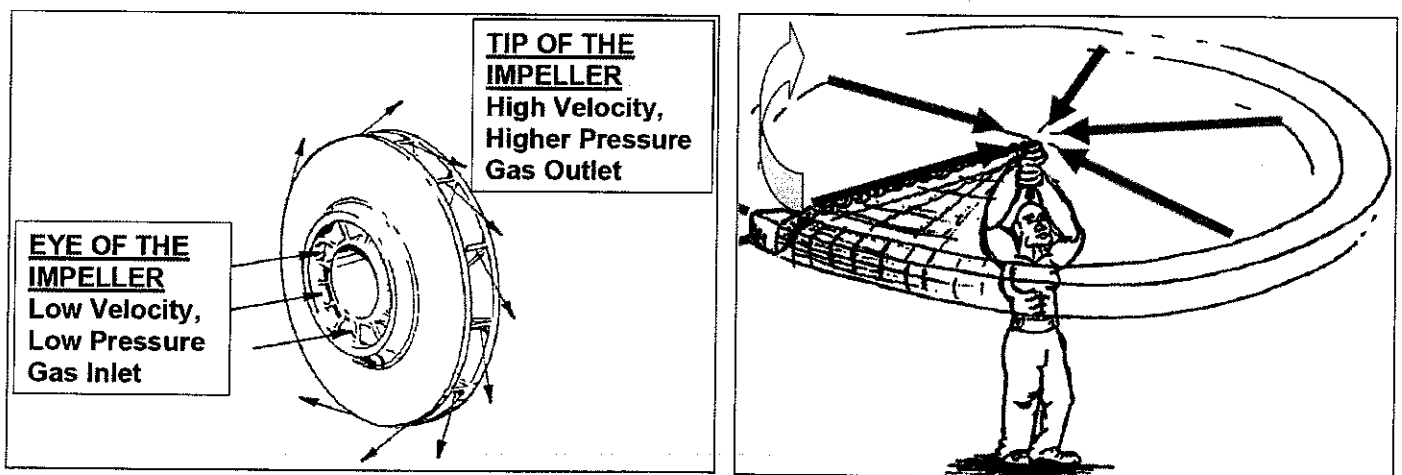


Figure.1.1 : Basic principles of centrifugal compressor. (Dresser Rand, 2008)

Next, the impellers rotation is utilized with a rotor shaft compresses the gas where the high speed gas will enter a diffuser passage (Figure 1.2) which will enter the low flow path which increase significantly the gas pressure (Figure 1.3). Stationary components form a flow path for the gas to flow from suction to discharge. Pressurized gas is contained inside a casing during operation.

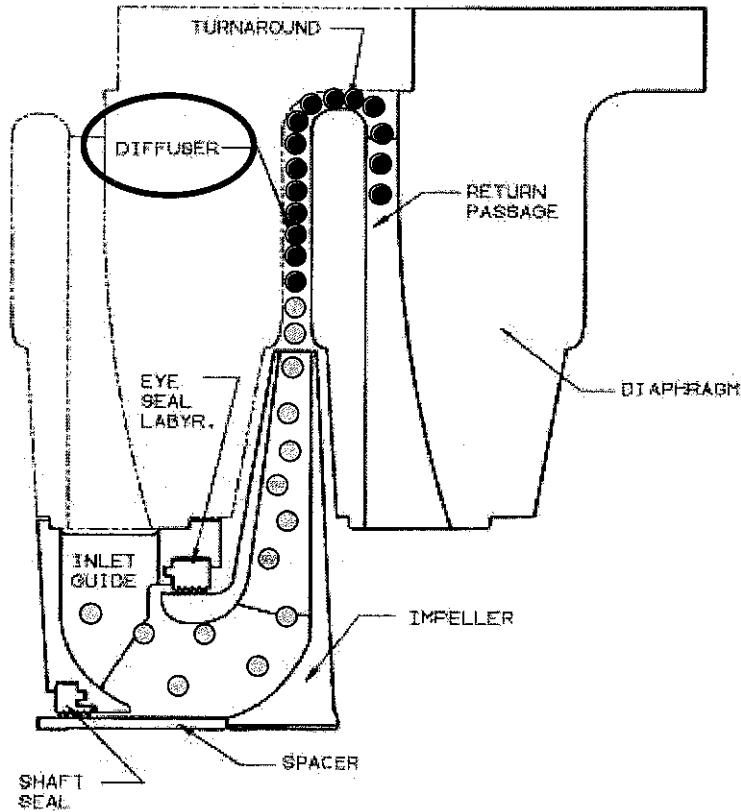


Figure 1.2 : Compression of high velocity gas through the diffuser. (Dresser Rand, 2008)

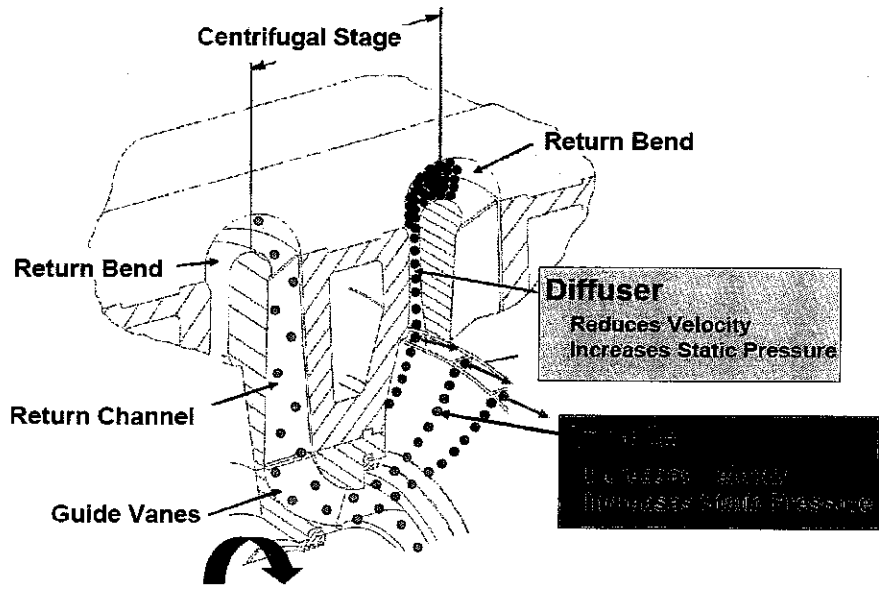


Figure 1.3 : Stage of Compression. (Dresser Rand, 2008)

Every centrifugal compressor is designed to operate at a preferred optimum speed point relative to the impeller design. Impellers are designed to raise the gas pressure within limits that ensure the gas will flow at a desired production rate from the suction [inlet] of the compressor to the discharge of the compressor. This operating point is graphically defined (Figure 1.4) along an operating curve and is referred to as “Design Point” operation which sometimes are called as the Best Efficiency Point.

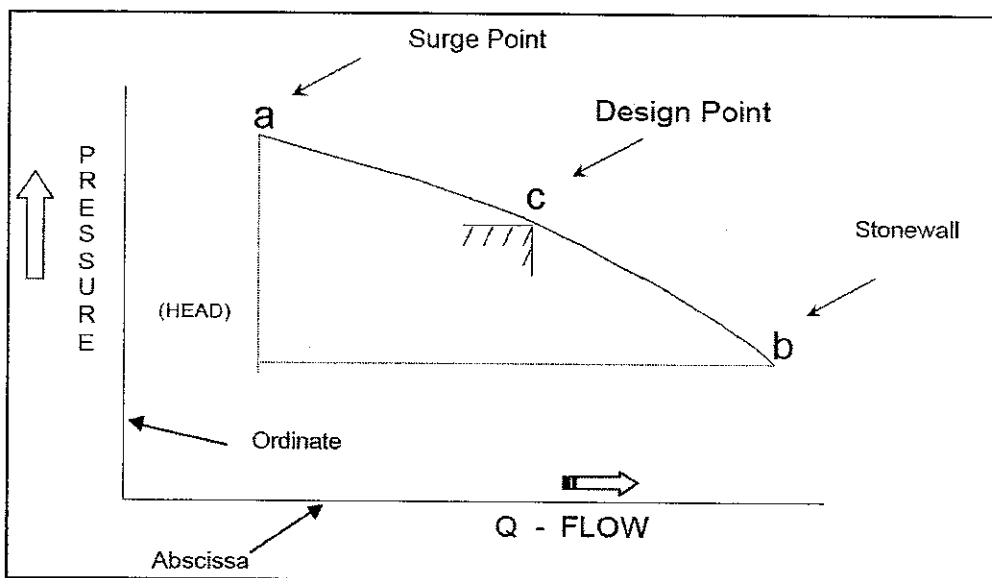


Figure 1.4 : Compressor performance curve (Dresser Rand, 2008).

Although in reality, it is rarely for the centrifugal compressors to run consistently on the design point parameters, it should be run at the nearest point to the design point parameter. Therefore, a consistent check up or test on the centrifugal compressor performance should always be observed. Such test is called Compressor Performance Test. The main reasons for conducting such test are to confirm aerodynamic performance of the compressor and the guaranteed operating conditions are met. The overall picture of the Centrifugal Compressor Assessment is shown in Figure 1.5 in the next page.

Table 10.1.1.1 Compressor Design Characteristics	
Model	10.1.1.1
Capacity	10.1.1.1
Pressure Ratio	10.1.1.1
Efficiency	10.1.1.1
Power	10.1.1.1
Speed	10.1.1.1
Temperature	10.1.1.1
Humidity Ratio	10.1.1.1
Specific Volume	10.1.1.1
Specific Heat	10.1.1.1
Gas Constant	10.1.1.1
Compressor Type	10.1.1.1
Compressor Configuration	10.1.1.1
Compressor Inlet Conditions	10.1.1.1
Compressor Outlet Conditions	10.1.1.1
Compressor Performance	10.1.1.1
Compressor Efficiency	10.1.1.1
Compressor Power	10.1.1.1
Compressor Temperature	10.1.1.1
Compressor Humidity Ratio	10.1.1.1
Compressor Specific Volume	10.1.1.1
Compressor Specific Heat	10.1.1.1
Compressor Gas Constant	10.1.1.1
Compressor Inlet Conditions	10.1.1.1
Compressor Outlet Conditions	10.1.1.1
Compressor Performance	10.1.1.1
Compressor Efficiency	10.1.1.1
Compressor Power	10.1.1.1
Compressor Temperature	10.1.1.1
Compressor Humidity Ratio	10.1.1.1
Compressor Specific Volume	10.1.1.1
Compressor Specific Heat	10.1.1.1
Compressor Gas Constant	10.1.1.1

Design Characteristic of Centrifugal Compressor (obtained from the manufacturer)

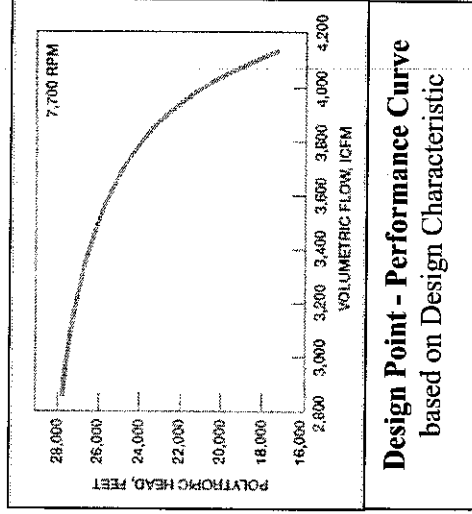


Table 10.1.1.2 Compressor Design Characteristics	
Model	10.1.1.2
Capacity	10.1.1.2
Pressure Ratio	10.1.1.2
Efficiency	10.1.1.2
Power	10.1.1.2
Speed	10.1.1.2
Temperature	10.1.1.2
Humidity Ratio	10.1.1.2
Specific Volume	10.1.1.2
Specific Heat	10.1.1.2
Gas Constant	10.1.1.2
Compressor Type	10.1.1.2
Compressor Configuration	10.1.1.2
Compressor Inlet Conditions	10.1.1.2
Compressor Outlet Conditions	10.1.1.2
Compressor Performance	10.1.1.2
Compressor Efficiency	10.1.1.2
Compressor Power	10.1.1.2
Compressor Temperature	10.1.1.2
Compressor Humidity Ratio	10.1.1.2
Compressor Specific Volume	10.1.1.2
Compressor Specific Heat	10.1.1.2
Compressor Gas Constant	10.1.1.2
Compressor Inlet Conditions	10.1.1.2
Compressor Outlet Conditions	10.1.1.2
Compressor Performance	10.1.1.2
Compressor Efficiency	10.1.1.2
Compressor Power	10.1.1.2
Compressor Temperature	10.1.1.2
Compressor Humidity Ratio	10.1.1.2
Compressor Specific Volume	10.1.1.2
Compressor Specific Heat	10.1.1.2
Compressor Gas Constant	10.1.1.2

Actual Plant Data of the same Centrifugal Compressor (obtained from Operator)

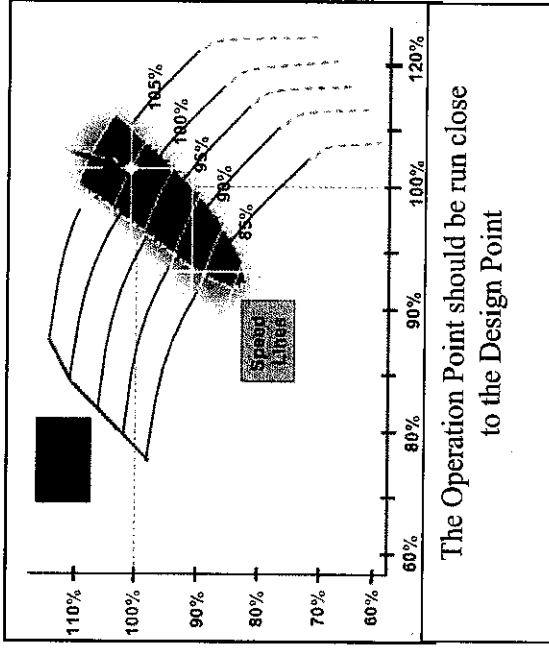
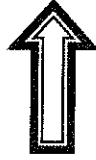
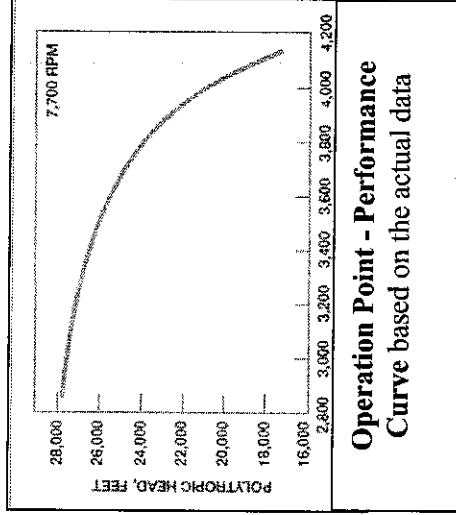


Figure 1.5 : Overall picture of centrifugal compressor performance assessment. (Dresser Rand, 2006)

2.2 PROBLEM STATEMENT

Gas Compressor performance assessment is crucial in ensuring the Gas Compressor is working at the best efficiency point (BEP) or Desired Point. The Gas Compressor performance is assessed by evaluating the thermodynamics efficiency as well as the head produced. The assessment is conducted using computer program which normally is proprietary to the owner of the program making it inaccessible to any other parties and thus not available in the market. Therefore, this project is commenced to develop a Generic Gas Compressor performance assessment program that can be used for any model of the Gas Compressor.

3 OBJECTIVES

The main objectives of this project are:

- Design the performance assessment program
- Evaluate Gas Compressor performance
- Validate the assessment result with the actual data.

4 SCOPE OF STUDY

The work to be carried out can be summarized as follows:

- Develop mathematical model to allow thermodynamic analysis of the Centrifugal Compressor system
- Validate the mathematical model by using an actual set of plant data obtained from any Gas Compressor vendor
- Apply the mathematical models into the computer program
- Develop a user-friendly computer program to assess centrifugal compressor performance based on the mathematical models.

CHAPTER 2 LITERATURE REVIEW

1.5 LITERATURE REVIEW

After a certain time period of operation, the Gas Compressor performance will drop and need to be improved. The user must try to obtain the same compressor performance as designed by the compressors' vendor since it is the point where the Gas compressor will work at the best efficiency point or desired point. The operation of a centrifugal compressor units means keeping the performance within the operating limits for which machines were specified in order to avoid any inefficiency in the plant and to obtain the highest economic profit. The Gas Compressor performance is assessed generally by evaluating the thermodynamics efficiency as well as the head produced. The parameters that should be taken into consideration when running a thermodynamic test of the centrifugal compressors are:

- Polytrophic Head
- Inlet Flow Rate
- Compressor Efficiency

In Appendix III, the author has compiled several mathematical models from other authors whose works are related to this project. After making a critical literature review, the author has decided to use the following as the reference of this project:

1.5.1 Polytrophic Head

The Polytrophic Head is an expression used for dynamic compressors to denote the foot-pounds of work required per pound of gas. It can be defined as the energy accumulated in the fluid of the system and expressed in feet (*ft*).

Article refer to Scott Golden, Scott A. Fulton & Daryl W. Hanson (2002), the compressor curve flow term is always based on the inlet conditions; consequently inlet gas density, ρ influences volumetric flow, v . Flow rate, v is shown on the X-axis and head, H on the Y-axis. For a fixed impeller speed (RPM), the curve shows that for a known inlet flow rate v , a fixed head, H is developed. Centrifugal compressor inlet flow rate, v increases as the head, H decreases. Gas plant operating pressure and gas composition determine the value of head, H .

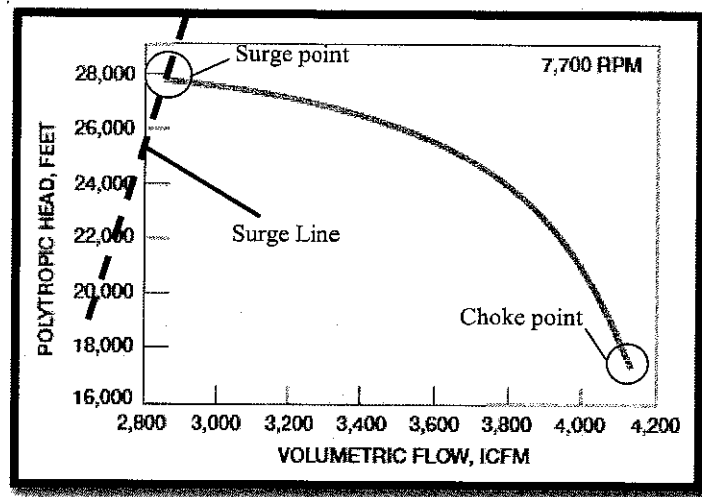


Figure 2.1 : Compressor performance curve. (Scott Golden, Scott A. Fulton and Daryl W. Hanson, 2002)

Increasing suction pressure, P_s , decreasing gas plant operating pressure, P_D and/or decreasing process system pressure drop, P_{drop} will increase inlet flow rate, v as long as the compressor is not operating at choke flow. A compressor curve as can be seen in Figure 2.1 starts at the surge point and ends at stonewall, or choke flow. The surge point is the head at which inlet flow is at its minimum. At this point, the compressor suffers from flow reversal, which is a very unstable operation that is accompanied by vibration and possible damage. Surge begins when the operating point of the compressor crosses the surge line. Surge line is the stability limit of the compressor performance map [7].

On the other end of the curve is the choke (or stonewall) point. At the choke point, the inlet flow through the compressor cannot increase no matter what operating changes are made. Therefore, the range of compressor performance is defined between these two flow head limitations. Normally, the curve is flat near the surge point and becomes steeper as flow is increased. Thus, small head, H changes near the surge point causes a large increase in compressor flow rate capacity, v . As compressor operation moves toward stonewall, decreasing head, H has less influence on inlet flow rate because the curve slope increases. As the stonewall point is approached, changes in head, H will have negligible effect on inlet flow rate [3].

Equation 1 shows the polytropic head term. (Appendix III-E)

$$H_{poly}[ft] = \frac{1,545}{MW} Z_{avg} T_s \times \left(\frac{k}{k-1} \right) \times \left[\left(\frac{P_d}{P_s} \right)^{\frac{k-1}{k}} - 1 \right] \quad \dots (1)$$

Where ;

Z_{avg} is the average compressibility factor between the suction and discharge section, $Z_{avg} = \frac{Z_s + Z_d}{2}$;

T_s is the gas suction temperature (R);

P_s is the gas suction pressure (psia);

P_d is the gas discharge pressure (psia);

k is the ratio of specific heat $k = \left(\frac{C_p}{C_v} \right)$

MW is the gas molecular weight

The value of the constant 1545 in the Equation 1 represents the universal gas constant, R which:

$$R = \frac{1545 [ft \cdot lb / ^\circ R]}{MW [lb / mol]} = [ft \cdot lb / lb \cdot mol \cdot ^\circ R]$$

The compressibility, Z_s value is determine at the suction condition with respect to the suction pressure, P_s and suction temperature, T_s . While for the Z_d the value is determine at the discharge condition.

The value of Z at each suction and discharge can be determined from the following equation:

$$Pv = ZRT$$

where P is the absolute pressure in Pascal, Pa .

v is the specific volume in m^3/kg .

R is the Universal Gas Constant in $J/kg.K$

T is the absolute temperature in Kelvin, K

Specific Heat Ratio, k is the ratio of the specific heat at constant pressure, c_p to the specific heat at constant volume, c_v . These two values can be obtained from the thermodynamic table (refer Appendix VI).

Reducing polytrophic head, H will increase compressor capacity, v by moving the operating point to the right (Figure 2.2). A higher gas molecular weight, MW raising suction pressure, P_s or lowering discharge pressure, P_D are few process changes that move the operating point to right of the performance curve (Figure 2.2). However, the gas temperature, T changes have little influence on head, H .

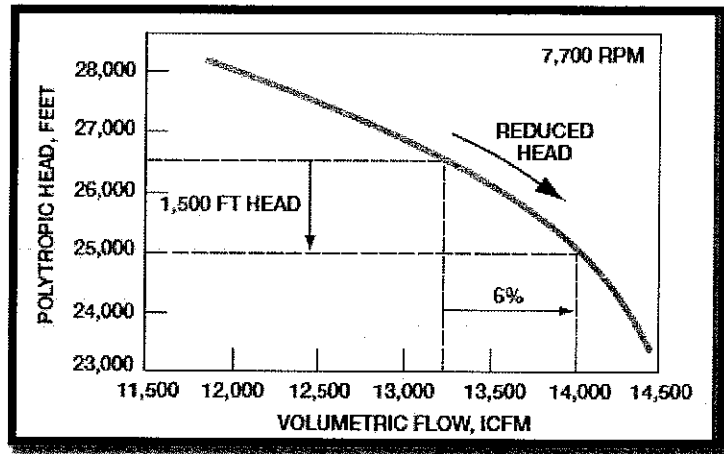


Figure 2.2 : Any process changes will moves the operating point on the curve. (Scott Golden, Scott A. Fulton and Daryl W. Hanson, 2002)

Volumetric Inlet Flowrate

The Compressor performance curve is also developed based on the volumetric flowrate capacity of the suction conditions. The volumetric flowrate capacity is located at the x-axis of the compressor performance map. Typically, the unit of ACFM (actual cubic feet per minute) is used to represents the volumetric flowrate capacity. However, some compressor operators & manufacturers use ICFM (inlet cubic feet per minute). But ICFM is not a standard gas flow metering units since wet gas is a compressible fluid, and thus changes in a compressor suction conditions that increase the gas density will reduce the wet gas volumetric flow rate and free up compressor capacity. Hence, for a better result, the author has decided to use the unit of ACFM to represent the flowrate capacity.

The equation for volumetric flowrate capacity is:

$$ACFM = \frac{14.73 \times Q \times Z T_s}{520 \times P_s \times 0.00144} \quad \dots (2)$$

Where

- Z is the Compressibility Factor at the inlet
- T_s is the Suction Temperature in ($^{\circ}R$)
- P_s is the Suction Pressure in (psia)
- Q is the unit flow in MMcfd

1.5.2 Compressor Efficiency, η_{isen}

Compressor efficiency can be measured using suction and discharge gas temperatures. However, the gas temperature measurement necessary for accurate compressor efficiency measurement requires “laboratory” type temperature measurement accuracy that is not practical for field measurement. The equation for Compressor efficiency using gas temperatures is:

$$\eta_{isen} [\%] = \left[\frac{T_s + 460}{T_d - T_s} \right] \times \left[\left(\frac{P_d}{P_s} \right)^{\frac{k-1}{k}} - 1 \right] \quad \dots (3)$$

where T_s is the suction temperature Fahrenheit, $^{\circ}F$

T_d is the discharge temperature in Fahrenheit, $^{\circ}F$

the value 460 is to convert the Temperature into the unit of Rankine, R.

Commonly, the efficiency of a compressor ranged from a minimum of 60% to a maximum of 80 %. Lower than this value shows the operator that maintenance is required.

CHAPTER 3 METHODOLOGY

3.1 METHODOLOGY AND PROJECT WORK

3.1.1

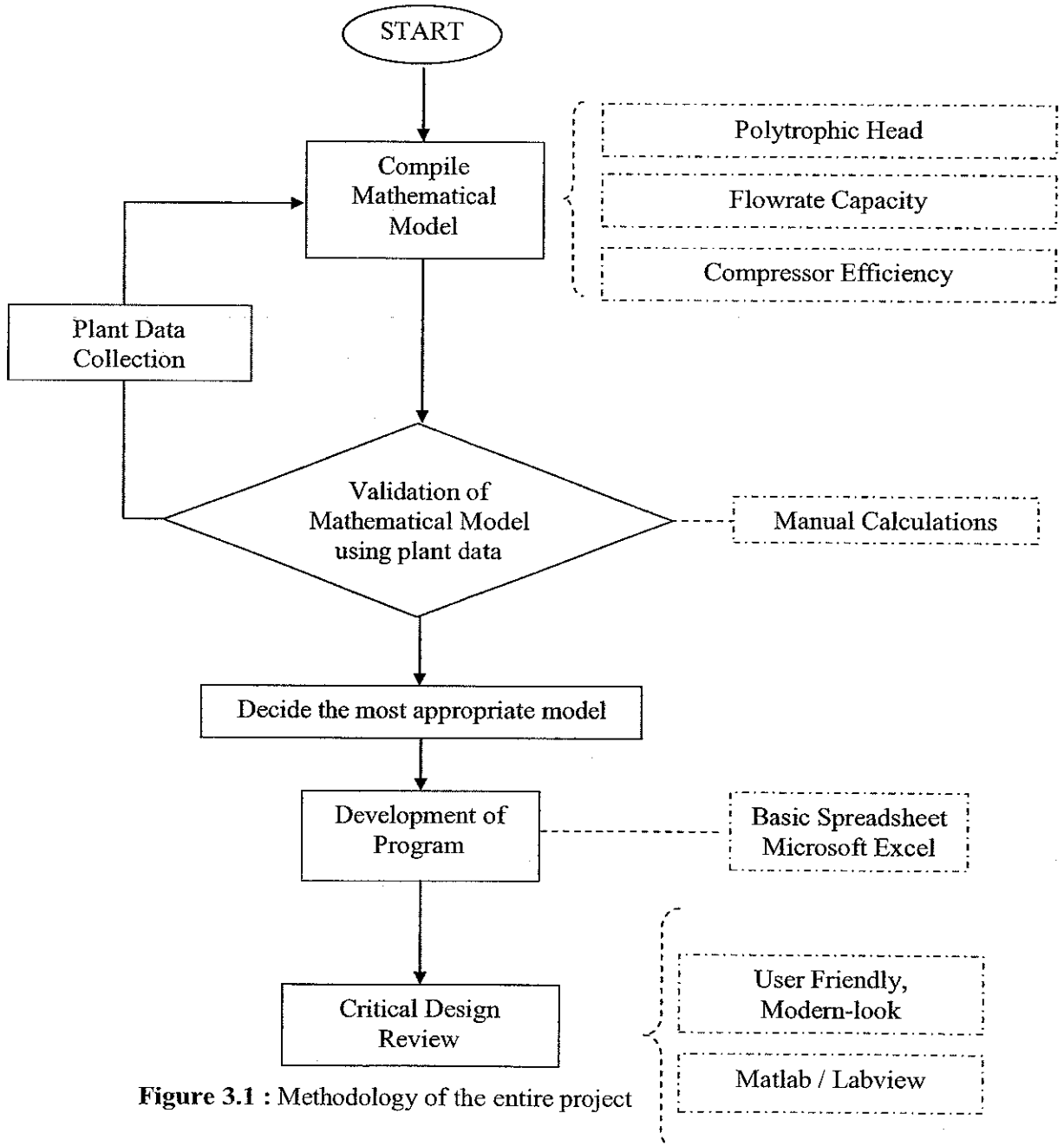


Figure 3.1 : Methodology of the entire project

3.1.2 Compilation of Mathematical Model:

In this part, the author would compile several mathematical models which are related to a thermodynamic of a compressor system; i.e. Polytrophic head, Volumetric Flowrate and also the Compressor Efficiency. These mathematical models are taken from any previous author's paper-work, training manual, lecture notes and etc which are related to the centrifugal systems. Each mathematical model is similar from one author to another, but there are slight different in term of the results output.

The author will then compare all the compiled mathematical models to choose one which is the most suitable mathematical model for this project. The criteria of the most suitable mathematical model are based on the compromise between accurate result and simplicity.

After the author has chosen a particular mathematical model for the project, the next step would be using the mathematical model in a program to evaluate the output of the centrifugal gas compressor. In order to build this program, the author would be using either MatLab software or Labview software. However, before the author uses the said software, the author would first develop the basic spreadsheet by using Microsoft Excel.

3.1.3 Collection of Plant Data:

In order to evaluate these mathematical models (Appendix III), the author will use a same data acquired from the plant as the input (refer Appendix V). The said plant data must at least consist of:-

- Inlet Pressure
- Inlet Temperature
- Flowrate capacity
- Gas compositions, thus the Gas Molecular Weight

The data can be obtained from any plant/factory that operates centrifugal compressor. The author however can obtain the set of data from PETRONAS Fertilizer, Bintulu in Sarawak; the place where he has had gone through his industrial internship. Example of plant data can be seen in **Appendix IV**.

However, the example of plant data showed in Appendix IV is a Design Characteristics of a particular Centrifugal Compressor. Thus, it is not an actual data of the centrifugal compressor. The user will have to use this data as the Design Point / Recommended Point / Best Efficiency Point for the Centrifugal Compressor. And next, the user should have another list of actual data for the same centrifugal compressor from the operator. He should then compared the current performance of the centrifugal compressor (evaluated from the actual data) with the design point (refer. Appendix IV). The illustration of the centrifugal compressor performance assessment can be seen above in Figure 1.5.

However, the author will use these set of data obtained to demonstrate the performance assessment of the centrifugal gas compressor. Using the same flowrate from the Design Data, the operator has come out with the Actual Operating Data. The compilation of these data can be seen in Table 4.2 and Table 4.3.

3.1.4 Development of Computer Program

The last stage of this project would be the development of computer program to assess centrifugal compressor performance. The computer program would be able to plot the centrifugal compressor performance map after the user has entered input to it.

As a start, the author would use Microsoft Excel to construct a basic spreadsheet in order for him to have a rough idea on the computer program but still meets the main objective. At this level, the user would have to enter the particular properties of the gas being compressed in the centrifugal compressor in order to obtain a particular output. The properties of the gas are:

- Gas Compositions (Molecular Weight or Percentage)
- Inlet Pressure & Temperature

Next, the user would need to vary the flowrate capacity and as well as discharge pressure. Each vary would determine one specific point for the compressor performance map (Appendix IV). Basically, the detailed processes in the development of the basic spreadsheet are:

- i. Construct a column for input to be entered
- ii. Set any unknown parameters using assumptions
- iii. Evaluate polytrophic head and Flowrate Capacity for the first point of the Compressor Performance Map
- iv. Evaluate polytrophic head and Flowrate Capacity for the second – final point
- v. Plot the graph
- vi. Repeat the process for other data in order to make comparison

However, the author does not intend to use basic spreadsheet as the main tool to assess the centrifugal compressor performance assessment since they are few set-backs using it. They are:

- the instructions may be unclear for a first time user,
- the user has to manually plot the performance curve by selecting the correct data,
- the user has to save each performance curve construct – thus he can then compare the current compressor performance with the one recommended by the manufacturer

Therefore, after developing the basic spreadsheet, the author would then start to use more advanced software such as **Matlab** or **LabView** to develop the computer program that able to assess the centrifugal compressor performance. In the end, the computer program will be a user-friendly, easy to conduct, and modern-look.

CHAPTER 4

RESULTS

4.1 THE PLANT DATA

For demonstration purposes, the author will utilize the developed program to evaluate the performance of the centrifugal compressor based on the obtained plant data. For this purposes, the author will use the basic spreadsheet program developed in order to have a quick grasp of evaluation on the main concept of the program. The obtained plant data for both design point and actual operating point can be seen in Appendix VII. For the ease of reference, Appendix VII has been compressed into the table below:

Table 4.1 : List of gas properties for both obtained design data and operating plant data.

Properties	Unit	Value
Atm Pressure	barg	1.01
Suction Pressure, P_s	barg	3.43
Suction Temperature, T_s	$^{\circ}\text{C}$	20.00
Specific Volume, v (from table)	kJ/kg	0.3083
Specific Heat at Constant Volume, c_v (from table)	kJ/kg	1.66
Specific Heat at Constant Pressure, c_p (from table)	kJ/kg	2.25
Gas Molecular Weight, MW	g/mol	17.03
Specific Heat Ratio, k	-	1.36
$(k-1)/k$	-	0.26
Universal Gas Constant, R	$\text{ft-lb} / (\text{lbmol} \cdot ^{\circ}\text{R})$	90.72
Specific Gas Constant, R	J/kg.K	488.20
Compressibility Factor, Z	-	0.96

Table 4.2 : List of design data discharge properties.

#	Flow Rate q (ft^3/min)	Discharge Temperature T_d ($^{\circ}C$)	Discharge Pressure P_d ($barg$)	Pressure Ratio P_r
1	3450	100	4.73	1.29
2	3800	110	4.72	1.29
3	4200	120	4.69	1.28
4	4600	130	4.63	1.27
5	5000	140	4.55	1.25
6	5400	150	4.44	1.23
7	5800	160	4.28	1.19
8	6100	170	4.13	1.16
9	3690	100	4.95	1.34
10	3800	110	4.94	1.34
11	4200	120	4.93	1.34
12	4600	130	4.88	1.33
13	5000	140	4.82	1.31
14	5400	150	4.72	1.29
15	5800	160	4.61	1.26
16	6200	170	4.43	1.23
17	6490	180	4.24	1.18
18	3950	100	5.18	1.39
19	4200	110	5.16	1.39
20	4600	120	5.13	1.38
21	5000	130	5.07	1.37
22	5400	140	5.01	1.36
23	5800	150	4.91	1.33
24	6200	160	4.78	1.30
25	6600	170	4.58	1.26
26	6920	180	4.37	1.21
27	4200	100	5.44	1.45
28	4600	110	5.40	1.44
29	5000	120	5.36	1.43
30	5400	130	5.28	1.42
31	5800	140	5.21	1.40
32	6200	150	5.11	1.38
33	6600	160	4.96	1.34
34	7000	170	4.77	1.30
35	7400	180	4.54	1.25

Continue . . .

Continued . . .

#	Flow Rate q (ft ³ /min)	Discharge Temperature T_d (°C)	Discharge Pressure P_d (barg)	Pressure Ratio P_r
36	4480	100	5.74	1.52
37	4600	110	5.73	1.52
38	5000	120	5.69	1.51
39	5400	130	5.63	1.50
40	5800	140	5.55	1.48
41	6200	150	5.45	1.45
42	6600	160	5.32	1.43
43	7000	170	5.18	1.39
44	7400	180	4.98	1.35
45	7840	190	4.66	1.28
46	4700	100	6.04	1.59
47	5000	110	6.02	1.58
48	5400	120	5.98	1.57
49	5800	130	5.91	1.56
50	6200	140	5.82	1.54
51	6600	150	5.70	1.51
52	7000	160	5.57	1.48
53	7400	170	5.41	1.45
54	7800	180	5.17	1.39
55	8240	190	4.83	1.32
56	4980	100	6.37	1.66
57	5400	110	6.34	1.66
58	5800	120	6.29	1.64
59	6200	130	6.22	1.63
60	6600	140	6.11	1.60
61	7000	150	5.98	1.57
62	7400	160	5.85	1.54
63	7800	170	5.65	1.50
64	8200	180	5.35	1.43
65	8680	190	4.99	1.35
66	5200	100	6.72	1.74
67	5800	110	6.67	1.73
68	6200	120	6.62	1.72
69	6600	130	6.52	1.69
70	7000	140	6.41	1.67
71	7400	150	6.29	1.64
72	7800	160	6.13	1.61
73	8200	170	5.90	1.56
74	8600	180	5.61	1.49
75	9110	190	5.16	1.39

Table 4.3 : List of operating plant data discharge properties.

#	Flow Rate q (ft^3/min)	Discharge Temperature T_d ($^{\circ}C$)	Discharge Pressure P_d ($barg$)	Pressure Ratio P_r
1	3450	100	4.74	1.30
2	3800	110	4.74	1.29
3	4200	120	4.71	1.29
4	4600	130	4.65	1.28
5	5000	140	4.56	1.25
6	5400	150	4.46	1.23
7	5800	160	4.28	1.19
8	6100	170	4.15	1.16
9	3690	100	4.96	1.35
10	3800	110	4.96	1.34
11	4200	120	4.93	1.34
12	4600	130	4.89	1.33
13	5000	140	4.83	1.32
14	5400	150	4.74	1.29
15	5800	160	4.64	1.27
16	6200	170	4.46	1.23
17	6490	180	4.25	1.18
18	3950	100	5.22	1.40
19	4200	110	5.18	1.39
20	4600	120	5.17	1.39
21	5000	130	5.10	1.38
22	5400	140	5.02	1.36
23	5800	150	4.93	1.34
24	6200	160	4.79	1.31
25	6600	170	4.59	1.26
26	6920	180	4.38	1.21
27	4200	100	5.45	1.45
28	4600	110	5.41	1.45
29	5000	120	5.35	1.43
30	5400	130	5.30	1.42
31	5800	140	5.22	1.40
32	6200	150	5.12	1.38
33	6600	160	4.99	1.35
34	7000	170	4.81	1.31
35	7400	180	4.56	1.25

Continue...

Continued...

#	Flow Rate q (ft^3/min)	Discharge Temperature T_d ($^{\circ}C$)	Discharge Pressure P_d ($barg$)	Pressure Ratio P_r
36	4480	100	5.77	1.53
37	4600	110	5.73	1.52
38	5000	120	5.69	1.51
39	5400	130	5.67	1.50
40	5800	140	5.55	1.48
41	6200	150	5.45	1.45
42	6600	160	5.32	1.42
43	7000	170	5.18	1.39
44	7400	180	4.98	1.35
45	7840	190	4.67	1.28
46	4700	100	6.06	1.59
47	5000	110	6.02	1.58
48	5400	120	5.96	1.57
49	5800	130	5.91	1.56
50	6200	140	5.81	1.53
51	6600	150	5.70	1.51
52	7000	160	5.57	1.48
53	7400	170	5.41	1.45
54	7800	180	5.16	1.39
55	8240	190	4.82	1.31
56	4980	100	6.37	1.66
57	5400	110	6.34	1.66
58	5800	120	6.29	1.64
59	6200	130	6.15	1.61
60	6600	140	6.04	1.59
61	7000	150	5.90	1.56
62	7400	160	5.77	1.53
63	7800	170	5.57	1.48
64	8200	180	5.34	1.43
65	8680	190	4.85	1.32
66	5200	100	6.73	1.74
67	5800	110	6.69	1.73
68	6200	120	6.64	1.72
69	6600	130	6.52	1.69
70	7000	140	6.39	1.67
71	7400	150	6.29	1.64
72	7800	160	6.13	1.61
73	8200	170	5.74	1.52
74	8600	180	5.41	1.45
75	9110	190	4.85	1.32

4.2 THE PERFORMANCE CURVE

By using the data from Table 4.2 & Table 4.3, two separate Performance Curves of Polytropic Head at the Y-axis versus Flowrate at the X-axis are plotted. These two curves are then compared to evaluate the performance of the compressor. Refer to the figures (Figure 4.1 & Figure 4.2) below to see the differences: The behavior of each figure is discussed on the next section.

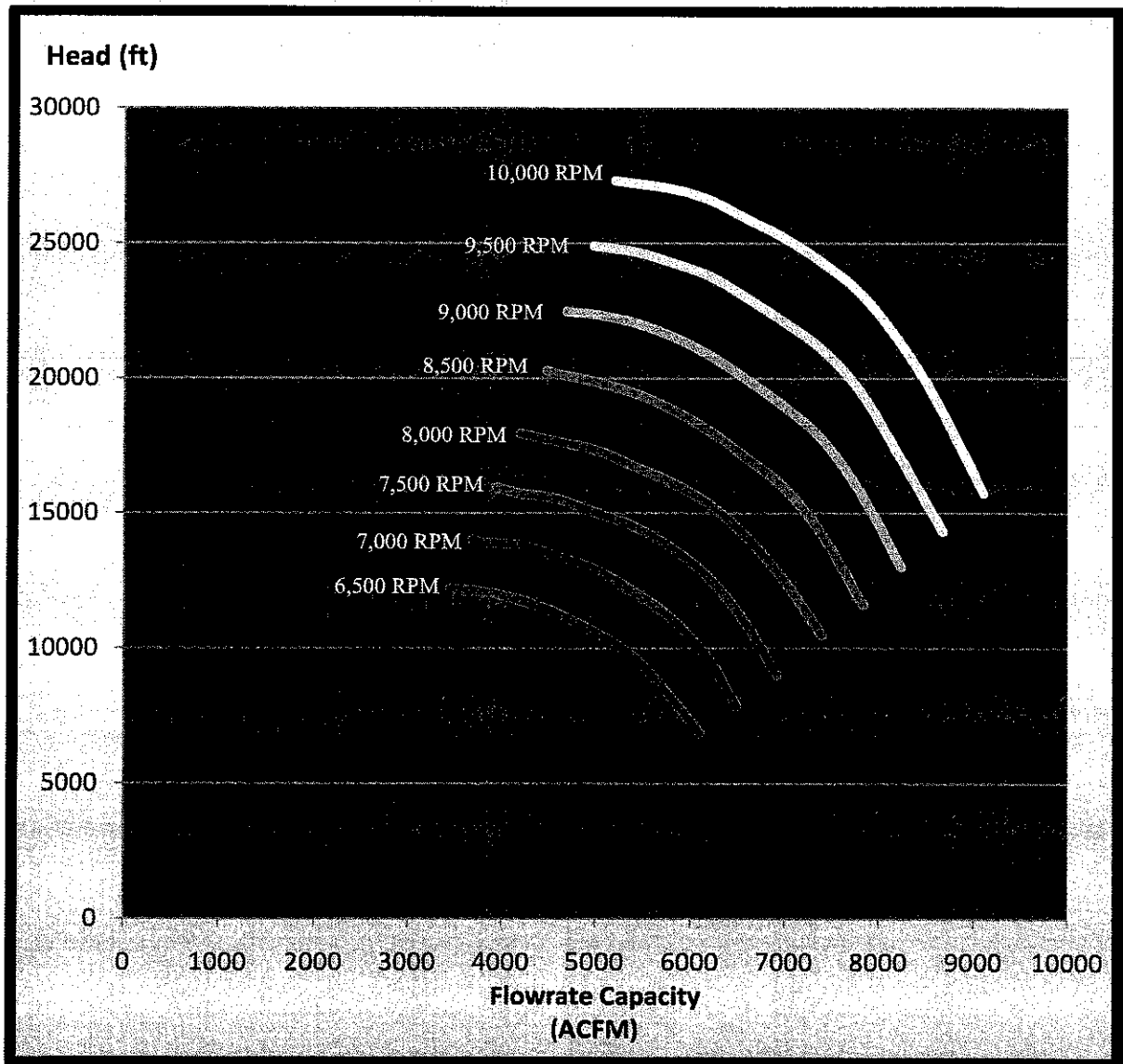


Figure 4.1 : Performance curve of the design point

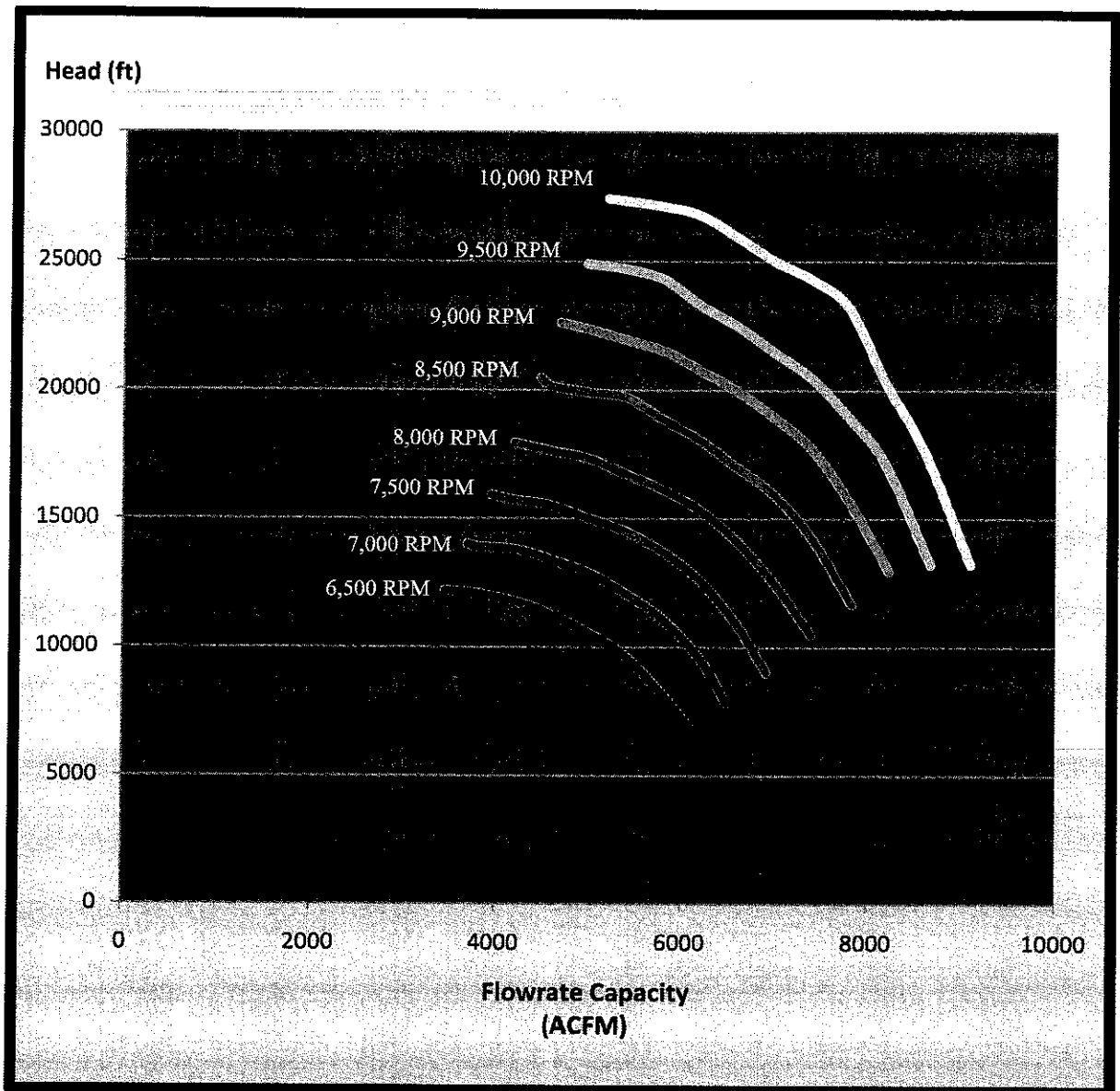


Figure 4.2 : Performance curve of the actual operation data.

4.3 COMPRESSOR EFFICIENCY VS FLOWRATE

Additionally, a graph of Compressor Efficiency versus Flowrate for each curve is plotted. These graphs are shown in figure below (Figure 4.3 & Figure 4.4). This graphs show the efficiency of the compressor at any particular flowrate capacity. The behavior of each curve is discussed in the next chapter.

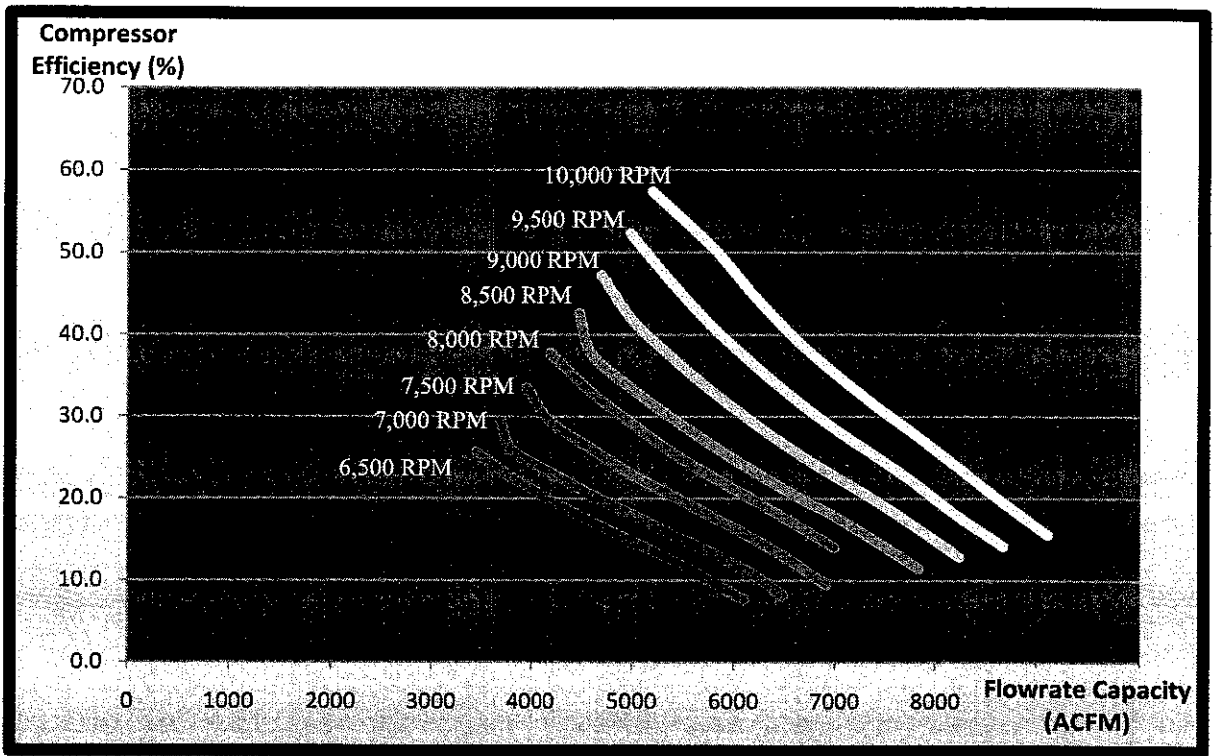


Figure 4.3 : Compressor efficiency vs flowrate (design point).

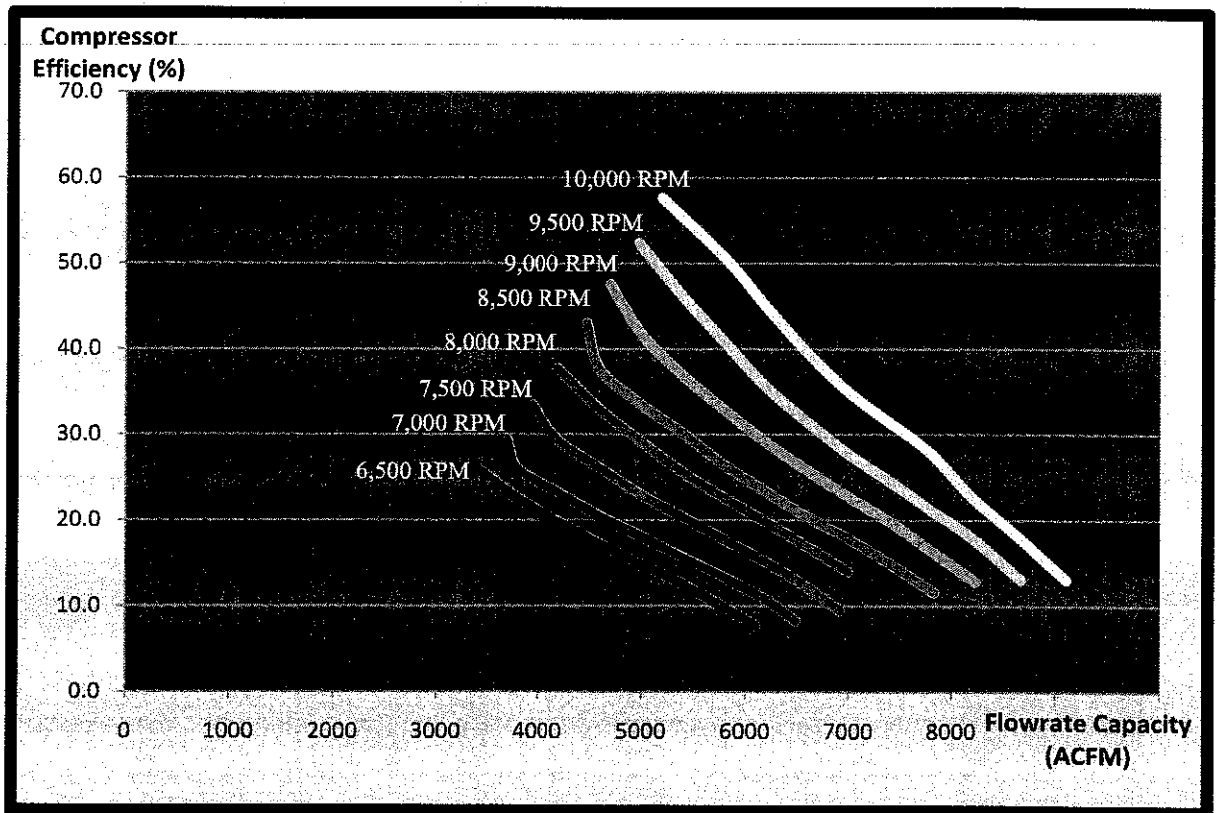


Figure 4.4 : Compressor efficiency vs flowrate (actual operating point)

CHAPTER 5

DATA EVALUATION & DISCUSSION

5.1 DATA EVALUATION

5.1.1 The Performance Curve

The two performance curves in the previous chapter represent the data obtained from the PETRONAS Fertilizer Bintulu, Sarawak as compiled in Appendix VII. The two data; Design Point and Actual Operating Point are taken from the same centrifugal compressor. By using the same values of the flowrate from the Design Point, the operator had obtained the actual polytrophic head values for the centrifugal compressor. These values are called Actual Operating Data. These two data; Design Data and Actual Operation Data the performance curves are plotted as in Figure 4.1 and Figure 4.2.

There are number of curves in each of the figure, which represents the speed of the compressor was running. The lowest curve represents the lowest speed which was running around 6500 RPM and the highest curve represents the highest compressor speed which was around 10,000 RPM. The lowest curves for both figures (Figure 4.1 and Figure 4.2) have only 8 points and these numbers of points increase as the compressor speed increase. For instance, the second, third and fourth (from bottom) curves for each data have 9 points in each curve, and the rest have 10 points. The first point in each curve is called the surge point (the point where surge will occur), while the last point is called the choke point. The line that connects all the surge point is called the surge line; while the line connecting the choke point is called the choke line.

Overall, the two performance curves are showing a similar behavior, data ranged but a very slight different for the top curves. Apparently, we can see a same characteristic / behavior of the curves which are; a slope-down curve as shown in figure below:

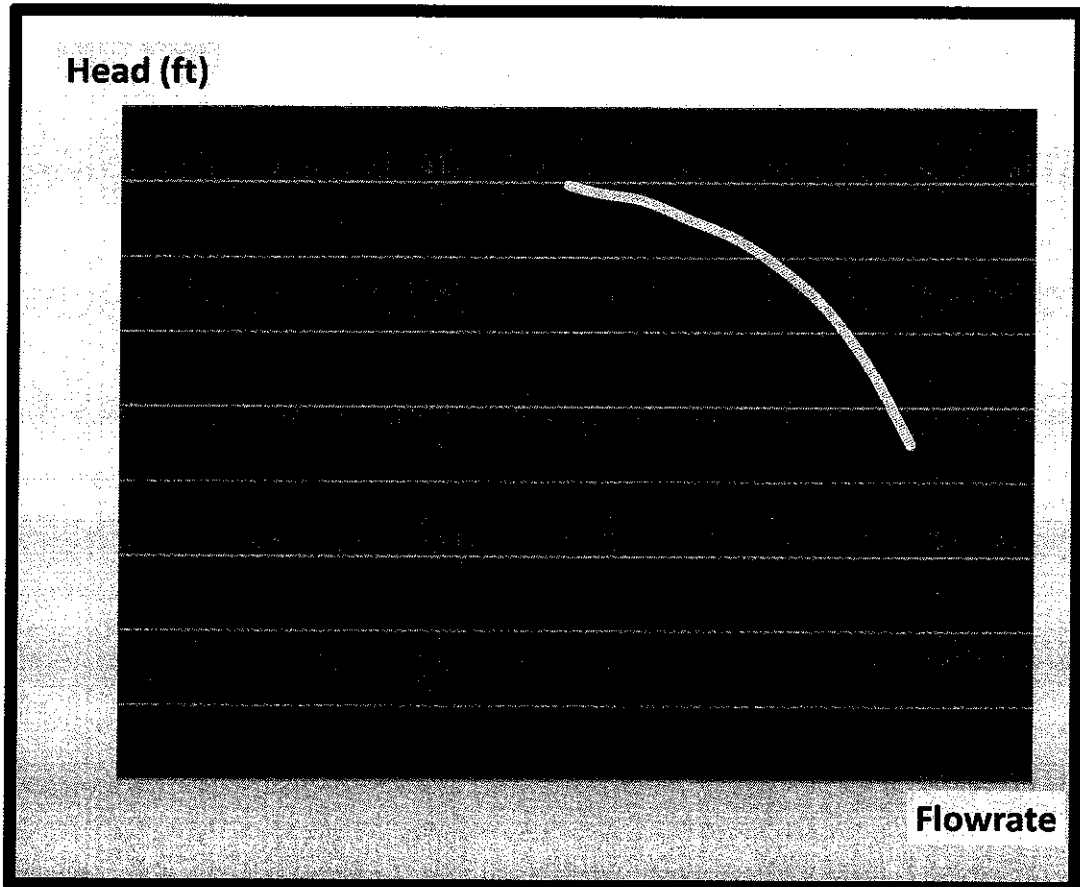


Figure 4.5 : The two performance curves from Figure 4.1 and Figure 4.2 show the same behavior; a slope-out curve

Although these two performance curves are showing the same behavior, there are little differences for the top curves behavior. To see them clearly, the author has superimposed both of the performance curves together as can be seen in the figure on the next page (Figure 4.6).

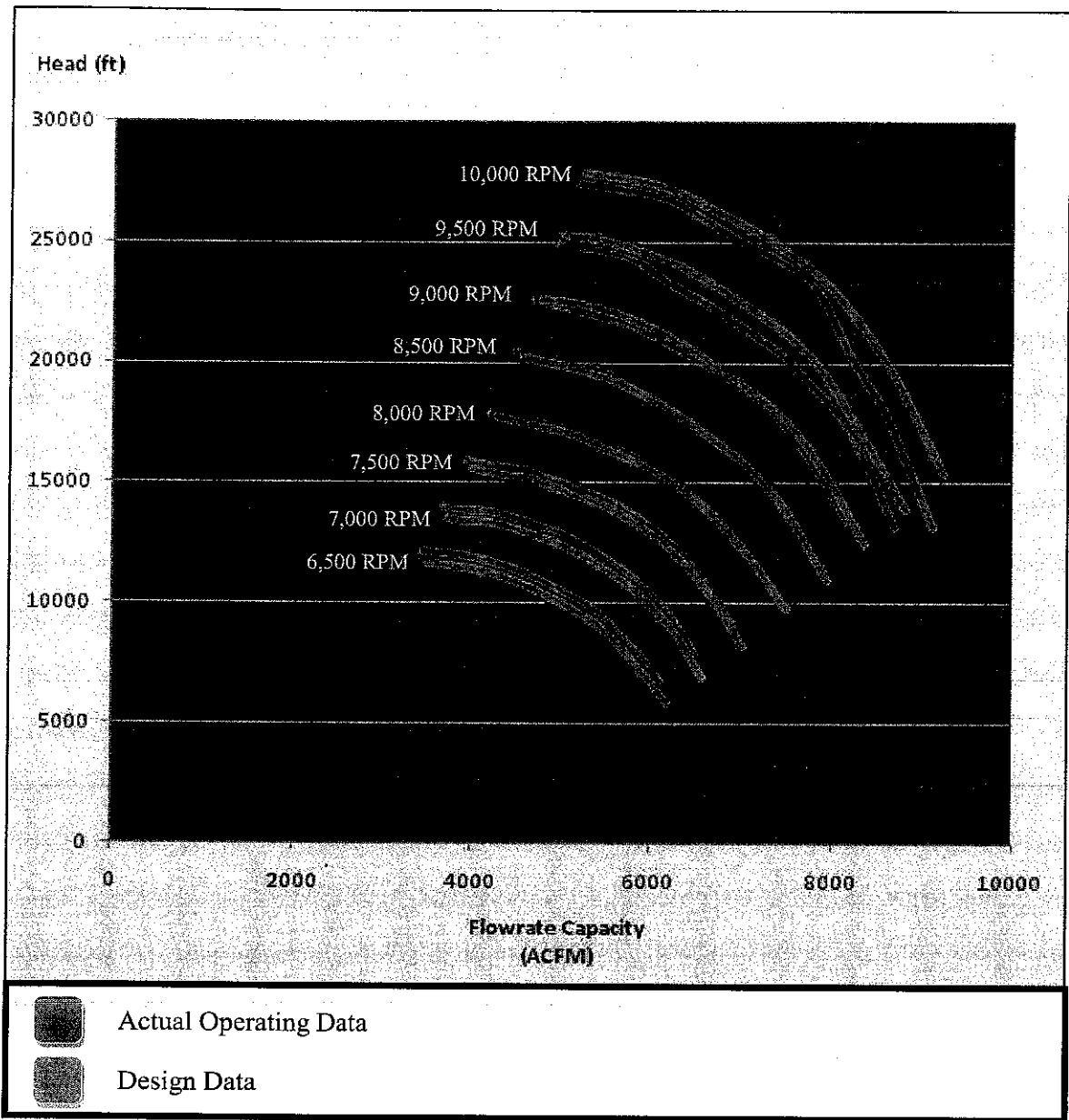


Figure 4.6 : Comparison of the two performance curves from Figure 4.1 and Figure 4.2. Green curves are the Design Data while curves in Orange are the Actual Operating Data

As shown in Figure 4.6, there are slight differences between the green curves (design data) and the orange curves (actual operating data). These differences are not much noticeable for the middle curves where the speed of the centrifugal compressor is around 8000 RPM or operating nearby the 100% of the compressor speed. The differences are much clearer for the top curves and the bottom curves.

There are few variables and conditions that lead to such differences of these two (2) data types. These differences are not desirable and considered as drop of performance. The reasons that lead to the performance drop are may due to mechanical failure such as fouling inside the compressor, leakage of the system, high friction between the devices and etc.

Thus, if the operators intend to run the compressor at the high compressor speed, some modifications should be made in order to obtain a high efficiency. They are required either to increase the compressor speed at the same flowrate, or increase the discharge pressure to obtain a higher Polytrophic Head and eliminate any mechanical failures and etc.

5.1.2 Compressor Efficiency versus Flowrate

The other two graphs in the previous chapter represent the centrifugal compressor efficiency for the Design Point and Actual Operating. From the Design Point Flowrate values, the operators are able to obtain the readings for the Actual Operating Point. The Compressor Efficiency basically is derived from the Temperature Readings and Pressure Ratio of the centrifugal compressor as can be seen in Equation 3 in page 12.

There are number of curves in each of the figure, which represents the speed of the compressor. The lowest curve represents the lowest speed which is running around 6500 RPM and the highest curve represents the highest compressor speed which is around 10,000 RPM. The lowest curves for both figures (Figure 4.1 and 4.2) have only 8 points and these numbers of points increase as the compressor speed increase. i.e. The second, third and fourth (from bottom) curves for each data have 9 points in each curve, and the rest have 10 points.

Taken as a whole, the two graphs are showing a similar behavior and data ranged. Apparently, we can see a same characteristic / behavior of the curves which are; a slope-down curve as shown in figure below:

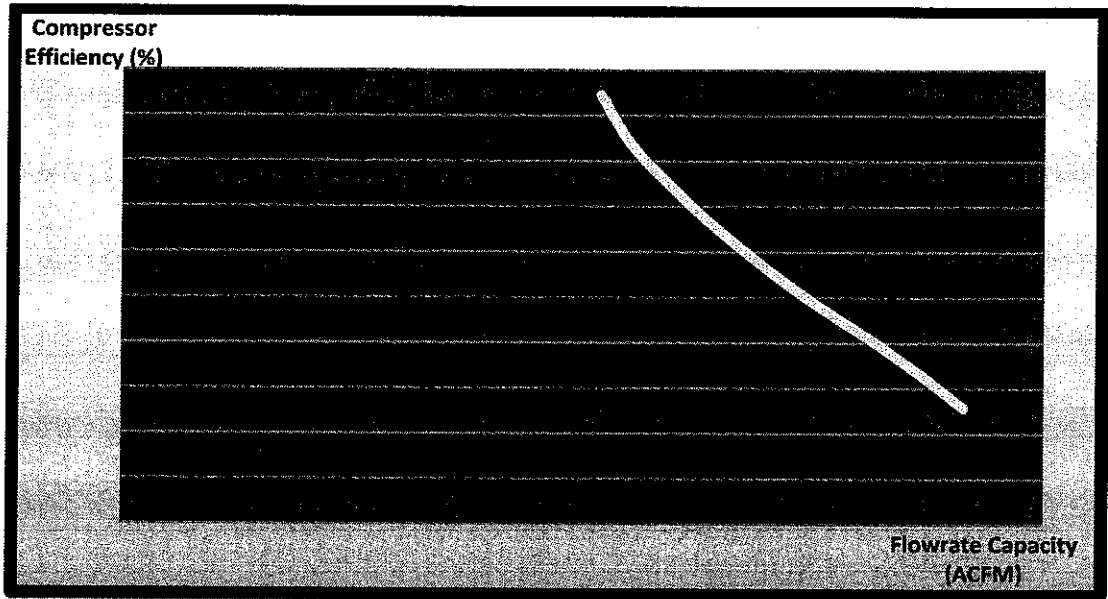


Figure 4.7 : Graphs from Figure 4.3 & 4.4 are showing the similar behavior curve which is a non-linear slope-in curve.

From those two (2) figures as well, we can conclude that as the flowrate increases the compressor efficiency of the compressor drops. Another thing that can be seen here is that as the compressor speed increases the compressor efficiency increases for the same value of the flowrate.

CONCLUSION

By using the program designed by the author, it provides the basic necessary evaluation of centrifugal compressor by showing the operator at which point or condition does the problem occurs. The operator then can check for any failure that brings to the differences of the performance curves evaluated from the program. The differences of the performance curves are often referred as performance drop of the centrifugal compressor. Next, the operator can perform any action to remedy the performance drop and assure the centrifugal compressor is operating at the highest efficiency which is closely related to the fuel consumption of the centrifugal compressor driver. Therefore, consistent check-up of the centrifugal compressor should always be made in order to maintain a high-efficiency of the centrifugal compressor performance. This is to avoid the increase of fuel-consumption and thus affecting the profits made. Two data types are required to make a performance check. The Design Point where usually obtained from the compressor manufacturer and the Actual Operating Data where is obtained from the operator of the centrifugal compressor. These two (2) types of data are then compared to each other to see any bid dissimilarities between them. Any dissimilarity in the Performance Curve of the Actual Operating Data to the Performance Curve of the Design Data shows that the centrifugal gas compressor is not running at the desired point at the particular compressor speed and flowrate capacity. The operator is then able to make any modification or changes to the centrifugal compressor which will relocate the point of dissimilarities of the curve to the desired point as in the Design Data's performance curve. The said spreadsheet program can be used by any company with the permission and approval of the university.

RECOMMENDATIONS

In order to improve the program, several things should be made. The LabView software has the capability to run a real-time assessment of any device. By connecting the program from a computer to the centrifugal gas compressor, the operator will be able to run the assessment continuously for a quick detection of performance drop. This will surely enhanced the assessment mode of the centrifugal gas compressor. The user can as well perform real-time thermodynamic analysis on the compressor by using this software.

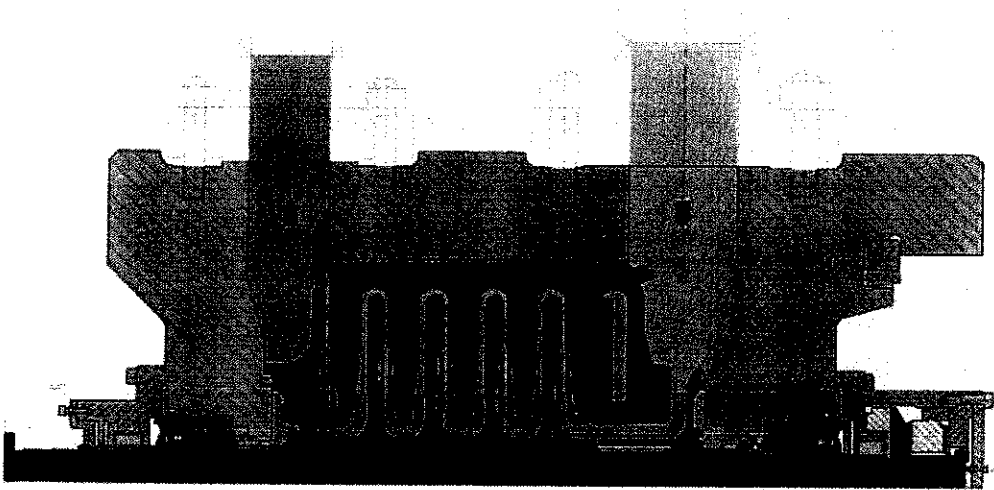
This program however, requires the operators to have Microsoft Excel installed into their computer in order to run it. Thus, the other improvement that can be made is using Microsoft Visual Basic to create a similar program. This is because Microsoft Visual Basic can create a standalone / independent program without any Microsoft products installed on the user's computer. Thus it can be run by any computer which is used to perform the assessment.

REFERENCES

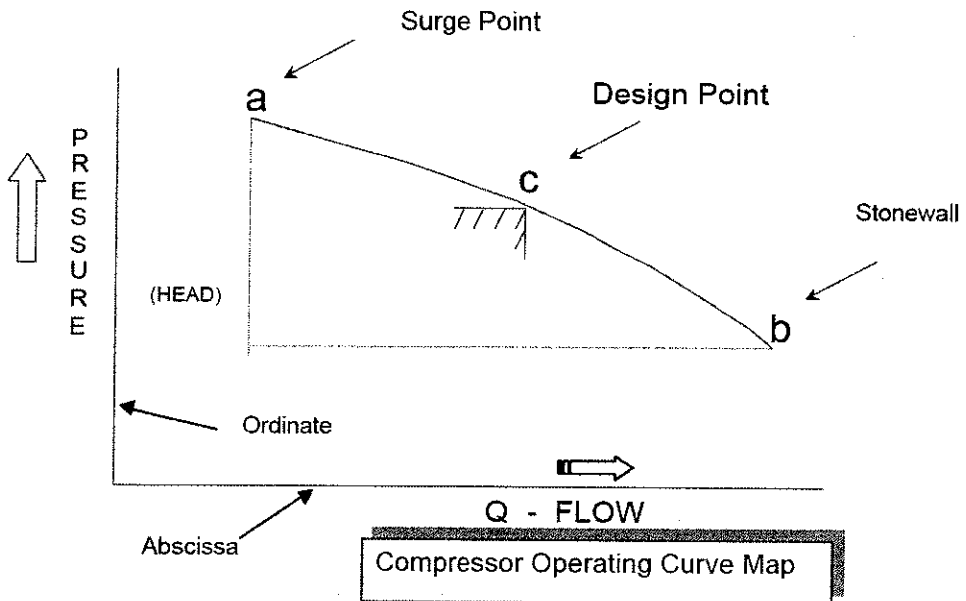
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3. Scott Golden, Scott A. Fulton and Daryl W. Hanson, 2002, "Understanding Centrifugal Compressor Performance in a Connected Process System" *Petroleum Technology Quarterly, Process Consulting Services Inc., Houston, Texas.*
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7. Syuieb Ali, Centrifugal Compressor, Basic and Understanding, 2006, PETRONAS Carigali Sdn Bhd (PCSB)
8. Ing. Jiří Oldřich, CSc, 2004, Variable Composition Gas Centrifugal Compressor Antisurge Protection, Klečákova Praha, Czech Republic

APPENDICES

I. Anatomy of Centrifugal Compressor (Rolls Royce Training, 2008)



II. Operating at Design Point (Dresser Rand Training, 2008)



III. Critical Literature Review

No	Author & Title of Paper	Scope of Mathematical Model	Approach	Discussion
A	<p>Syuieb Ali, Centrifugal Compressor, Basic and Understanding, 2006, PETRONAS Carigali Sdn Bhd (PCSB)</p>	<p>Polytropic Head, Isentropic Head</p>	$H_{poly} \left[\frac{ft \cdot lb_f}{lb_m} \right] = 53.3 Z_{avg} \left(\frac{T_s}{SG} \right) \left(\frac{k \times n_p}{k-1} \right) \left(\frac{P_d}{P_s} \right)^{\frac{k-1}{k}} \left(\frac{P_d}{P_s} \right)^{\frac{k-1}{k}} - 1$	<p>Required a lot of information gathering, Moderate calculations difficulty, Accurate result evaluation</p>
			$H_{isen} \left[\frac{ft \cdot lb_f}{lb_m} \right] = 53.3 Z_{avg} \left(\frac{T_s}{SG} \right) \left(\frac{k}{k-1} \right) \left(\frac{P_d}{P_s} \right)^{\frac{k-1}{k}} - 1$	
<p>Where</p>			<p>Z_{avg} is average compressibility factor = $(Z_s + Z_d)/2$ T_s is the Suction Temperature ($^{\circ}R$) P_d is the Discharge Pressure ($psia$) SG is the specific gravity of the gas = $\frac{\rho_{gas}}{\rho_{H_2O}}$ k is the ratio of the specific heat = $\frac{c_p}{c_v}$</p>	

No	Author & Title of Paper	Scope	Approach	Discussion
B	Rolls Royce Technical Training	Polytrophic Head	$H = ZRT_s \times \left[\left(\frac{P_d}{P_s} \right)^{\frac{(k-1)}{k}} - 1 \right] \times \frac{MW}{k}$ <p>Where</p> <p>Z is the Compressibility Factor R is the Universal Gas Constant T_s is the Suction Temperature (°R) P_d is the Discharge Pressure in (psia) MW is the gas mole weight k is the ratio of the specific heat = $\frac{c_p}{c_v}$</p>	Less data required, Basic calculations Difficultly, Acceptable result of calculations


No	Author & Title of Paper	Scope	Approach	Discussion
C	Dresser Rand: Compressor Training, www.dresser-rand.com , info@dresser-rand.com .	Polytropic Head, Polytropic Efficiency	$\text{Head} \left[\frac{\text{ft} \cdot \text{lb}_f}{\text{lb}_m} \right], H = ZRT_s \times \left(\frac{\left(\frac{P_d}{P_s} \right)^{\frac{k-1}{k-\eta}} - 1}{\left(\frac{k-1}{k-\eta} \right)} \right)$ $\text{Polytropic Efficiency, } \eta_p = \left(\frac{k-1}{k} \right) \times \left(\frac{\log \frac{P_d/P_s}{T_d/T_s}}{\log \frac{P_d/P_s}{T_d/T_s}} \right)$ <p>Where;</p> <ul style="list-style-type: none"> Z is the Compressibility Factor R is the Universal Gas Constant = $\frac{1545 \text{ ft} \cdot \text{lb}_f / \text{lbmol} \cdot ^\circ R}{\text{MW}}$ T_s is the Suction Temperature (°R) k is the ratio of the specific heat = $\frac{c_p}{c_v}$ η is the polytropic index 	Less data required, Basic calculations Difficulty, Few conversions needed, Strong result of calculations

No	Author & Title of Paper	Scope	Approach	Discussion
D	Rick Brown & Kevin Rahman, Pacific Gas and Electric Corporation, Turbine / Compressor Performance Monitoring Software and Flow Capacity	Isentropic Head, Volumetric flowrate, Compressor Efficiency	$H_{isen} \left[\frac{ft \cdot lb_f}{lb_m} \right] = ZRT_s \times \frac{\left[\left(\frac{P_d}{P_s} \right)^{\frac{k-1}{k}} - 1 \right]}{k-1}$ $ACFM = \frac{14.73 \times Q \times ZT_s}{520 \times P_s \times 0.00144}$ $\eta = \left[\frac{T_s + 460}{T_d - T_s} \right] \times \left[\left(\frac{P_d}{P_s} \right)^{\frac{k-1}{k}} - 1 \right]$ <p>Where;</p> <p>Z is the Compressibility Factor, $Z = \frac{Pv}{RT}$</p> <p>T_s is the Suction Temperature in ($^{\circ}R$)</p> <p>P_d is the Discharge Pressure in (<i>psia</i>)</p> <p>Q is the unit flow in MMcf/d</p> $R = 91.3 = \frac{1545 \text{ ft} \cdot \text{lb}_f / \text{lbmol} \cdot ^{\circ}R}{S.G. \times 28.97}$	Less data required, Basic calculations Difficultly, Acceptable result of calculations


No	Author & Title of Paper	Scope	Approach	Discussion
E	Scott Golden, Scott A. Fulton & Daryl W. Hanson; Understanding Centrifugal Compressor Performance in a Connected Process System; Process Consulting Services Inc., Houston, Texas, U.S.A	Polytrophic Head	$H_{poly}[\beta] = \frac{1,545}{MW} Z_{avg} T_s \times \left(\frac{k}{k-1} \right) \times \left[\left(\frac{P_d}{P_s} \right)^{\frac{k-1}{k}} - 1 \right]$ <p>Where</p> <p>Z_{avg} is average compressibility factor = $(Z_s + Z_d)/2$</p> <p>T_s is the Suction Temperature ($^{\circ}R$)</p> <p>P_d is the Discharge Pressure ($psia$)</p> <p>k is the ratio of the specific heat = $\frac{c_p}{c_v}$</p> <p>MW is the molecular weight</p> <p>k is the ratio of the specific heat = $\frac{c_p}{c_v}$</p>	Less data required, Basic calculations Difficulty, Acceptable result of calculations

IV. A. Example of Data-sheet

I-4

		Technical Specification COMPRESSOR "THERMODYNAMIC DATA"				GAN 01-0793	
						NOM / CODE 02-K001	
						Page AA	
X No	DESIGNATION	DIM	DIM				
X11	Operating point	-	-	NORMAL (CLEANST)			
X12	Process stage	-	-	1	2	3	-
X13	Casing arrangement	-	-	LA	LA	RA	RA
X14		-	-				
X15	Medium	-	-	AIR			
X16	Volume flow at 1.013 bar / 273 K DRY		l/min	38567	-	-	32 213.4
X17	Inlet volume flow <input type="checkbox"/> dry <input checked="" type="checkbox"/> wet		m ³ /h	45430	21980	7960	4426
X18	Inlet mass flow <input type="checkbox"/> dry <input checked="" type="checkbox"/> wet		kg/h	51070	-	50300	48540
X19	Outlet mass flow <input checked="" type="checkbox"/> dry <input type="checkbox"/> wet		kg/h	-	-	-	359.47
X20	Inlet pressure		bar	0.9955	2.14	5.75	10.32
X21	Outlet pressure after COMPRESSOR		bar	2.27	5.88	10.45	35.13
X22	Inlet temperature		°C	25	42	47	65
X23	Outlet temperature after COMPRESSOR		°C	139	127	120	254
X24	Pressure ratio		-	2.29	2.75	1.82	3.42
X25	Pressure losses (DIPPER, DRAIN, SEPARATOR)		bar	0.13	0.13	0.13	-
X26	Blow-off vol. flow at 1.013 bar / 273 K		l/min	-	-	-	-
X27	REL. HUMIDITY (SUCTION)		%	20.7	-	-	-
X28							
X29							
X30	Intermediate inlet flow		m ³ /h	-	-	-	-
X31	Intermediate inlet pressure		bar	-	-	-	-
X32	Intermediate inlet temperature		°C	-	-	-	-
X33	Extraction flow <input checked="" type="checkbox"/> dry <input type="checkbox"/> wet		m ³ /h	-	-	159	-
X34	Extraction pressure (10-12 bar abs.)		bar	-	-	10.3	-
X35	Extraction temperature		°C	-	-	65	-
X36	EXTRACTION FLOW @ DRY		l/min	-	-	40.2	-
X37	EXTRACTION FLOW @ WET		l/min	-	-	1349	-
X38							
X39	Overall specific work <input type="checkbox"/> dry <input checked="" type="checkbox"/> wet <input type="checkbox"/> wet		kJ/kg	3.70 x 10 ³			
X40	Overall efficiency <input type="checkbox"/> dry <input checked="" type="checkbox"/> wet <input type="checkbox"/> wet		%	60.5 (INTERNAL EFF. WITHOUT M.L.)			
X41	Sp. work per stage <input type="checkbox"/> dry <input checked="" type="checkbox"/> wet <input type="checkbox"/> wet		kJ/kg	25.790	112.500	61.020	149.480
X42	Efficiency per stage <input type="checkbox"/> dry <input checked="" type="checkbox"/> wet <input type="checkbox"/> wet		%	79	77	74	72
X43	Total efficiency at coupling		%	59.2 (ISOTHERM EFF. WITH M.L.)			
X44	Speed		min ⁻¹	7660			
X45	Speed range		min ⁻¹	10397			
X46	Speed range		%	20 - 105			
X47	Surge limit at p/c const. (2)		%	APPROX. 65			
X48							
X49	Total power consumption (3)		kW	7570			
X50	Power consumption per STAGE		kW	1549	2080	1145	7802
X51	Mechanical losses		kW	97			
X52	Sp. losses (IF APPLICABLE)		kW	20			
X53							
X54	Power recommended for driver		kW				
X55							
X56	Rotation of compressor viewed from			<input checked="" type="checkbox"/> cw (clockwise) <input type="checkbox"/> ccw (counterclockwise)			
X57	Remarks						

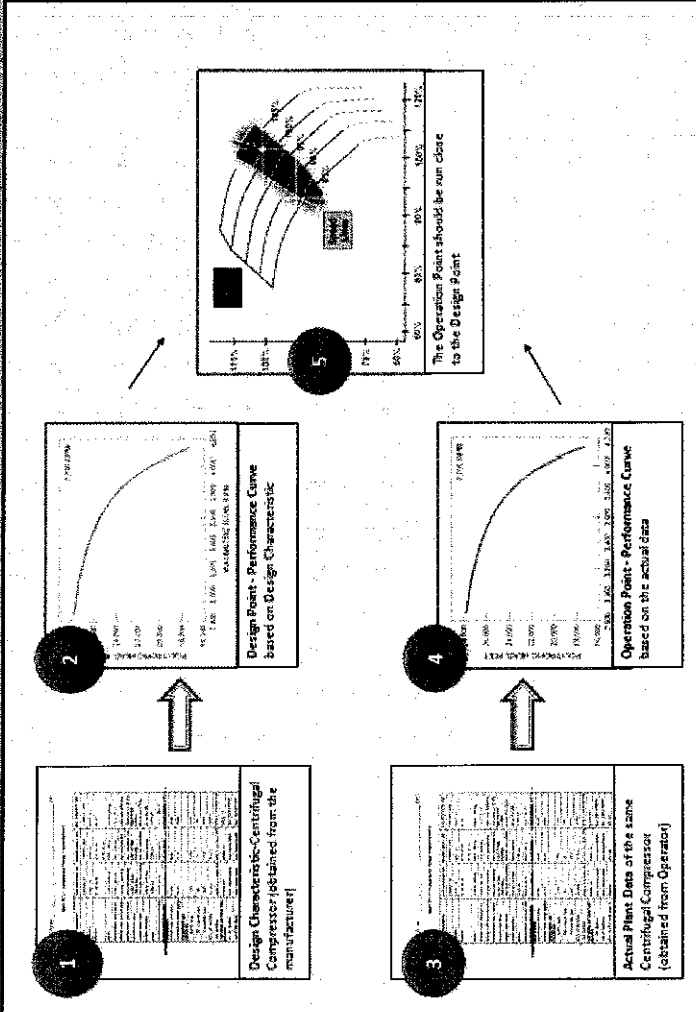
IV) B. Example of Data sheet

		Technical Specification COMPRESSOR "THERMODYNAMIC DATA"	
X No	DESIGNATION	DIM	DIM
		-	-
13	Casing arrangement	-	-
			HP
			HORIZONTAL
			SEE PROCESS ARRANGEMENT PAGE NO.
X 15	Medium	-	-
			NB ₂
16	Volume flow at 1.013 bar / 273 K DRY	m ³ /h	42760
			50130
17	Inlet volume flow <input checked="" type="checkbox"/> dry <input type="checkbox"/> wet	m ³ /h	12270
			6507
	Inlet mass flow <input checked="" type="checkbox"/> dry <input type="checkbox"/> wet		
	Outlet mass flow <input checked="" type="checkbox"/> dry <input type="checkbox"/> wet	kg/h	32500
			32100
	Inlet pressure	bar	3.42
			2.6
	Outlet pressure, after COMP.	bar	8.25 #
			18.1
X 18	Inlet temperature	°C	0
			22
19	Outlet temperature, after COMP.	°C	81
			100
24	Pressure ratio	b/p	2.41
			2.26
X 15	Pressure losses	bar	0.25
16	Blow-off vol. flow at 1.013 bar / 273 K	m ³ /h	
17			
18			
19			
20	Intermediate inlet flow	m ³ /h	
21	Intermediate inlet pressure	abs. bar	
22	Intermediate inlet temperature	°C	
23	Extraction flow <input type="checkbox"/> dry	m ³ /h	
24	Extraction pressure	abs. bar	
25	Extraction temperature	°C	
26			
27			
28			
29	Overall specific work <input type="checkbox"/> Y _c <input checked="" type="checkbox"/> Y _T <input type="checkbox"/> Y _{pol}	kJ/kg	211.6
			66
30	Overall efficiency <input type="checkbox"/> η _s <input checked="" type="checkbox"/> η _T <input type="checkbox"/> η _{pol}	%	
31	Spec. work per stage <input type="checkbox"/> Y _c <input type="checkbox"/> Y _T <input checked="" type="checkbox"/> Y _{pol}	kJ/kg	129.200
			125.600
32	Efficiency per stage <input type="checkbox"/> η _s <input type="checkbox"/> η _T <input checked="" type="checkbox"/> η _{pol}	%	75
			74
33	Total efficiency at coupling	%	74
34	Speed	min ⁻¹	10800
35	Speed range	min ⁻¹	8445 - 11823
		%	76
		%	63
39	Total power consumption ³⁾	kW	3350
40	Power consumption per STAGE	kW	1352
41	Mechanical losses	kW	88
42	Gear losses	kW	
43			
44			

V. A. Gas Compressor Performance Assessment Program – Main Section

Introduction

This spreadsheet is to evaluate the performance of the centrifugal compressor. The user needs to enter the characteristics of a particular centrifugal compressor. The user should obtain a Design Characteristics of the centrifugal compressor from the manufacturer when they bought the compressor. Next, the user will plot its actual data of the same centrifugal compressor and evaluate them by plotting its performance curve. The spreadsheet should be able to plot the first plot of the centrifugal compressor. The illustrations of the spreadsheet are as follows (see the table below).



Quick Link

1 [Compressor Assessment](#)

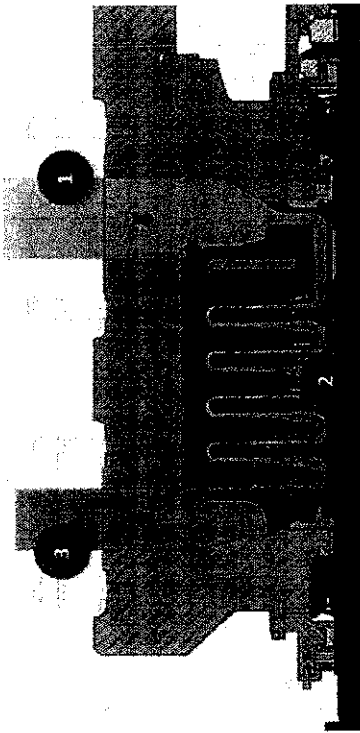
2 [Help](#)

Instructions

- The user should obtain a Design Characteristics of the centrifugal compressor from the manufacturer when they bought the compressor.
- By using this Design Characteristics, the user should set it as the Design Operating Point. Evaluate the data by using the Compressor Assessment section to obtain a Design Point - Performance Curve.
- The user should run the compressor to obtain the actual data of the centrifugal compressor. He should vary the Inlet condition and outlet condition as in the design characteristics data. Next, evaluate the actual data by using the Compressor Assessment section to plot its performance curve.
- Next, the user should ensure that the Actual Data - Performance Curve is running close to the Design Point - Performance Curve. If it is not the case, then he should make some modifications / maintenance / repair the centrifugal compressor in order to

B. Gas Compressor Performance Assessment Program -- Help Section

Symbol	Unit	Descriptions
P_s	barg bara psig Pa	Suction Pressure in bar (gauge) Suction Pressure in bar (absolute) Suction Pressure in psi (gauge) Suction Pressure in Pascal
T_s	°C °F K	Suction Temperature in Celsius Suction Temperature in Fahrenheit Suction Temperature in Kelvin
v (from table)	m ³ /kg	Specific Volume
c_p (from table)	kJ/kg.K	Specific Heat at constant volume
c_p (from table)	kJ/kg.K	Specific Heat at constant pressure
MW	g/mol	Molecular weight
k	-	Specific Heat ratio
$(k-1)/k$	-	-
R	ft-lb / (lbmol · °R)	Universal Gas Constant in English Unit
\bar{R}	J/kg.K	Universal Gas Constant Metric Unit
MW	g/mol	Molecular weight
q (ft ³ /min)	ft ³ /min	-
T_d (°C)	°C	Suction Temperature in Celsius
T_d (°F)	°F	Suction Temperature in Fahrenheit
P_d (barg)	barg	Suction Pressure in bar (gauge)



Suction Nozzle

Compression Process

Discharge Nozzle

$$H_{\text{prop}} [ft] = \frac{1.545}{MW} Z_{\text{avg}} T_s \left(\frac{k}{k-1} \right) \times \left[\left(\frac{P_d}{P_s} \right)^{\frac{k-1}{k}} - 1 \right]$$

$$\eta_{\text{isem}} [\%] = \left[\frac{T_s + 460}{T_d - T_s} \right] \times \left[\left(\frac{P_d}{P_s} \right)^{\frac{k-1}{k}} - 1 \right]$$

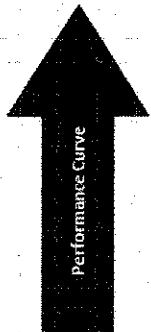
[Back to Main Page.](#)
[Compressor Assessment.](#)

C. Gas Compressor Performance Assessment Program - Assessment Section

i. Data Input Section

This section will calculate the Polytropic Head vs the Flow rate. The graph on the right-hand side shows the performance curve of the input data. Boxes in white are the inputs required.

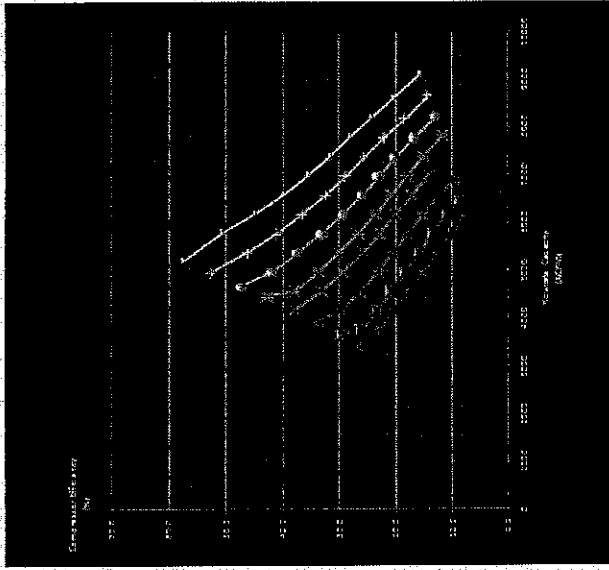
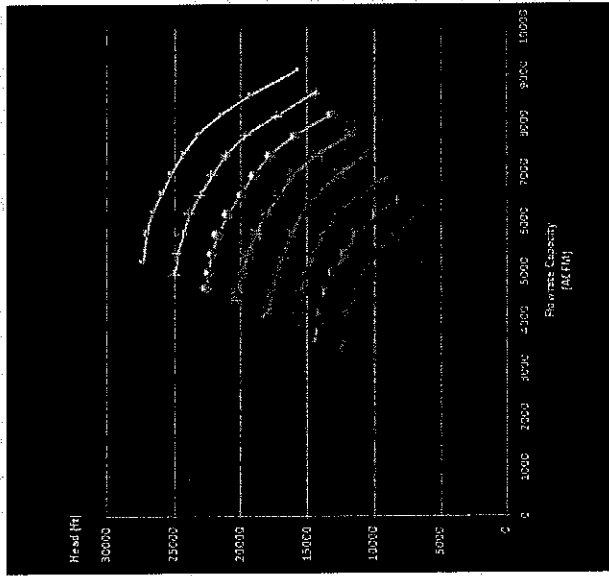
Air Properties		Gas Properties	
Atm Pressure (bar)	1.01	γ (from table)	0.3083
P_1 (bar)	3.45	C_p (from table)	1.66
P_2 (bar)	4.4	C_v (from table)	2.25
P_1 (psig)	49.75	MW	17.03
P_2 (psig)	444.325	k	1.36
T_1 (°C)	20.00	$(k-1)/k$	0.26
T_1 (°F)	68.00	R	90.72
T_2 (K)	293.15	R	488.20
		Z	0.96



Calculations									
Point	q (ft ³ /min)	T_1 (°C)	T_2 (°F)	P_1 (bar)	P_2 (bar)	H_{poly} (ft)	P_2	η_{poly} (%)	Rowwise Capacity [ACFM]
1	3450	100.0	212.0	4.7	68.7	12198	1.3	25.6	
2	3800	110.0	230.0	4.7	68.5	12097	1.3	22.6	
3	4200	120.0	248.0	4.7	68.0	11795	1.3	19.8	
4	4600	130.0	266.0	4.6	67.1	11291	1.3	17.9	
5	5000	140.0	284.0	4.5	66.0	10585	1.3	14.8	
6	5400	150.0	302.0	4.4	64.5	9677	1.2	12.5	
7	5800	160.0	320.0	4.3	62.0	8465	1.2	9.8	
8	6100	170.0	338.0	4.1	59.9	6954	1.2	7.7	
9	3690	100.0	212.0	4.9	71.8	14013	1.3	29.4	
10	3800	110.0	230.0	4.9	71.6	13913	1.3	26.0	
11	4200	120.0	248.0	4.9	71.4	13812	1.3	23.2	
12	4600	130.0	266.0	4.9	70.7	13408	1.3	20.5	
13	5000	140.0	284.0	4.8	69.9	12904	1.3	18.1	
14	5400	150.0	302.0	4.7	68.5	12097	1.3	15.6	
15	5800	160.0	320.0	4.6	66.8	11089	1.3	13.3	
16	6200	170.0	338.0	4.4	64.3	9576	1.2	10.7	
17	6490	180.0	356.0	4.2	61.5	7862	1.2	8.3	
18	3950	100.0	212.0	5.2	75.2	15930	1.4	33.5	
19	4200	110.0	230.0	5.2	74.8	15728	1.4	29.4	
20	4600	120.0	248.0	5.1	74.5	15526	1.4	26.1	

ii. Performance Curves Plotter

shows the performance curve of



P_r	η_{flow} (%)
1.3	25.6
1.3	22.6
1.3	19.8
1.3	17.3
1.3	14.8
1.2	12.5
1.2	9.8
1.2	7.7
1.3	29.4
1.3	26.0
1.3	23.2
1.3	20.5
1.3	18.1
1.3	15.6
1.3	13.3
1.2	10.7
1.2	8.3
1.4	33.5
1.4	29.4
1.4	26.1

VI. a. Properties of various common gases:

THERMODYNAMICS

Molar mass, gas constant, and critical-point properties

Substance	Formula	Molar mass, M kg/kmol	Gas constant, R kJ/kg · K*	Critical-point properties		
				Tempera- ture, K	Pressure, MPa	Volume, m ³ /kmol
Air	—	28.97	0.2870	132.5	3.77	0.0883
Ammonia	NH ₃	17.03	0.4882	405.5	11.28	0.0724
Argon	Ar	39.948	0.2081	151	4.86	0.0749
Benzene	C ₆ H ₆	78.115	0.1064	562	4.92	0.2603
Bromine	Br ₂	159.808	0.0520	584	10.34	0.1355
n-Butane	C ₄ H ₁₀	58.124	0.1430	425.2	3.80	0.2547
Carbon dioxide	CO ₂	44.01	0.1889	304.2	7.39	0.0943
Carbon monoxide	CO	28.011	0.2968	133	3.50	0.0930
Carbon tetrachloride	CCl ₄	153.82	0.05405	556.4	4.56	0.2759
Chlorine	Cl ₂	70.906	0.1173	417	7.71	0.1242
Chloroform	CHCl ₃	119.38	0.06964	536.6	5.47	0.2403
Dichlorodifluoromethane (R-12)	CCl ₂ F ₂	120.91	0.06876	384.7	4.01	0.2179
Dichlorofluoromethane (R-21)	CHCl ₂ F	102.92	0.08078	451.7	5.17	0.1973
Ethane	C ₂ H ₆	30.070	0.2765	305.5	4.48	0.1480
Ethyl alcohol	C ₂ H ₅ OH	46.07	0.1805	516	6.38	0.1673
Ethylene	C ₂ H ₄	28.054	0.2964	282.4	5.12	0.1242
Helium	He	4.003	2.0769	5.3	0.23	0.0578
n-Hexane	C ₆ H ₁₄	86.179	0.09647	507.9	3.03	0.3677
Hydrogen (normal)	H ₂	2.016	4.1240	33.3	1.30	0.0649
Krypton	Kr	83.80	0.09921	209.4	5.50	0.0924
Methane	CH ₄	16.043	0.5182	191.1	4.64	0.0993
Methyl alcohol	CH ₃ OH	32.042	0.2595	513.2	7.95	0.1180
Methyl chloride	CH ₃ Cl	50.488	0.1647	416.3	6.68	0.1430
Neon	Ne	20.183	0.4119	44.5	2.73	0.0417
Nitrogen	N ₂	28.013	0.2968	126.2	3.39	0.0899
Nitrous oxide	N ₂ O	44.013	0.1889	309.7	7.27	0.0997
Oxygen	O ₂	31.999	0.2598	154.8	5.08	0.0820
Propane	C ₃ H ₈	44.097	0.1885	370	4.26	0.1524
Propylene	C ₃ H ₆	42.081	0.1976	365	4.62	0.1327
Sulfur dioxide	SO ₂	64.063	0.1298	430.7	7.88	0.1799
Tetrafluoroethane (R-134a)	CF ₃ CH ₂ F	102.03	0.08149	374.3	4.067	0.2463
Trichlorofluoromethane (R-11)	CCl ₃ F	137.37	0.06052	471.2	4.38	0.2403
Water	H ₂ O	18.015	0.4615	647.3	22.09	0.0560
Xenon	Xe	131.30	0.06332	289.8	5.88	0.0903

*The unit kJ/kg · K is equivalent to kPa · m³/kg · K. The gas constant is calculated from $R = R_u/M$, where $R_u = 8.314$ kJ/kmol · K and M is the molar mass in kg/kmol.
Source: K. A. Kobe and R. E. Lyrin, Jr., *Chemical Review* 52 (1953), pp. 117–236; and ASHRAE, *Handbook of Fundamentals* (Atlanta, GA, 1993), pp. 16.4 and 36.1.

a. Properties of various common gases:

Ideal-gas specific heats of various common gases

(a) At 300 K

Gas	Formula	Gas constant, R kJ/kg · K	C_p kJ/kg · K	C_v kJ/kg · K	k
Air	—	0.2870	1.005	0.718	1.400
Argon	Ar	0.2081	0.5203	0.3122	1.667
Butane	C ₄ H ₁₀	0.1433	1.7164	1.5734	1.091
Carbon dioxide	CO ₂	0.1889	0.846	0.657	1.289
Carbon monoxide	CO	0.2968	1.040	0.744	1.400
Ethane	C ₂ H ₆	0.2765	1.7662	1.4897	1.186
Ethylene	C ₂ H ₄	0.2964	1.5482	1.2518	1.237
Helium	He	2.0769	5.1926	3.1156	1.667
Hydrogen	H ₂	4.1240	14.307	10.183	1.405
Methane	CH ₄	0.5182	2.2537	1.7354	1.299
Neon	Ne	0.4119	1.0299	0.6179	1.667
Nitrogen	N ₂	0.2968	1.039	0.743	1.400
Octane	C ₈ H ₁₈	0.0729	1.7113	1.6385	1.044
Oxygen	O ₂	0.2598	0.918	0.658	1.395
Propane	C ₃ H ₈	0.1885	1.6794	1.4909	1.126
Steam	H ₂ O	0.4615	1.8723	1.4108	1.327

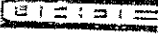
Ideal-gas specific heats of various common gases (Continued)

(b) At various temperatures

Temperature, K	C_p	C_v	k	C_p	C_v	k	C_p	C_v	k
	kJ/kg · K	kJ/kg · K		kJ/kg · K	kJ/kg · K		kJ/kg · K	kJ/kg · K	
	Air			Carbon dioxide, CO ₂			Carbon monoxide, CO		
250	1.003	0.716	1.401	0.791	0.602	1.314	1.039	0.743	1.400
300	1.005	0.718	1.400	0.846	0.657	1.288	1.040	0.744	1.399
350	1.008	0.721	1.398	0.895	0.706	1.268	1.043	0.746	1.398
400	1.013	0.726	1.395	0.939	0.750	1.252	1.047	0.751	1.395
450	1.020	0.733	1.391	0.978	0.790	1.239	1.054	0.757	1.392
500	1.029	0.742	1.387	1.014	0.825	1.229	1.063	0.767	1.387
550	1.040	0.753	1.381	1.046	0.857	1.220	1.075	0.778	1.382
600	1.051	0.764	1.376	1.075	0.886	1.213	1.087	0.790	1.376
650	1.063	0.776	1.370	1.102	0.913	1.207	1.100	0.803	1.370
700	1.075	0.788	1.364	1.126	0.937	1.202	1.113	0.816	1.364
750	1.087	0.800	1.359	1.148	0.959	1.197	1.126	0.829	1.358
800	1.099	0.812	1.354	1.169	0.980	1.193	1.139	0.842	1.353
900	1.121	0.834	1.344	1.204	1.015	1.186	1.163	0.866	1.343
1000	1.142	0.855	1.336	1.234	1.045	1.181	1.185	0.888	1.335
	Hydrogen, H ₂			Nitrogen, N ₂			Oxygen, O ₂		
250	14.051	9.927	1.416	1.039	0.742	1.400	0.913	0.653	1.398
300	14.307	10.183	1.405	1.039	0.743	1.400	0.918	0.658	1.395
350	14.427	10.302	1.400	1.041	0.744	1.399	0.928	0.668	1.399
400	14.476	10.352	1.398	1.044	0.747	1.397	0.941	0.681	1.382
450	14.501	10.377	1.398	1.049	0.752	1.395	0.956	0.696	1.375
500	14.513	10.389	1.397	1.056	0.759	1.391	0.972	0.712	1.362
550	14.530	10.405	1.396	1.065	0.768	1.387	0.988	0.728	1.350
600	14.546	10.422	1.395	1.075	0.778	1.382	1.003	0.743	1.340
650	14.571	10.447	1.395	1.086	0.789	1.376	1.017	0.758	1.332
700	14.604	10.480	1.394	1.098	0.801	1.371	1.031	0.771	1.325
750	14.645	10.521	1.392	1.110	0.813	1.365	1.043	0.783	1.319
800	14.695	10.570	1.390	1.121	0.825	1.360	1.054	0.794	1.314
900	14.822	10.698	1.385	1.145	0.849	1.349	1.074	0.814	1.308
1000	14.983	10.859	1.380	1.167	0.870	1.341	1.090	0.830	1.303

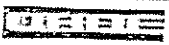
Source: Kenneth Wark, *Thermodynamics*, 4th ed. (New York: McGraw-Hill, 1983), p. 783, Table A-4M. Originally published in *Tables of Thermodynamic Properties of Gases*, NBS Circular 564, 1955.

VII. The Plant Data Obtained from PETRONAS Fertilizer, Bintulu
 a. Design Point Data

		Technical Specification COMPRESSOR "THERMODYNAMIC DATA"				JAN 1988	
		Page:					
X No	DESIGNATION	UNIT	DESIGN	MAX	MIN	AVG	REMARKS
X1	Operating point						
X2	Process pipes						
X3	Design arrangement						
X4							
X5	Medium						
X6	Volume flow at 1.013 bar / 273 K / 1.013 bar	m ³ /min		39.547			
X7	Inlet volume flow	m ³ /min		39.547			39.547
X8	Inlet mass flow	kg/h		62.42		77.35	78.13
X9	Outlet mass flow	kg/h					
X10	Inlet pressure	bar		1.013			
X11	Outlet pressure, after COMPRESSOR	bar		2.026		2.026	2.026
X12	Inlet temperature	°C		30		30	30
X13	Outlet temperature, after COMPRESSOR	°C		140		140	140
X14	Pressure ratio						
X15	Pressure increase (P2 - P1) / P1			0.13		0.13	0.13
X16	Blow-off velocity at 1.013 bar / 273 K	m/s					
X17	Blow-off velocity at 1.013 bar / 273 K	m/s					
X18	Intermediate inlet flow	m ³ /min					
X19	Intermediate inlet pressure	bar					
X20	Intermediate inlet temperature	°C					
X21	Extraction flow	m ³ /min				1.59	
X22	Extraction pressure (at 1.013 bar)	bar				1.013	
X23	Extraction temperature	°C				30	
X24	EXTRACTION FLOW @ 273 K	m ³ /min				1.59	
X25	EXTRACTION FLOW @ 273 K	m ³ /min				1.59	
X26	Overall specific work	kJ/kg		3.20 x 10 ⁴			
X27	Overall efficiency	%		40.5 (INTERNAL EFF WITHOUT M.L.)			
X28	Spec. work per stage	kJ/kg		25.790	112.500	61.020	142.400
X29	Efficiency per stage	%		70	77	74	77
X30	Total efficiency at operating	%		50.2 (INTERNAL EFF WITH M.L.)			
X31	Speed range	min		7200		10.897	
X32	Speed range	min					
X33	Surge limit at p2 const. 21	%		20 - 105			
X34				APPROX. 45			
X35	Total power consumption	kW		2870			
X36	Power consumption per stage	kW		154.3	2000	1145	7867
X37	Mechanical losses	kW					
X38	Leak losses (if applicable)	kW					
X39	Power recommended for driver	kW					
X40	Remarks						
X41	1) Isentropic compression						
X42	2) Isothermal compression						
X43	3) Polytropic compression						
X44	4) related to operating point						
X45	5) related to surge						
X46	6) AT COMPRESSOR (SCHEDULE) - CHECK VALVE ESTIMATED SPEAKING						
X47	7) AT COMPRESSOR (SCHEDULE) - BETWEEN COND & CHECK VALVE						
X48	8) AT COMPRESSOR (SCHEDULE) - 2.5% LOSS - 2.5% LOSS - 2.5% LOSS						
X49	9) COMPRESSOR (SCHEDULE) - SILENCED AND SURGE SIGNAL						
X50	10) COMPRESSOR (SCHEDULE)						
X51	11) COMPRESSOR (SCHEDULE)						
X52	12) COMPRESSOR (SCHEDULE)						
X53	13) COMPRESSOR (SCHEDULE)						
X54	14) COMPRESSOR (SCHEDULE)						
X55	15) COMPRESSOR (SCHEDULE)						
X56	16) COMPRESSOR (SCHEDULE)						
X57	17) COMPRESSOR (SCHEDULE)						
X58	18) COMPRESSOR (SCHEDULE)						
X59	19) COMPRESSOR (SCHEDULE)						
X60	20) COMPRESSOR (SCHEDULE)						
X61	21) COMPRESSOR (SCHEDULE)						
X62	22) COMPRESSOR (SCHEDULE)						
X63	23) COMPRESSOR (SCHEDULE)						
X64	24) COMPRESSOR (SCHEDULE)						
X65	25) COMPRESSOR (SCHEDULE)						
X66	26) COMPRESSOR (SCHEDULE)						
X67	27) COMPRESSOR (SCHEDULE)						
X68	28) COMPRESSOR (SCHEDULE)						
X69	29) COMPRESSOR (SCHEDULE)						
X70	30) COMPRESSOR (SCHEDULE)						
X71	31) COMPRESSOR (SCHEDULE)						
X72	32) COMPRESSOR (SCHEDULE)						
X73	33) COMPRESSOR (SCHEDULE)						
X74	34) COMPRESSOR (SCHEDULE)						
X75	35) COMPRESSOR (SCHEDULE)						
X76	36) COMPRESSOR (SCHEDULE)						
X77	37) COMPRESSOR (SCHEDULE)						
X78	38) COMPRESSOR (SCHEDULE)						
X79	39) COMPRESSOR (SCHEDULE)						
X80	40) COMPRESSOR (SCHEDULE)						
X81	41) COMPRESSOR (SCHEDULE)						
X82	42) COMPRESSOR (SCHEDULE)						
X83	43) COMPRESSOR (SCHEDULE)						
X84	44) COMPRESSOR (SCHEDULE)						
X85	45) COMPRESSOR (SCHEDULE)						
X86	46) COMPRESSOR (SCHEDULE)						
X87	47) COMPRESSOR (SCHEDULE)						
X88	48) COMPRESSOR (SCHEDULE)						
X89	49) COMPRESSOR (SCHEDULE)						
X90	50) COMPRESSOR (SCHEDULE)						
X91	51) COMPRESSOR (SCHEDULE)						
X92	52) COMPRESSOR (SCHEDULE)						
X93	53) COMPRESSOR (SCHEDULE)						
X94	54) COMPRESSOR (SCHEDULE)						
X95	55) COMPRESSOR (SCHEDULE)						
X96	56) COMPRESSOR (SCHEDULE)						
X97	57) COMPRESSOR (SCHEDULE)						
X98	58) COMPRESSOR (SCHEDULE)						
X99	59) COMPRESSOR (SCHEDULE)						
X100	60) COMPRESSOR (SCHEDULE)						


Technical Specification
COMPRESSOR
"THERMODYNAMIC DATA"

NO.	DESIGNATION	UNIT	VAL.	UNIT	VAL.	UNIT	VAL.
X01	Geometric point						
X02	Process class						
X03	Gas no. assignment		25		25		25
X04	Medium						
X05	Volume flow at 1012 bar (1012 K) [1012]	l/min	30271				30271
X06	Inlet volume flow	l/min	2855		2115		1824
X07	Inlet mass flow	g/min	2855		2115		1824
X08	Outlet mass flow	g/min	2855		2115		1824
X09	Inlet pressure	bar	0.24		0.24		0.24
X10	Outlet pressure after compression	bar	5.57		5.57		5.57
X11	Inlet temperature	°C	20		20		20
X12	Outlet temperature after compression	°C	140		140		140
X13	Pressure ratio						
X14	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X15	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X16	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X17	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X18	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X19	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X20	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X21	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X22	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X23	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X24	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X25	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X26	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X27	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X28	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X29	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X30	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X31	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X32	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X33	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X34	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X35	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X36	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X37	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X38	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X39	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X40	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X41	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X42	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X43	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X44	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X45	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X46	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X47	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X48	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X49	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X50	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X51	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X52	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X53	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X54	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X55	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X56	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X57	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X58	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X59	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X60	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X61	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X62	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X63	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X64	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X65	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X66	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X67	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X68	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X69	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X70	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X71	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X72	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X73	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X74	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X75	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X76	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X77	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X78	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X79	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X80	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X81	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X82	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X83	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X84	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X85	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X86	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X87	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X88	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X89	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X90	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X91	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X92	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X93	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X94	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X95	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X96	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X97	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X98	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X99	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				
X100	Blow-off pressure at 1012 bar (1012 K)	bar	0.15				



Technical Specification
COMPRESSOR
 "THERMODYNAMIC DATA"

Item	Designation	Dim	Unit	Value	Value	Value	Value
X1	Operating point	-	-	-	-	-	-
X2	Process stage	-	-	-	-	-	-
X3	Design arrangement	-	-	71	72	73	74
X4	Medium	-	-	-	-	-	-
X5	Volume flow at 1.012 bar / 173 K (dry)	m ³ /min		40.277	-	-	-
X6	Inlet volume flow	m ³ /min		37.5	38.4	39.3	40.2
X7	Inlet mass flow	kg/min		2.175	2.254	2.333	2.412
X8	Outlet mass flow	kg/min		-	-	-	-
X9	Inlet pressure	bar		1.012	1.012	1.012	1.012
X10	Outlet pressure, after compression	bar		4.44	4.44	4.44	4.44
X11	Inlet temperature	°C		20	20	20	20
X12	Outlet temperature, after compression	°C		70	70	70	70
X13	Pressure ratio	-		4.44	4.44	4.44	4.44
X14	Volume ratio	-		0.25	-	-	-
X15	Blow-off vol. flow at 1.012 bar / 173 K	m ³ /min		2.17	-	-	-
X16	Intermediate inlet flow	m ³ /min		-	-	-	-
X17	Intermediate inlet pressure	bar		-	-	-	-
X18	Intermediate inlet temperature	°C		-	-	-	-
X19	Extraction flow	m ³ /min		-	-	-	-
X20	Extraction pressure	bar		-	-	-	-
X21	Extraction temperature	°C		-	-	-	-
X22	Overall efficiency	-		-	-	-	-
X23	Overall efficiency	-		-	-	-	-
X24	Overall efficiency	-		-	-	-	-
X25	Overall efficiency	-		-	-	-	-
X26	Overall efficiency	-		-	-	-	-
X27	Overall efficiency	-		-	-	-	-
X28	Overall efficiency	-		-	-	-	-
X29	Overall efficiency	-		-	-	-	-
X30	Overall efficiency	-		-	-	-	-
X31	Overall efficiency	-		-	-	-	-
X32	Overall efficiency	-		-	-	-	-
X33	Overall efficiency	-		-	-	-	-
X34	Overall efficiency	-		-	-	-	-
X35	Overall efficiency	-		-	-	-	-
X36	Overall efficiency	-		-	-	-	-
X37	Overall efficiency	-		-	-	-	-
X38	Overall efficiency	-		-	-	-	-
X39	Overall efficiency	-		-	-	-	-
X40	Overall efficiency	-		-	-	-	-
X41	Overall efficiency	-		-	-	-	-
X42	Overall efficiency	-		-	-	-	-
X43	Overall efficiency	-		-	-	-	-
X44	Overall efficiency	-		-	-	-	-
X45	Overall efficiency	-		-	-	-	-
X46	Overall efficiency	-		-	-	-	-
X47	Overall efficiency	-		-	-	-	-
X48	Overall efficiency	-		-	-	-	-
X49	Overall efficiency	-		-	-	-	-
X50	Overall efficiency	-		-	-	-	-
X51	Overall efficiency	-		-	-	-	-
X52	Overall efficiency	-		-	-	-	-
X53	Overall efficiency	-		-	-	-	-
X54	Overall efficiency	-		-	-	-	-
X55	Overall efficiency	-		-	-	-	-
X56	Overall efficiency	-		-	-	-	-
X57	Overall efficiency	-		-	-	-	-
X58	Overall efficiency	-		-	-	-	-
X59	Overall efficiency	-		-	-	-	-
X60	Overall efficiency	-		-	-	-	-
X61	Overall efficiency	-		-	-	-	-
X62	Overall efficiency	-		-	-	-	-
X63	Overall efficiency	-		-	-	-	-
X64	Overall efficiency	-		-	-	-	-
X65	Overall efficiency	-		-	-	-	-
X66	Overall efficiency	-		-	-	-	-
X67	Overall efficiency	-		-	-	-	-
X68	Overall efficiency	-		-	-	-	-
X69	Overall efficiency	-		-	-	-	-
X70	Overall efficiency	-		-	-	-	-
X71	Overall efficiency	-		-	-	-	-
X72	Overall efficiency	-		-	-	-	-
X73	Overall efficiency	-		-	-	-	-
X74	Overall efficiency	-		-	-	-	-
X75	Overall efficiency	-		-	-	-	-
X76	Overall efficiency	-		-	-	-	-
X77	Overall efficiency	-		-	-	-	-
X78	Overall efficiency	-		-	-	-	-
X79	Overall efficiency	-		-	-	-	-
X80	Overall efficiency	-		-	-	-	-
X81	Overall efficiency	-		-	-	-	-
X82	Overall efficiency	-		-	-	-	-
X83	Overall efficiency	-		-	-	-	-
X84	Overall efficiency	-		-	-	-	-
X85	Overall efficiency	-		-	-	-	-
X86	Overall efficiency	-		-	-	-	-
X87	Overall efficiency	-		-	-	-	-
X88	Overall efficiency	-		-	-	-	-
X89	Overall efficiency	-		-	-	-	-
X90	Overall efficiency	-		-	-	-	-
X91	Overall efficiency	-		-	-	-	-
X92	Overall efficiency	-		-	-	-	-
X93	Overall efficiency	-		-	-	-	-
X94	Overall efficiency	-		-	-	-	-
X95	Overall efficiency	-		-	-	-	-
X96	Overall efficiency	-		-	-	-	-
X97	Overall efficiency	-		-	-	-	-
X98	Overall efficiency	-		-	-	-	-
X99	Overall efficiency	-		-	-	-	-
X100	Overall efficiency	-		-	-	-	-

				Technical Specification COMPRESSOR "THERMODYNAMIC DATA"				UNIT TON / COSE	
				Page:					
X No.	DESIGNATION	UNIT	UNIT						
X1	Operating point	-	-						
X11	Process stage	-	-	27	28	29	30		
X12	Discharge arrangement	-	-	27	28	29	30		
X13	Medium	-	-						
X14	Volume flow at 1.013 bar / 273 K dry	m ³ /min		285.7				55.210	
X15	Inlet volume flow <input type="checkbox"/> dry <input type="checkbox"/> wet	m ³ /min		71.93	73.75	220.5		6.74	
X16	Inlet mass flow <input type="checkbox"/> dry <input type="checkbox"/> wet	kg/h							
X17	Outlet mass flow <input type="checkbox"/> dry <input type="checkbox"/> wet	kg/h							
X18	Inlet pressure	abs.	bar	1.013	1.013	1.013	1.013		
X19	Outlet pressure, after COMPRESSOR	abs.	bar	6.85	5.41	6.37	6.29		
X20	Inlet temperature	°C		20	20	20	20		
X21	Outlet temperature, after COMPRESSOR	°C		160	116	120	150		
X22	Pressure ratio	g/g	-						
X23	Pressure losses, VALVE SPRING REACTION	bar		0.13	0.13	0.13			
X24	Blow-off vol. flow at 1.013 bar / 273 K	m ³ /min							
X25	EXTRACTION FLOW (A)	g/g		24					
X26	EXTRACTION FLOW (B)	g/g							
X27	EXTRACTION FLOW (C)	g/g							
X28	EXTRACTION FLOW (D)	g/g							
X29	EXTRACTION FLOW (E)	g/g							
X30	EXTRACTION FLOW (F)	g/g							
X31	EXTRACTION FLOW (G)	g/g							
X32	EXTRACTION FLOW (H)	g/g							
X33	EXTRACTION FLOW (I)	g/g							
X34	EXTRACTION FLOW (J)	g/g							
X35	EXTRACTION FLOW (K)	g/g							
X36	EXTRACTION FLOW (L)	g/g							
X37	EXTRACTION FLOW (M)	g/g							
X38	EXTRACTION FLOW (N)	g/g							
X39	EXTRACTION FLOW (O)	g/g							
X40	EXTRACTION FLOW (P)	g/g							
X41	EXTRACTION FLOW (Q)	g/g							
X42	EXTRACTION FLOW (R)	g/g							
X43	EXTRACTION FLOW (S)	g/g							
X44	EXTRACTION FLOW (T)	g/g							
X45	EXTRACTION FLOW (U)	g/g							
X46	EXTRACTION FLOW (V)	g/g							
X47	EXTRACTION FLOW (W)	g/g							
X48	EXTRACTION FLOW (X)	g/g							
X49	EXTRACTION FLOW (Y)	g/g							
X50	EXTRACTION FLOW (Z)	g/g							
X51	Overall specific work <input type="checkbox"/> y ₀ <input type="checkbox"/> y _{0,0} <input type="checkbox"/> y _{0,1}	kJ/kg						3.20 x 10 ⁴	
X52	Overall efficiency <input type="checkbox"/> η ₀ <input type="checkbox"/> η _{0,0} <input type="checkbox"/> η _{0,1}	%						40.5 (INTERNAL EFF. WITHOUT M.L.)	
X53	Spec. work per stage <input type="checkbox"/> w ₀ <input type="checkbox"/> w _{0,0} <input type="checkbox"/> w _{0,1}	kJ/kg						25.790 117.500 61.020 144.400	
X54	Efficiency per stage <input type="checkbox"/> η ₀ <input type="checkbox"/> η _{0,0} <input type="checkbox"/> η _{0,1}	%						79 77 74 73	
X55	Total efficiency at coupling	%						59.2 (ISOTHERM EFF. WITH M.L.)	
X56	Speed	min ⁻¹						7260	
X57	Speed range	min ⁻¹						10,297	
X58	Speed range	%						80 + 10.5	
X59	Surge limit at 0.9 const. β)	%						APPROX. 6.5	
X60	Total power consumption β)	kW						7570	
X61	Power consumption per STAGE	kW						1543 2380 1185 2407	
X62	Mechanical losses	kW						27	
X63	Gear losses (IF APPLICABLE)	kW						30	
X64	Power recommended for driver	kW							
X65	Rotation of compressor viewed from	clockwise						clockwise	
X66	Remarks								
X67	1) Isothermal compression								
X68	2) Isothermal compression								
X69	3) related to guarantee point								
X70	4) inlet air state								
X71	5) AT COMPRESSOR DISCHARGE BETWEEN INLET AND CHECK VALVE								
X72	6) DOWNSTREAM OF CHECK VALVE (SILENCED AND SMOOTH FINING)								
X73	7) ...								
X74	8) ...								
X75	9) ...								
X76	10) ...								
X77	11) ...								
X78	12) ...								
X79	13) ...								
X80	14) ...								
X81	15) ...								
X82	16) ...								
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X159	93) ...								
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X161	95) ...								
X162	96) ...								
X163	97) ...								
X164	98) ...								
X165	99) ...								
X166	100) ...								

GEIPIC		Technical Specification				MAN	
		COMPRESSOR				CON / CODE	
		"THERMODYNAMIC DATA"				Page 1	
X No	DESIGNATION	UNIT	UNIT				
X1	Bearing point						
X2	Process stage			26	27	28	29
X3	Casing arrangement			25	25	25	25
X4	Medium				14H3		
X5	Volume flow at 1.013 bar / 273 K	m ³ /min		385.67			2221.4
X6	Inlet volume flow	m ³ /min		78.25	84.65	917.4	945.8
X7	Inlet mass flow	kg/min					
X8	Outlet mass flow	kg/min					
X9	Inlet pressure	bar		2.443	2.443	2.443	2.443
X10	Outlet pressure, after COMPRESSOR	bar		7.029	7.029	7.029	7.029
X11	Inlet temperature	°C		160	160	160	160
X12	Outlet temperature, after COMPRESSOR	°C					
X13	Pressure ratio						
X14	Pressure losses (WATER SPRING HEADS)	bar		0.12	0.12	0.12	
X15	Blow-off vol. flow at 1.013 bar / 273 K	m ³ /min					
X16	REL. HUMIDITY (WATER)	%		25			
X17	Intermediate inlet flow	m ³ /min					
X18	Intermediate inlet pressure	bar					
X19	Intermediate inlet temperature	°C					
X20	Extraction flow	m ³ /min				159	
X21	Extraction pressure (1.013 bar / 273 K)	bar				10.2	
X22	Extraction temperature	°C				153	
X23	EXTRACTION FLOW @ 273 K	m ³ /min				10.2	
X24	EXTRACTION FLOW @ 273 K	kg/min				13.41	
X25	Overall specific work	kJ/kg		3.70 x 10 ⁴			
X26	Overall efficiency	%		40.51 (INTERNAL EFF. WITHOUT M.L.)			
X27	Spec. work per stage	kJ/kg		25.790	112.500	61.070	142.400
X28	Efficiency per stage	%		78	77	74	72
X29	Total efficiency at coupling	%		40.2 (INTERNAL EFF. WITH M.L.)			
X30	Speed	min ⁻¹		7060		10397	
X31	Speed range	min ⁻¹					
X32	Speed range	%		25 - 10.5			
X33	Surge limit at 0.9 cond. 21	%		APPROX. 65			
X34	Total power consumption	kW		2570			
X35	Power consumption per stage	kW		1543	2340	1185	7407
X36	Mechanical losses	kW		37			
X37	Gear losses (IF APPLICABLE)	kW		40			
X38	Power recommended for driver	kW					
X39	Rotation of compressor viewed from			FORWARD	OR (BACKWARD)	OR (BACKWARD)	
X40	Remarks						
X41	1) Isentropic compression						
X42	2) Isothermal compression						
X43	3) Real gas isentropic compression						
X44	4) Related to guarantee point						
X45	5) Inc. in losses						
X46	6) WATER SPRING WAVE ESTIMATED APPROX. 20% BETWEEN COMP. B AND C WAVE						
X47	7) AT COMPRESSORS WITH 1.013 bar - 273 K INLET AND 2.0 - 2.5 bar						
X48	8) DOWNSTREAM INTERPOLAR SILENCER AND SECTION PIPING						
X49							
X50							
X51							
X52							
X53							
X54							
X55							
X56							
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Technical Specification
 COMPRESSOR
 "THERMODYNAMIC DATA"

Item	Designation	Unit	Dim	Value	Value	Value	Value
X11	Operating point						
X12	Process name			B	D	E	F
X13	Output improvement						
X14	Medium						
X15	Volume flow at 1.013 bar (101.3 kPa)	l/min		4440			38000
X16	Inlet volume flow	l/min		1025	1516	2350	321
X17	Inlet mass flow	kg/h					
X18	Outlet mass flow	kg/h					
X19	Inlet pressure	bar		1.01	1.01	1.01	1.01
X20	Outlet pressure, after compression	bar		1.17	1.50	1.78	2.35
X21	Inlet temperature	°C		20	20	20	20
X22	Outlet temperature, after compression	°C		40	50	60	70
X23	Pressure ratio						
X24	Pressure ratio, after compression			1.15			
X25	Shutoff vol. flow at 1.013 bar (101.3 kPa)	l/min					
X26	Information inlet flow	l/min					
X27	Information inlet pressure	bar					
X28	Information inlet temperature	°C					
X29	Extraction flow	l/min				100	
X30	Extraction pressure (after valve)	bar				1.01	
X31	Extraction temperature	°C				20	
X32	Extraction flow	l/min				100	
X33	Extraction pressure	bar				1.01	
X34	Extraction temperature	°C				20	
X35	Extraction flow	l/min				100	
X36	Extraction pressure	bar				1.01	
X37	Extraction temperature	°C				20	
X38	Overall efficiency						
X39	Overall efficiency						
X40	Overall efficiency						
X41	Speed	min ⁻¹		1140		10815	
X42	Speed range	min ⁻¹		1140 - 1170		10815 - 11015	
X43	Speed range	min ⁻¹		1140 - 1170		10815 - 11015	
X44	Power consumption	kW		1400	1100	1000	2800
X45	Mechanical losses	kW					
X46	Electrical losses	kW					
X47	Power consumption for driver	kW					
X48	Rotation of compressor viewed from			clockwise	clockwise	counter-clockwise	
X49	Information						
X50	Information						
X51	Information						
X52	Information						
X53	Information						
X54	Information						
X55	Information						
X56	Information						
X57	Information						
X58	Information						
X59	Information						
X60	Information						
X61	Information						
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X95	Information						
X96	Information						
X97	Information						
X98	Information						
X99	Information						
X100	Information						

b. Actual Operating Data

G E P I E		Technical Specification				UAN	
		COMPRESSOR				TON/2000	
		"THERMODYNAMIC DATA"				Feet	
No.	DESIGNATION	UNIT	UNIT				
X11	Operating point				NORMAL REQUEST		
X12	Process rate			1	2	3	
X13	Stage arrangement			1P	2P		
X14	Medium						
X15	Volume flow at 1.013 bar, 273 K	m ³ /s		0.0027			0.0027
X16	Inlet volume flow	m ³ /s		7.05	7.05	8.495	9.74
X17	Inlet mass flow	kg/s					
X18	Outlet mass flow	kg/s					
X19	Inlet pressure	bar		2.443	2.443	2.443	2.443
X20	Outlet pressure, absolute	bar		5.75	5.75	5.75	5.75
X21	Inlet temperature	°C		10	10	10	10
X22	Outlet temperature, absolute	°C		160	146	130	130
X23	Pressure ratio						
X24	Pressure ratio, theoretical			6.12			
X25	Flow velocity at 1.013 bar, 273 K	m/s					
X26	Flow velocity (theoretical)	m/s					
X27	Intermediate mass flow	kg/s					
X28	Intermediate inlet pressure	bar					
X29	Intermediate inlet temperature	°C					
X30	Extraction flow	kg/s				1.76	
X31	Extraction pressure (at 1.013 bar)	bar				10.31	
X32	Extraction temperature	°C				133	
X33	Extraction flow, theoretical	kg/s				15.2	
X34	Extraction pressure, theoretical	bar				13.87	
X35	Overall isentropic work	kJ/kg				2.20	1.07
X36	Overall efficiency	%				60.5	INTERNAL EFF WITHOUT H.C.
X37	Isentropic work per stage	kJ/kg				1.10	1.07
X38	Efficiency per stage	%				77	77
X39	Stage efficiency at constant	%				62.7	INTERNAL EFF WITH H.C.
X40	Stage	kg/s				10.612	
X41	Stage range	m ³ /s				1.12	1.13
X42	Stage range	kg/s				20	133
X43	Stage length at 1.013 bar, 273 K	m				APPROX. 6.5	
X44	Total power consumption	kW				7.415	
X45	Power consumption per 1.013 bar	kW				1552	1101
X46	Isentropic power	kW				27	
X47	Cost index	kW				80	
X48	Power requirement for driver	kW					
STANDARD COMPRESSOR VIEWED FROM: <input checked="" type="checkbox"/> LOW PRESSURE SIDE <input type="checkbox"/> HIGH PRESSURE SIDE							
Compression:							
<input type="checkbox"/> 1.5 isentropic compression							
<input type="checkbox"/> 2.0 isentropic compression							
<input type="checkbox"/> 2.5 isentropic compression							
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<input type="checkbox"/> 49.5 isentropic compression							
<input type="checkbox"/> 50.0 isentropic compression							

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Globe		Technical Specification COMPRESSOR "THERMODYNAMIC DATA"				UAN	
						TON / CODE	
						Page:	
X No	DESIGNATION	DIM	DIM				
X 11	Operating point	-	-				
X 12	Process stage	-	-	52 - 55			
X 13	Casing arrangement	-	-	HORIZONTAL			
X 14		-	-	SEE PROCESS ARRANGEMENT PAGE NO.			
X 15	Medium	-	-	NH ₃			
X 16	Volume flow at 1.013 bar / 273 K DRY		m ³ /h				
X 17	Inlet volume flow <input type="checkbox"/> dry <input type="checkbox"/> wet		m ³ /h	11893	12512	13252	13777
X 18	Inlet mass flow <input checked="" type="checkbox"/> dry <input type="checkbox"/> wet		kg/h				
	Outlet mass flow <input checked="" type="checkbox"/> dry <input type="checkbox"/> wet		kg/h				
	Inlet pressure abs.		bar	4.443	4.443	4.443	4.443
	Outlet pressure, after COMP. abs.		bar	6.58	6.42	6.17	5.83
X 19	Inlet temperature		°C	20	20	20	20
X 20	Outlet temperature, after COMP.		°C	160	170	180	190
X 21	Pressure ratio	D/P	-				
X 22	Pressure losses		bar	0.25			
X 23	Blow-off vol. flow at 1.013 bar / 273 K		m ³ /h				
X 24							
X 25							
X 26							
X 27							
X 28							
X 29	Intermediate inlet flow		m ³ /h				
X 30	Intermediate inlet pressure abs.		bar				
X 31	Intermediate inlet temperature		°C				
X 32	Extraction flow <input type="checkbox"/> dry		m ³ /h				
X 33	Extraction pressure abs.		bar				
X 34	Extraction temperature		°C				
X 35							
X 36							
X 37	Overall specific work <input type="checkbox"/> Y _s <input type="checkbox"/> Y _T <input type="checkbox"/> Y _{pol}		kJ/kg	211.6			
X 38	Overall efficiency <input type="checkbox"/> η _s <input type="checkbox"/> η _T <input type="checkbox"/> η _{pol}		%	66			
X 39	Spec. work per stage <input type="checkbox"/> Y _s <input type="checkbox"/> Y _T <input type="checkbox"/> Y _{pol}		kJ/kg	129.200		125.600	
X 40	Efficiency per stage <input type="checkbox"/> η _s <input type="checkbox"/> η _T <input type="checkbox"/> η _{pol}		%	75		74	
X 41	Total efficiency at coupling		%	74			
X 42	Speed		min ⁻¹	10200			
X 43	Speed range		min ⁻¹	8445 - 11823			
X 44	Speed range		%	75 - 105			
X 45	Surge limit at p/p const. 2)		%	63			
X 46							
X 47	Total power consumption ³⁾		kW	3350			
X 48	Power consumption per STAGE		kW	1552		1798	
X 49	Mechanical losses		kW	88			
X 50	Gear losses		kW				
X 51	Power recommended for driver		kW				
X 52							
X 53	Rotation of compressor viewed from IMPELLER			<input checked="" type="checkbox"/> CW (clockwise) <input type="checkbox"/> CCW (counterclockwise)			
X 54	REMARKS:						
X 55	1) S = isentropic compression						
X 56	T = isothermal compression						
X 57	pol = polytropic compression						
X 58	2) related to guarantee point						
X 59	3) incl. all losses						
X 60	4) PRESSURE RATIO VARIES ACC. TO DESIGN OF COMPRESSOR						
X 61	5) NON-FLARE REVISIONS MUST INFORM UNDER DESIGN AREA REPRESENTATIVE						
X 62							
X 63							
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Technical Specification
COMPRESSOR
"THERMODYNAMIC DATA"

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X No	DESIGNATION	DIM	DIM	
X 1	Operating point	-	-	
X 2	Process stage	-	-	
X 3	Casing arrangement	-	-	62-65 HORIZONTAL
X 4		-	-	SEE PROCESS ARRANGEMENT PAGE NO.
X 5	Medium	-	-	NH3
X 6	Volume flow at 1.013 bar / 273 K DRY		m ³ /h	
X 7	Inlet volume flow <input checked="" type="checkbox"/> dry <input type="checkbox"/> wet		m ³ /h	12572 13252 13431 14271
X 8	Inlet mass flow <input checked="" type="checkbox"/> dry <input type="checkbox"/> wet		kg/h	
X 9	Outlet mass flow <input checked="" type="checkbox"/> dry <input type="checkbox"/> wet		kg/h	
X 10	Inlet pressure abs.		bar	4.443 4.443 4.443 4.443
X 11	Outlet pressure, after COMP. abs.		bar	6.75 6.58 6.35 5.86
X 12	Inlet temperature		°C	20 20 20 20
X 13	Outlet temperature, after COMP.		°C	160 170 180 190
X 14	Pressure ratio p/p	-	-	
X 15	Pressure losses		bar	0.25
X 16	Slow-off vol. flow at 1.013 bar / 273 K		m ³ /h	
X 17				
X 18				
X 19				
X 20	Intermediate inlet flow		m ³ /h	
X 21	Intermediate inlet pressure abs.		bar	
X 22	Intermediate inlet temperature		°C	
X 23	Extraction flow <input type="checkbox"/> dry		m ³ /h	
X 24	Extraction pressure abs.		bar	
X 25	Extraction temperature		°C	
X 26				
X 27				
X 28				
X 29	Overall specific work <input type="checkbox"/> Yc <input checked="" type="checkbox"/> Yr <input type="checkbox"/> Ytot		kJ/kg	211.6
X 30	Overall efficiency <input type="checkbox"/> ηs <input checked="" type="checkbox"/> ηr <input type="checkbox"/> ηtot		%	66
X 31	Spec. work per stage <input type="checkbox"/> Yc <input checked="" type="checkbox"/> Yr <input type="checkbox"/> Ytot		kJ/kg	129.200 125.600
X 32	Efficiency per stage <input type="checkbox"/> ηs <input checked="" type="checkbox"/> ηr <input type="checkbox"/> ηtot		%	75 74
X 33	Total efficiency at coupling		%	74
X 34	Speed		min ⁻¹	10800
X 35	Speed range		min ⁻¹	8445 - 11823
X 36	Speed range		%	75 - 105
X 37	Surge limit at p/p const. 2)		%	63
X 38				
X 39	Total power consumption 3)		kW	3350
X 40	Power consumption per STAGE		kW	1552 1798
X 41	Mechanical losses		kW	88
X 42	Gear losses		kW	
X 43				
X 44	Power recommended for driver		kW	
X 45				
X 46	Rotation of compressor viewed from			VIEWLINE <input checked="" type="checkbox"/> CW (clockwise) <input type="checkbox"/> CCW (counterclockwise)
X 47	Remarks:			
X 48	1) S # isentropic compression			
X 49	T # isothermal compression			
X 50	pol # polytropic compression			
X 51	2) related to guarantee point			
X 52	3) incl. all losses			
X 53	4) PRESSURE RATIO VALUE REL. TO DESIGN OF COMPRESSOR			
X 54	5) POWER PENALTY MUST INFORM UNDER ASSET PROTECTION			
X 55				
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Rev.	Date	Name	Check	Description
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G I E I E		Technical Specification				MAR	
		COMPRESSOR				TOM/2000	
		"THERMODYNAMIC DATA"				Page	
Item	Designation	Unit	Value	Value	Value	Value	Value
X11	Operating speed	rpm	—	—	—	—	—
X12	Process stage	—	—	15	10	20	21
X13	Design improvement	—	—	15	10	20	21
X14	Medium	—	—	—	—	—	—
X15	Volume flow at 1.013 bar / 273 K	m ³ /min	30037	—	—	—	—
X16	Inlet volume flow	m ³ /min	577	725	725	—	—
X17	Inlet mass flow	kg/min	—	—	—	—	—
X18	Outlet mass flow	kg/min	—	—	—	—	—
X19	Inlet pressure	bar	2.443	2.443	2.443	2.443	—
X20	Outlet pressure	bar	5.22	6.15	6.15	6.11	—
X21	Inlet temperature	°C	10	10	10	10	—
X22	Outlet temperature	°C	150	110	150	150	—
X23	Pressure ratio	—	—	—	—	—	—
X24	Pressure ratio	—	—	—	—	—	—
X25	Pressure ratio	—	—	—	—	—	—
X26	Pressure ratio	—	—	—	—	—	—
X27	Pressure ratio	—	—	—	—	—	—
X28	Pressure ratio	—	—	—	—	—	—
X29	Pressure ratio	—	—	—	—	—	—
X30	Pressure ratio	—	—	—	—	—	—
X31	Pressure ratio	—	—	—	—	—	—
X32	Pressure ratio	—	—	—	—	—	—
X33	Pressure ratio	—	—	—	—	—	—
X34	Pressure ratio	—	—	—	—	—	—
X35	Pressure ratio	—	—	—	—	—	—
X36	Pressure ratio	—	—	—	—	—	—
X37	Pressure ratio	—	—	—	—	—	—
X38	Pressure ratio	—	—	—	—	—	—
X39	Pressure ratio	—	—	—	—	—	—
X40	Pressure ratio	—	—	—	—	—	—
X41	Pressure ratio	—	—	—	—	—	—
X42	Pressure ratio	—	—	—	—	—	—
X43	Pressure ratio	—	—	—	—	—	—
X44	Pressure ratio	—	—	—	—	—	—
X45	Pressure ratio	—	—	—	—	—	—
X46	Pressure ratio	—	—	—	—	—	—
X47	Pressure ratio	—	—	—	—	—	—
X48	Pressure ratio	—	—	—	—	—	—
X49	Pressure ratio	—	—	—	—	—	—
X50	Pressure ratio	—	—	—	—	—	—
X51	Pressure ratio	—	—	—	—	—	—
X52	Pressure ratio	—	—	—	—	—	—
X53	Pressure ratio	—	—	—	—	—	—
X54	Pressure ratio	—	—	—	—	—	—
X55	Pressure ratio	—	—	—	—	—	—
X56	Pressure ratio	—	—	—	—	—	—
X57	Pressure ratio	—	—	—	—	—	—
X58	Pressure ratio	—	—	—	—	—	—
X59	Pressure ratio	—	—	—	—	—	—
X60	Pressure ratio	—	—	—	—	—	—
X61	Pressure ratio	—	—	—	—	—	—
X62	Pressure ratio	—	—	—	—	—	—
X63	Pressure ratio	—	—	—	—	—	—
X64	Pressure ratio	—	—	—	—	—	—
X65	Pressure ratio	—	—	—	—	—	—
X66	Pressure ratio	—	—	—	—	—	—
X67	Pressure ratio	—	—	—	—	—	—
X68	Pressure ratio	—	—	—	—	—	—
X69	Pressure ratio	—	—	—	—	—	—
X70	Pressure ratio	—	—	—	—	—	—
X71	Pressure ratio	—	—	—	—	—	—
X72	Pressure ratio	—	—	—	—	—	—
X73	Pressure ratio	—	—	—	—	—	—
X74	Pressure ratio	—	—	—	—	—	—
X75	Pressure ratio	—	—	—	—	—	—
X76	Pressure ratio	—	—	—	—	—	—
X77	Pressure ratio	—	—	—	—	—	—
X78	Pressure ratio	—	—	—	—	—	—
X79	Pressure ratio	—	—	—	—	—	—
X80	Pressure ratio	—	—	—	—	—	—
X81	Pressure ratio	—	—	—	—	—	—
X82	Pressure ratio	—	—	—	—	—	—
X83	Pressure ratio	—	—	—	—	—	—
X84	Pressure ratio	—	—	—	—	—	—
X85	Pressure ratio	—	—	—	—	—	—
X86	Pressure ratio	—	—	—	—	—	—
X87	Pressure ratio	—	—	—	—	—	—
X88	Pressure ratio	—	—	—	—	—	—
X89	Pressure ratio	—	—	—	—	—	—
X90	Pressure ratio	—	—	—	—	—	—
X91	Pressure ratio	—	—	—	—	—	—
X92	Pressure ratio	—	—	—	—	—	—
X93	Pressure ratio	—	—	—	—	—	—
X94	Pressure ratio	—	—	—	—	—	—
X95	Pressure ratio	—	—	—	—	—	—
X96	Pressure ratio	—	—	—	—	—	—
X97	Pressure ratio	—	—	—	—	—	—
X98	Pressure ratio	—	—	—	—	—	—
X99	Pressure ratio	—	—	—	—	—	—
X100	Pressure ratio	—	—	—	—	—	—

TECHNICAL SPECIFICATION		COMPRESSOR		"THERMODYNAMIC DATA"			
DESIGNATION		DIA	DRN	UNIT			
X11	Operating point	-	-	-	-	-	-
X12	Process stage	-	-	35	37	38	39
X13	Stage arrangement	-	-	1.5	1.5	1.5	1.5
X14	Medium	-	-	-	-	-	-
X15	Volume flow at 1.013 bar / 273 K	m ³ /min		30037			30037
X16	Inlet volume flow	m ³ /min		7673	7773	3305	3172
X17	Inlet mass flow	kg/min					
X18	Inlet pressure	bar		4.443	4.443	4.443	4.443
X19	Outlet pressure, standard	bar		6.73	6.74	6.76	6.77
X20	Inlet temperature	°C		20	20	20	20
X21	Outlet temperature, standard	°C		130	131	132	133
X22	Pressure ratio	-		-	-	-	-
X23	Pressure ratio, standard	-		0.14	-	-	-
X24	Volume flow at 1.013 bar / 273 K	m ³ /min					
X25	Volume flow at 1.013 bar / 273 K	m ³ /min					
X26	Intermediate inlet flow	m ³ /min					
X27	Intermediate inlet pressure	bar					
X28	Intermediate inlet temperature	°C					
X29	Extraction flow	kg/min				155	
X30	Extraction pressure	bar				10.81	
X31	Extraction temperature	°C				55	
X32	Extraction flow	kg/min				18.2	
X33	Extraction flow	kg/min				18.2	
X34	Overall efficiency	%					
X35	Isentropic efficiency	%					
X36	Isentropic efficiency	%					
X37	Isentropic efficiency	%					
X38	Isentropic efficiency	%					
X39	Isentropic efficiency	%					
X40	Isentropic efficiency	%					
X41	Isentropic efficiency	%					
X42	Isentropic efficiency	%					
X43	Isentropic efficiency	%					
X44	Isentropic efficiency	%					
X45	Isentropic efficiency	%					
X46	Isentropic efficiency	%					
X47	Isentropic efficiency	%					
X48	Isentropic efficiency	%					
X49	Isentropic efficiency	%					
X50	Isentropic efficiency	%					
X51	Isentropic efficiency	%					
X52	Isentropic efficiency	%					
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X66	Isentropic efficiency	%					
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X68	Isentropic efficiency	%					
X69	Isentropic efficiency	%					
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X81	Isentropic efficiency	%					
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X89	Isentropic efficiency	%					
X90	Isentropic efficiency	%					
X91	Isentropic efficiency	%					
X92	Isentropic efficiency	%					
X93	Isentropic efficiency	%					
X94	Isentropic efficiency	%					
X95	Isentropic efficiency	%					
X96	Isentropic efficiency	%					
X97	Isentropic efficiency	%					
X98	Isentropic efficiency	%					
X99	Isentropic efficiency	%					
X100	Isentropic efficiency	%					

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UNION		Technical Specification COMPRESSOR "THERMODYNAMIC DATA"				VAN			
						CON / CODE			
						Page: 12			
X No	DESIGNATION	DIM	DIM						
X 11	Operating point	-	-						
X 12	Process stage	-	-	72 - 75					
X 13	Casing arrangement	-	-	HORIZONTAL					
X 14		-	-	SEE PROCESS ARRANGEMENT DRAWING					
X 15	Medium	-	-	NH ₃					
X 16	Volume flow at 1.013 bar / 273 K DRY		m ³ /h						
X 17	Inlet volume flow <input checked="" type="checkbox"/> dry <input type="checkbox"/> wet		m ³ /h	13252	13731	14611	15477		
X 18	Inlet mass flow <input checked="" type="checkbox"/> dry <input type="checkbox"/> wet		kg/h						
	Outlet mass flow <input checked="" type="checkbox"/> dry <input type="checkbox"/> wet		kg/h						
	Inlet pressure	abs.	bar	4.443	4.443	4.443	4.443		
	Outlet pressure, after COMP.	abs.	bar	7.14	6.75	6.44	5.86		
X 19	Inlet temperature		°C	70	70	70	70		
X 20	Outlet temperature, after COMP.		°C	160	170	180	190		
X 21	Pressure ratio	p/p	-						
X 22	Pressure losses		bar	0.25					
X 23	Blow-off vol. flow at 1.013 bar / 273 K		m ³ /h						
X 24	Intermediate inlet flow		m ³ /h						
X 25	Intermediate inlet pressure	abs.	bar						
X 26	Intermediate inlet temperature		°C						
X 27	Extraction flow <input type="checkbox"/> dry		m ³ /h						
X 28	Extraction pressure	abs.	bar						
X 29	Extraction temperature		°C						
X 30	Overall specific work <input type="checkbox"/> V _s <input checked="" type="checkbox"/> V _m <input type="checkbox"/> V _{pol}		kJ/kg	211.6					
X 31	Overall efficiency <input type="checkbox"/> V _s <input checked="" type="checkbox"/> V _m <input type="checkbox"/> V _{pol}		%	66					
X 32	Spec. work per stage <input type="checkbox"/> V _s <input checked="" type="checkbox"/> V _m <input type="checkbox"/> V _{pol}		kJ/kg	129.200			125.600		
X 33	Efficiency per stage <input type="checkbox"/> V _s <input checked="" type="checkbox"/> V _m <input type="checkbox"/> V _{pol}		%	75			74		
X 34	Total efficiency at coupling		%	74					
X 35	Speed		min ⁻¹	10800					
X 36	Speed range		min ⁻¹	8445 - 11823					
X 37	Surge limit at p/p const. 2)		%	75 - 105					
X 38				63					
X 39	Total power consumption 3)		kW	3350					
X 40	Power consumption per STAGE		kW	1552			1798		
X 41	Mechanical losses		kW	88					
X 42	Gear losses		kW						
X 43	Power recommended for driver		kW						
X 44	Rotation of compressor viewed from TURBINE			<input checked="" type="checkbox"/> cw (clockwise) <input type="checkbox"/> ccw (counterclockwise)					
X 45	Remarks:								
X 46	1) S = isentropic compression								
X 47	T = isothermal compression								
X 48	pol = polytropic compression								
X 49	2) related to guaranteed point								
X 50	3) incl. all losses								
X 51	Pressure ratio								
X 52	Power consumption								
X 53	Efficiency								
X 54	Speed								
X 55	Surge limit								
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