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Reciprocating Compressor Performance Analysis

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***Abstract* - One of the process units in oil refining companies is the Athmospheric Residue Hydro Demetalizer (ARHDM). ARHDM is a feed storage unit for Residue Catalytic Cracker (RCC) which functions to clean atmospheric residue from metal compounds, especially nickel and vanadium with the help of a catalyst and hydrogen. The hydrogen used comes from outside the plant with lower system pressure. In order for this processing unit to operate well, especially the ARHDM unit, it needs to be supported by several very important equipment, including the 12-K-501B piston compressor which functions as a make-up for hydrogen in oil processing purposes. This compressor has three six-cylinder stages (2 cylinder stages). This compressor uses an electric motor drive with a power rate of 5,700 KW. This research explains the evaluation of the performance of the 12-K-501B compressor and the form of optimization so that the quality of the compressor performance remains as expected.**

Keywords: Reciprocating compressor, hydrogen make-up, ARHDM unit, performance.

I. INTRODUCTION

Petroleum is a fossil fuel which is the raw material for fuel oil, gasoline and many chemical products. Petroleum is an important energy source because petroleum has a significant percentage in meeting world energy consumption [1]. Even though currently many countries have conducted research into the potential of renewable energy, the world's dependence on petroleum cannot be ignored. Currently, fossil fuels are still the most important energy source with oil contributing 33%, coal 28% and natural gas 23% of total energy sources [2]. Some of the benefits of petroleum that we usually feel every day include liquefied petroleum gas, aviator turbine, kerosene, gasoline, diesel, asphalt, paraffin and others which are the results of processing the crude oil that makes up petroleum.The Indonesian government has a state oil company whose role is to manage, process and develop oil and gas mining. One of the units owned by this company is the refinery unit, which is a unit that has an important role in sustaining the availability of national fuel oil needs. This makes this unit a very vital strategic object.

The Atmospheric Residue Hydro Demetalizer Unit (ARHDM) is a unit that prepares feed for the Residue Catalytic Cracking Unit (RCC) [3]. The ARHDM unit processes residue with a design capacity of 58,000 BPSD which functions to clean atmospheric residue from the CDU unit, and a small part of the RCC unit which contains metal compounds, especially nickel and vanadium as well as high amounts of carbon. The results of this processing produce hydrometallized atmospheric residue which contains nickel and vanadium metal compounds as well as carbon in smaller quantities. The processing process uses catalysts and hydrogen at high temperatures and pressure.

The ARHDM unit consists of two reactor section trains and one fractionation section train. For this reason, a reciprocating compressor is needed which is useful for increasing the pressure [4]. The compressor, as the heart of several processes, can potentially cause problems if it is not operated and maintained properly. There are various maintenance methods that can be used to optimize compressor performance. For this reason, reliable equipment maintenance and optimization techniques are needed. By conducting performance evaluations, it is hoped that compressor performance will be produced which can be used as a reference for determining the best compressor operation and maintenance steps.

II. 12-K-501B RECIPROCATING COMPRESSOR

A compressor is a device that can compress air or gas which functions as a pressure amplifier or vacuum pump. The basic difference with a pump is that the compressor not only flows fluid, but also compresses the fluid. When the compressor compresses air or gas, the compressor works as an amplifier (increases pressure). If the volume of air or gas in a closed room is reduced, then the air or gas experiences an increase in pressure, and conversely the compressor can also function as a vacuum pump [5].The 12-K-501B piston compressor is a gas compressor that operates in ARHDM units at state oil companies. Its main function is to increase the pressure of hydrogen gas from the H2 plant unit for use in the reactor process. This compressor has six cylinders in three compression stages, with an intercooler and fluid separator at each stage. The compressed gas is used in the reactor process system. In operation, the compressor discharge pressure is

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different from the value stated on the data sheet. Knowledge of compressor operation is important to detect and overcome abnormalities and their causes by referring to the Instruction Manual Book.The operation of a compressor is closely related to the system contained in the compressor. The system in question is a set of equipment installed as a single unit to support smooth operations and to be able to monitor the operating conditions of the compressor so that it operates safely and according to capabilities.

2.1 Lubrication and Colling System

The lubrication system functions to lubricate parts that rub and rotate. For example, crank pin bearings, cylinders, pistons and drive rods. So the purpose of lubrication is to prevent wear, close the piston ring and gasket, cool parts that rub against each other, and prevent rusting [6]. To lubricate the inside of the cylinder, a thicker lubricating oil and a pressure higher than the pressure in the cylinder are needed. If not, the lubricant will be blown and the lubricant will not be able to flow. There are several types of compressors that do not require lubrication of the cylinder, piston and piston rod. The goal is to get compressed gas/air that is not contaminated with lubricants.

There are two series of external and internal lubrication systems. External oil lubrication functions to lubricate the bearing mechanism. External oil lubrication has a main pump driven directly from the crankshaft and an auxiliary pump driven by an electric motor. The auxiliary pump is used when starting and stopping. The switching is managed automatically by the instrumentation system. Other equipment is a relief valve, a lubricant filter, and a lubricant cooler. Usually there are two lubricant filters that are used alternately to allow maintenance without having to stop the compressor from working. This lubrication system is generally used on large compressors. Furthermore, internal oil lubrication functions to lubricate the cylinder and piston rod gasket which uses a separate pump with high pressure. The cooling system functions to cool the compressor parts so that the temperature remains at normal conditions. On the 12-K-501B compressor, the cooling system uses cooling water which is flowed around the cylinder and piston rod gasket.

The volume rate of gas/air produced by the compressor must be adjusted to the amount of gas/air needed. If the compressor is left operating while the gas produced is not used, the pressure will rise to dangerous limits [7], therefore the compressor must be equipped with a device called a load reliever. One way is to use an unloader suction valve [8]. This tool works by pressing the suction valve plate continuously during the suction and compression strokes. Because the intake valve is continuously open, compression does not occur in the cylinder. Another method to adjust the load relief method is to use a valve clearance (clearance pocket). In the cylinder head there is a cavity with a valve to regulate its capacity. If this valve is opened, the residual volume becomes large and reduces the compression ratio. Because of this, less gas comes out of the cylinder.

2.2 Compressor Calculation

In theory, there are three main parameters in determining the performance of a reciprocating compressor, namely compressor capacity, compressor power and driving power.

2.2.1 Compressor Capacity

The following are several parameters calculated regarding compressor capacity:

- Simplex, single acting can be calculated with the equation:
  $Q = (\pi/4) \text{ x } D^2 \text{ xSx NxVe... (cfm)}$
- Simplex, double acting at head end and crank end:
  $Q = (\pi/4) \text{ x } (D^2 - d^2) \text{ x S x N x Ve....(cfm)}$
- Duplex, double acting at head end and crank end:
  $Q = (\pi/4) \text{ x } (2D^2 - d^2) \text{ x S x N x 2 x Ve.....(cfm)}$

Where Q is compressor capacity (cfm), D is bore diameter (ft), S is stroke (ft), and N is speed (rpm).

Furthermore:

- Volumetric Efficiency (Ve) = 96 – C x $[(r)^{1/k} - 1]$.....(%)
- Cylinder Clearance (C) = (CV/ VC) x 100%
- Compression Ratio (r) = P_2 / P_1

The following is how to calculate capacity from actual to normal units:

$$\frac{Q_1 \times P_1}{T_1} = \frac{Q_{nr} \times P_{nr}}{T_{nr}}$$

2.2.2 Compressor Power

The following is the calculation of polytropic and adiabatic compressor power:

- Polytropic compressor power

$$NK_{pol} = \frac{\frac{n}{n-1} \times P_1 \times Q \times \left[\left(\frac{p2}{p1}\right)^{\frac{n-1}{n}} - 1\right]}{33{,}000 \times \eta \text{ mechanical}} \text{ .... (HP)}$$

Where NK_{pol} is polytropic compressor power (HP), η_m is mechanical efficiency (%), P_2 is discharge pressure (lbs/ft^2), P_1 is inlet pressure (lbs/ft^2), Q is compressor capacity (ACFM).

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For the value of n (polytropic exponent) it can be calculated using the formula:

$$NK_{ad} = \frac{n-1}{n} = \frac{\ln(T2/T_1)}{\ln(P_2/P_1)}$$

Where T_2 is the discharge temperature (^{o}Re), T_1 is the inlet temperature (^{o}Re), $P_2$is the discharge pressure (Psi), and $P_1$is the inlet pressure (Psi).

- Adiabatic compressor power

$$NK_{ad} = \frac{\frac{k}{k-1} \times P_1 \times Q \times \left[\left(\frac{p2}{p1}\right)^{\frac{k-1}{k}} - 1\right]}{33000 \times \eta \text{ mechanical}} \text{ ... (HP)}$$

Where NK is adiabatic compressor power (HP), η_ms mechanical efficiency (%), P_2s mechanical efficiency (lbs/ft^2), is inlet pressure (lbs/ft^2), and Q is compressor capacity (ACFM).

The compressor driving power can be calculated using the following formula:

$$N_p = \frac{NK}{\eta trans} \text{ ... (HP)}$$

Where NK is compressor power (HP), Np is driving power (HP), and η_{trans} is transmission efficiency (%). Empirical transmission efficiency for belts is 80 - 90%, for gear boxes is 90 - 98%, and for couplings is ≥ 98%.

III. RESULTS AND DISCUSSIONS

3.1 Actual Data

The operational flow diagram of the 12-K-501B compressor is shown in Figure 1. The 12-K-501 B piston compressor data is shown in Table 1. The operating data is shown in Table 2. The operating gas data is shown in Table 3.

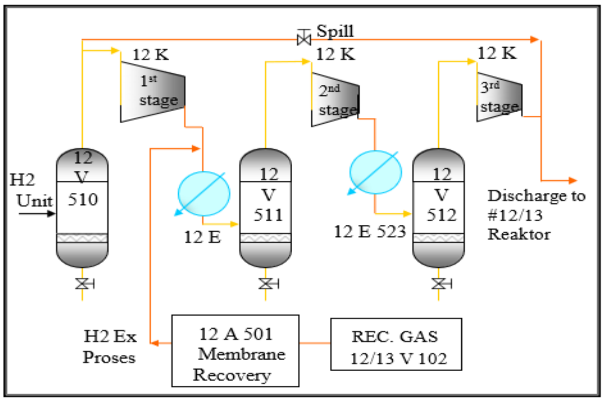

Figure 1: 12-K-501B operation flow diagram

Table 1: 12-K-501B Reciprocating Compressor Data

No	Description	Stage			Unit
		1st	2nd	3rd	
I. CilynderData					
1	Bore	390	290	210	mm
2	Stroke	320	320	320	mm
3	Roddiameter	110	110	110	mm
4	Rpm	370	370	370	rpm
5	Pistondisplacment	3,259.5	1,741.9	894.2	m^3/h
6	Clearance	19.5	26.5	29	%
7	Volumetriceffisiency	79	81.3	86.2	%
8	Apivalvegasvelocity	44.5	22.1	30.2	m/s
9	No.ofinlet/disch.valves	2/2	2/2	2/2	pcs
10	Typeofvavles	194CKD	194CKD	134CGD	
11	Inlet/disch. valveliftmm	2.0/2.0	1.8/1.8	1.6/1.6	mm
12	NormalpistonSpeed	3.947	3.947	3.947	m/s

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13	Maxallow cylpress	60	130	230	kg/C m^2
14	Hydrostatic test	90	195	345	kg/C m^2
15	Relievevalveset	56.2	118.5	214.6	kg/C m^2
II.Material					
1	Cylynder	A216WC B	A216WC B	AISI4140	
2	Cylynderliner	A278CL.4		AISI4140	
3	Piston	A278CL.4		AISI420	
4	Pistonring	CarbonFilledTeflon			
5	Riderring	CarbonFilledTeflon			
6	Pistonrodpacking	CarbonFilledTeflon			
7	Pistonrod	13% Cr			
8	Valveseats	AISI1410			
9	Valvestops	AISI1410			
10	Valveplates	AISI1410			
11	Valvesprings	AISI1410			
12	Crankshaft/crankcase	Inconel			
13	CrossHead	CarbonSteel			
III. Operation Data					
1	Gascompressed	H_2+HC			
2	InletTemp.	41			^{0}C
3	InletPress	20.5	51.5	104.1	kg/C m^2
4	DischargeTemp.	135	118	105	^{0}C
5	DischargePress	52	105.5	198.2	kg/C m^2
6	Cp/Cvvalvesuct/disch.	1.42/1.44	1.47/1.53	1.56/1.67	
7	Mol wgtatinlet	2,465	2,359	2,359	
8	Kg/hr	4,140	5,455	5,455	
9	NM^3/Hr	37,102	50,927	50,927	

Table 2: Operation Data

Description	1ststage	2ndstage	3rd stage
Speed (N)rpm	370		
Capacity (Qn)kNm³/hr	38.3	50.53	50.5
Suction Pressurekg/cm²	21.7(P_1)	53 (P_2)	104.3 (P_3)
Discharge Pressurekg/cm²	53 (P_2)	106 (P3)	182.2 (P_4)
Suction Temperature°C	35.3(T_1)	50.7(T_2)	55.1(T_3)
Discharge Temperature °C	131.5(T_2)	120.6(T_3)	107.2(T_4)
Cylinder Diameter mm	390	290	210
Piston rod diameter mm	110		
Stride Length mm	320		
currentkAmp	1,2		

Table 3: Gas Data

Gas Type	1stStage			2ndStage			3rdStage		
	%Mol.	Mcp at 35,3 °C	McpMix	%Mol	Mcpat 50,7°C	McpMix	%Mol.	Mcpat 55, 1 °C	McpMix
H_2	99.78	6.91	6.89	97.21	6.92	6.72	97.2	6.92	6.73
Methane	-	-	-	1.17	8.84	0.10	1.17	8.90	0.10
Ethane	-	-	-	0.26	13.40	0.03	0.26	13.54	0.03
Propane	-	-	-	0.47	18.97	0.08	0.47	19.20	0.09
i-Butane	-	-	-	0.18	25.04	0.04	0.18	25.32	0.04
n-Butane	-	-	-	0.32	25.10	0.08	0.32	25.37	0.08
i-Pentane	-	-	-	0.04	30.54	0.01	0.04	30.91	0.01

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n-Pentane				0.02	30.80	0.00	0.02	31.15	0.00
Hexane				0.06	32.51	0.01	0.06	32.87	0.01
Nitrogen	0.22	6.97	0.01	0.22	6.97	0.01	0.22	6.97	0.00
Total	100		6.90	99.95		7.13	99.9		7.14

3.2 Performance Calculations

3.2.1 Compressor Capacity Calculation

The clearance of the head end and crank end of the compressor is different so that the calculation of compressor capacity based on the cylinder is calculated partially as follows:

a) 1st Stage Capacity (Cylinder 5 and Cylinder 6)

- Compression Comparison (r)

$$r = \frac{P_2}{P_1} = \frac{53\ kg/cm^2}{21{,}7\ kg/cm^2} = 2.442$$

- Specific Heat Comparison (k)

Based on the composition table at T_1 = 35,3 ºC we get cp.mix = 6.912 Btu/lbmol/ºR, then

$$k = \frac{cp.mix}{cp.mix - 1.99} = \frac{6.912}{6.912 - 1.99} = 1.404$$

- Ve on the Head End (HE) side or Crank End (CE) side:

$Ve = 96 - C\times[(r)^{1/k} - 1] = 96 - 19.5\times[(2.442)^{1/1.404} - 1]$ %

$= 96 - 16.885\ \% = 79.115\%$

C is clearance of each CE and HE (19.5 %)

- Head End Operation Capacity:

$Q_{HE1} = 2\times[(\pi/4)\times D^2\times S\times N\times Ve]$

$= 2\times[0.785\times1.28^2\times1.05\times370\times0.79115]$

$= 790.620$ ft³/min

- Rack End Operation Capacity:

$Q_{CE1} = 2\times[(\pi/4)\times(D^2 - d^2)\times S\times N\times Ve]$

$= 2\times[0.785\times(1.28^2 - 0.36^2)\times1.05\times370\times0.79115]$

$= 728.082$ ft³/min

- Total operating capacity of stage 1

Qdt1 = QHE1 + QCE1

= 1,518.702 ft³/min

= 112,518.702 ft³/min ×1.6989

= 2,580.124 Am³/jam

(ACMH = Actual Cubic Meter per Hours).

- Operating capacity from actual to normal units:

$$\frac{Q_{dt1} \times P_1}{T_1} = \frac{Q_{nr5,6} \times P_{nr}}{T_{nr}}$$

$$Q_{nr5,6} = \frac{Q_{dt1} \times P_1 \times T_{nr}}{P_{nr} \times T_1}$$

$$= \frac{2{,}580.124\ Am^3 \times 21.7\ kg/cm^2 \times 273°K}{1.033 kg/cm^2 \times 404.5°K}$$

$$= 36{,}580.03\ Nm^3/hour$$

b) 2nd Stage Capacity (Cylinder 2 and Cylinder 4)

- Compression Comparison (r)

$$r = \frac{P_2}{P_1} = \frac{106\ kg/cm^2}{53\ kg/cm^2} = 2$$

- Specific Heat Comparison (k)

Based on the composition table at T_1 = 50.7 ºC we get cp.mix = 7.135 Btu/lbmol/ºR, then

$$k = \frac{cp.mix}{cp.mix - 1.99} = \frac{7.135}{7.135 - 1.99} = 1.387$$

- Ve on the Head End (HE) side or Crank End (CE) side:

$$Ve = 96 - C\times[(r)^{1/k} - 1] = 78.820\%$$

C is clearance of each CE and HE (26.5 %)

- Head End Operation Capacity:

$Q_{HE2} = 433.884$ ft³/min

- Rack End Operation Capacity:

$Q_{CE2} = 371.578$ ft³/min

- Total operating capacity of stage2

Qdt2 = QHE12+ QCE2

= 805.462 ft³/min

= 1,368.401 Am³/jam

- Operating capacity from actual to normal units:

$$Q_{nr2,4} = \frac{Q_{dt1} \times P_1 \times T_{nr}}{P_{nr} \times T_1}$$

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$= 48{,}696.364\ Nm^3/jam$

c) 3rd Stage Capacity (Cylinder 1 and Cylinder 3)

- Compression Comparison (r)

$r = \frac{P_2}{P_1} = \frac{182.2\ kg/cm^2}{104.3\ kg/cm^2} = 1.747$

- Specific Heat Comparison (k)

Based on the composition table at T_1 = 55.1 ºC we get cp.mix = 7.142 Btu/lbmol/ºR, then

$k = \frac{cp.mix}{cp.mix - 1{,}99} = \frac{7.142}{7.142 - 1.99} = 1.386$

- Ve on the Head End (HE) side or Crank End (CE) side :

Ve = 96 - C×[(r)$^{1/k}$ -1]=81.649%

C is clearance of each CE and HE (29 %)

- Head End Operation Capacity:

Q_{HE3} = 236.418 ft³/min

- Rack End Operation Capacity:

Q_{CE3} = 171.875 ft³/min

- Total operating capacity of stage 3

Qdt2 = QHE3+ QCE3

= 408.293 ft³/min

= 693.649 Am³/jam

- Operating capacity from actual to normal units:

$$Q_{nr\,1,3} = \frac{Q_{dt\,3} \times P_3 \times T_{nr}}{P_{nr} \times T_3}$$

$= 50{,}135.546\ Nm^3/jam$

3.2.2 Compressor Capacity Calculation

a) Polytropic Process Compressor Power

1) 1st Stage Compressor Power:

$$NKpol1 = \frac{\frac{n}{n-1} \times P_1 \times Q_{dt1} \times \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]}{33{,}000 \times \eta\ mechanical} \ldots(HP)$$

where the n value (polytropic exponents) can be calculated:

$$\frac{n-1}{n} = \frac{\ln(T2/T_1)}{\ln(P_2/P_1)} = \frac{\ln(728.37/555.21)}{\ln(753.837/322.869)} = 0.320$$

n = 1.47

$$so\ Nkpol1 = \frac{\frac{1.47}{1.47-1} \times 46{,}493.26 \times 1{,}518.702 \times \left[\left(\frac{10{,}8553}{46{,}493.26}\right)^{\frac{1.47-1}{1.47}} - 1\right]}{33000 \times 0{,}9}$$

= 2,315.615 HP

2) 2nd Stage Compresor Power

$$NKpol2 = \frac{\frac{n}{n-1} \times P_2 \times Q_{dt2} \times \left[\left(\frac{P_3}{P_2}\right)^{\frac{n-1}{n}} - 1\right]}{33{,}000 \times \eta\ mechanical} \ldots(HP)$$

where the n value (polytropic exponents) can be calculated:

$$\frac{n-1}{n} = \frac{\ln(T3/T_{2'})}{\ln(P_3/P_{2'})} = \frac{\ln(708.75/582.93)}{\ln(1507.67/753.837)} = 0.282$$

n = 1.392

$$so\ NKpol2 = \frac{\frac{1.392}{1.392-1} \times 108{,}553 \times 805.562 \times \left[\left(\frac{217{,}105}{108{,}553}\right)^{\frac{1.392-1}{1.392}} - 1\right]}{33000 \times 0{,}9}$$

= 2,253.907 HP

3) 3rd Stage Compresor Power

$$NKpol3 = \frac{\frac{n}{n-1} \times P_3 \times Q_{dt3} \times \left[\left(\frac{P_4}{P_3}\right)^{\frac{n-1}{n}} - 1\right]}{33{,}000 \times \eta\ mechanical}, \ldots(HP)$$

Where the n value (polytropic exponents) can be calculated:

$$\frac{n-1}{n} = \frac{\ln(T4/T_{3'})}{\ln(P_4/P_{3'})} = \frac{\ln(684.63/590.85)}{\ln(2{,}591.493/1{,}483.495)} = 0.264$$

n = 1.359

$$so\ NKpol3 = \frac{\frac{1.359}{1.359-1} \times 213{,}623.238 \times 408.293 \times \left[\left(\frac{373{,}175.01}{21{,}3623.238}\right)^{\frac{1.359-1}{1.359}} - 1\right]}{33000 \times 0{,}9}$$

= 1,765.064HP

Total compressor power of polytropic processes:

NKpol = Npol1 + Npol2 + Npol3

= 2,315.615 HP + 2,253.907 HP + 1,765.064 HP

= 6,334.586 HP

b) Adiabatic Process Compressor Power

1) 1st Stage Compresor power:

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$$\text{NK ad1} = \frac{\frac{k}{k-1} \times P_1 \times Qdt\,1 \times \left[\left(\frac{p2}{p1}\right)^{\frac{k-1}{k}} - 1\right]}{33{,}000 \times \eta \text{ mechanical}} \text{ ... (HP)}$$

Where the value of k is the ratio of specific heat (1,404)

so

$$NK_{ad1} = \frac{\frac{1.404}{.,404-1} \times 46{,}493.26 \times 1{,}518.702 \times \left[\left(\frac{108{,}553}{46{,}493.26}\right)^{\frac{1.404-1}{1.404}} - 1\right]}{33000 \times 0{,}9} \text{...(HP)}$$

= 2,283.104 HP

2) 2nd Stage Compresor Power:

$$NK_{ad2} = \frac{\frac{k}{k-1} \times P_2 \times Qdt\,2 \times \left[\left(\frac{P3}{P2}\right)^{\frac{k-1}{k}} - 1\right]}{33{,}000 \times \eta \text{ mechanical}} \text{ ... (HP)}$$

Where k = 1.387, then

$$NK_{ad2} = \frac{\frac{1.387}{1.387-1} \times 46{,}493.26 \times 1{,}532.566 \times \left[\left(\frac{108{,}553}{46{,}493.26}\right)^{\frac{1.387-1}{1.387}} - 1\right]}{33{,}000 \times 0.9} \text{...(HP)}$$

= 2,251.261 HP

3) 3rd Stage Compressor power:

$$NK_{ad3} = \frac{\frac{k}{k-1} \times P_3 \times Qdt\,3 \times \left[\left(\frac{P4}{P3}\right)^{\frac{k-1}{k}} - 1\right]}{33{,}000 \times \eta \text{ mechanical}} \text{ ... (HP)}$$

Where k = 1.386, then

$$NK_{ad3} = \frac{\frac{1.386}{1.386-1} \times 213{,}623.238 \times 412.773 \times \left[\left(\frac{373{,}175.01}{213{,}623.238}\right)^{\frac{1.386-1}{1.386}} - 1\right]}{33{,}000 \times 0.9} \text{...(HP)}$$

= 1,772.313 HP

Total Adiabatic Process Compressor Power:

$NK_{ad} = NK_{ad1} + NK_{ad2} + NK_{ad3}$

= 2,283.104 HP + 2,251.261 HP + 1,772.313 HP

= 6,306.678 HP

3.2.3 Calculation of Driving Power

The operating driving power is calculated as follows:

$$Nd = \frac{NK}{\eta_{trans}} \text{ ... (HP)}$$

Where, the clutch transmission efficiency ηtrans is 98%.

1. The driving force of operations based on polytropic processes:

$Nd_{pol} = \frac{NK_{pol}}{\eta_{trans}} = \frac{6{,}334.586}{0.98}$ = 6,463.863 HP× 0.7457 kW/HP

= 4,820.103

2. The operating driving force is based on an adiabatic process:

$Nd_{ad} = \frac{NK_{ad}}{\eta_{trans}} = \frac{6{,}306.678}{0.98}$ = 6,435.386 HP × 0.7457 kW/HP

= 4,798.867

3.3 Performance Analysis

A recapitulation of performance comparisons between operating conditions and calculation results and specification data is shown in Table 4.The compressor works with operating conditions that are different from the engine specifications. Comparison between operating conditions and specifications is shown in Table 5.

Table 4: Performance Recapitulation Data

Capacity Description (Nm^3/hour)	Design (Data)	Operating Conditions	The calculation results
1stStage 2nd Stage 3rd Stage	37,102 50,927 50,927	38,300 50,533 50,500	36,580.03 48,696.36 50,135.55
Driving Power(KW)	5,700	(Polytropic) 4,820.1	(Adiabatic) 4,798.8

Table 5: Compressor Specification and Operation Data

Description	Work rate data 1st stage		Work rate data 2nd stage		Work rate data 3rd stage	
	Specifications	Operation	Specifications	Operation	Specifications	Operation
Temp. Suct.°C	41	35.3	41	50.7	41	55.1
Temp. Disc.°C	135	131.5	118	120.6	105	107.2
Tek.Suct.kg/cm²	20,5	21.7	51.5	53	104.1	104.3
Tek.Dis. kg/cm²	52	53	105.5	106	198.2	182.2
Eff. Vol.	79	79.12	81.3	78.82	86.2	81.65

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Mechanical performance is the ability of equipment to operate optimally with reliable and available mechanical conditions so that it rarely experiences damage, whether minor or major. Historical data for the 12-K-501B piston compressor shows that the compressor is still in fairly good condition. Since it was operated in 1994 until now there has been no significant damage. Improvement activities that have been carried out include:

- Routine repairs, namely daily maintenance/repairs, are carried out if abnormalities or damage occurs to several materials, such as checking compressor parameters, checking lubricants, checking cooling systems, replacing valves, stuffing box leaks, re-stroke lubricator pump.
- Scheduled repairs based on operating hours (running hours), namely minor overhaul and major overhaul [9]. Minor overhaul work is carried out only on materials from the cylinder to the stuffing box, such as replacing valves, packing roof, piston rings and rider rings. Meanwhile, major overhaul work has also been carried out. During the overhaul, all major work equipment recommended by the manufacturer is replaced, such as crank shaft and cross head main bearings, cross head bushings, cross head shoes, roof packing, piston & rider rings, suction & discharge valves, accessory materials and others [10].

Based on the compressor specifications and operation data, it can be stated that there was no significant damage while the compressor was in operation, the condition of the compressor is currently good after a major overhaul, and the compressor performance data shows that overall the compressor is working at an operating efficiency condition of 90.93 %. Furthermore, regarding optimization, the efforts made on the 12-K-501B compressor are to maintain the performance of the compressor. Optimization is an action carried out using various methods which have the aim of improving the performance of equipment so that it can operate optimally (reliable and available) and under control (controlled) [11].

The form of effort or action taken in an effort to maintain good compressor performance is by improving the maintenance system, such as:

- Regularly monitor conditions such as checking and monitoring lubricant conditions, vibration, temperature, pressure and so on [12]. Carried out every day by related parties such as operations, rotating engineering and maintenance.
- Carrying out intensive maintenance on equipment as a determining factor in compressor performance, including the intercooler and water jacket, where the role of the intercooler and water jacket is very significant in saving power [13].
- Carrying out minor and major overhaul programs regularly and providing spare parts when needed for the 12-K-501B compressor to support the smooth running of operations.

However, the involvement of the operations department as first inspector plays a very important role in maintaining compressor performance. So that abnormalities that occur during operation can be quickly handled. So the performance of the 12-K-501B piston compressor will always be maintained.

IV. CONCLUSION

Based on the calculation results (recapitulation data) and mechanical conditions related to the performance evaluation of the 12-K-501B piston compressor, it can be concluded that the capacity conditions are Q_{design} = 50,927 Nm^3/hour, $Q_{operation}$ = 50,500 Nm^3/hour, and $Q_{theoretical}$ = 50,135.55Nm^3/hour . The condition of the compressor driving power is Nd_{design} = 5,700 KW, $Nd_{polytropic}$ = 4,801.756 KW, and $Nd_{adiabatic}$ = 4,798.867KW. The compressor is operated as needed with a capacity of 97.45% and a power of 84.19%. The compressor is in very good mechanical condition.

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