ENERGY IMPROVEMENT OF AN OIL INJECTED SCREW COMPRESSOR SKID

EFICIENTIZAREA ENERGETICĂ A UNUI SKID DE COMPRESOARE CU ŞURUB CU INJECŢIE DE ULEI

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Abstract: *Energy efficiency of a screw compressor skid, after 80,000 hours of operation, by introducing a lubrication pump for oil flow in the lubrication and injection system, eliminating the need to increase the discharge pressure by strangling the discharge, so that the oil can circulate through installation due to pressure in the separator vessel. So, the electric motor is overloaded and the required electric power for compressing the gas increases significantly.*

Keywords: screw compressor installation, natural gas compression, energy efficiency.

Rezumat: *Eficientizarea energetică a unui skid compresor cu şurub, după 80.000 de ore de funcţionare, prin introducerea unei pompe de ungere destinate circulaţiei uleiului în instalaţia de ungere şi injecţie, eliminând necesitatea de a mări presiunea de refulare prin strangularea refulării, pentru ca uleiul să poată circula prin instalaţie datorită presiunii din vasul separator. Astfel, motorul electric este suprasolicitat iar puterea electrică necesară pentru comprimarea gazului creşte semnificativ.*

Cuvinte cheie: compresor cu şurub, comprimare gaz natural, eficienţă energetică.

1. Introduction

From 1980 the oil-flooded screw compressors have been used in many gas compression process with many applications. From the beginning of 2010 National Research and Development Institute for Gas Turbines COMOTI manufacture screw compressors that are spread on the entire Romanian territory and some outside the borders. This paper will present details about the functionality of the gas compression installations and the newly modernized, energy-efficient, environment safety

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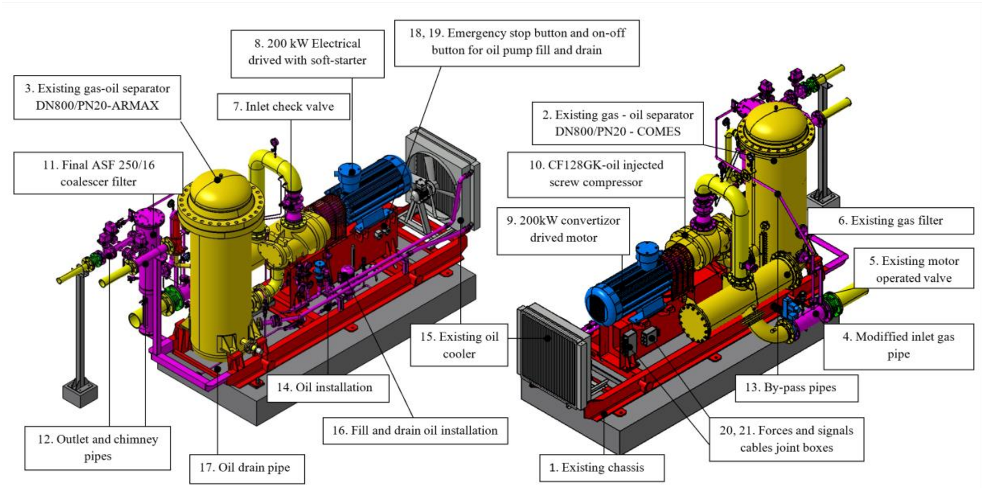
installations made by the National Research and Development Institute for Gas Turbines COMOTI. The demonstrated advantages in the course of years of this type of compressor, like high reliability, simple foundations, low operational cost, low initial cost, suitability for process fluctuation as in gas pressure, gas composition, led to significant demand for such compressors.

In Romania, National Research and Development Institute for Gas Turbines COMOTI is the sole manufacturer of natural gas screw compressors and compression groups equipped with oil-injected screw compressors and an important competitor on the market of such equipment. It is specialized in improving, diversifying and continuously modernizing its products in order to meet the requirements of the various requested applications and to raise the technical level of the products from other partners on the market and in the research and development niche. Sustained concern has been directed toward the development of energy-efficient products and safe solutions for the use of compression equipment to reduce the amount of gas evacuated in the atmosphere when the plant shuts down, with a strong interest in economic and environmental protection. Research has been specifically driven towards optimizing energy consumption in the compression process, improving compressed gas characteristics, oil consumption by reducing the residual oil content of compressed natural gas, increasing the reliability and life of the installation. The main interest is the reduction of the energy consumption of the equipment and the safe and long-term operation by installing a lubrication oil pump, that is mounted in the oil injection system.

2. Installation description

The ECS (Electro Screw Compressors) equipment is built to operate without restrictions at ambient temperatures from -30°C to + 40°C under the conditions of the continental temperate climate. The designed installations are continually improved, evolved and realized to a compact skid on which complex suction and discharge gas conditioning systems are installed, efficient filtering equipment to reduce the residual oil content in the compressed gas to about 1mg/Nm^3. The ECS screw compressor is a complex installation designed to compress natural gas flow at the parameters requested by the beneficiaries. The oil-injected screw compressor is so named because oil is continuously injected into the compressor to perform several functions, respectively taking over a quantity of heat during the compression process, lubrication and cooling of the compressor parts. In addition, the sealing of the compression spaces is improved and the noise is attenuated. It should be mentioned that the oil introduced into the compressor always remains in the liquid phase and thus has a high cooling capacity. The volume occupied by the oil is less than 1% of the gas volume and there can be no situation to force the compressor to compress the oil. The oil injection ensures the control of the gas temperature in the compression process which usually does not exceed 100°C. As a result of temperature control but also by improving the internal seal, high compression ratios can be obtained in a single step, 15-20 or even higher. The oil introduced into the compressor is mixed with the compressed gas and is evacuated together with it from the compressor. For this reason, screw compressors must have complex installations to ensure oil flow, cooling, filtration and a gas separator.

Separation of oil from gas is necessary both to ensure proper gas quality and to reduce oil consumption. The entire installation consists of a separator vessel, lubricating oil pump system, oil cooler, gas and oil filters, command and shut-off valves, measuring and protection devices as seen in figure 1.



Assembly skids components			
1. Existing chassis	7. Inlet check valve	13. By-pass pipes	19. On-off button for oil pump fill and drain
2. Existing gas - oil separator DN800/PN20 - COMES	8. 200 kW Electrical driver with soft-starter driver	14. Oil installation	20. Signals cables joint boxe
3. Existing gas-oil separator DN800/PN20-ARMAX	9. 200kW convertizor drived motor	15. Existing oil cooler	21. Forces cables joint boxe
4. Modiffied inlet gas pipe	10. CF128GK-oil injected screw compressor	16. Fill and drain oil installation	
5. Existing motor operated valve	11. Final ASF 250/16 coalescer filter	17. Oil drain pipe	
6. Existing gas filter	12. Outlet and chimney pipes	18. Emergency stop button	

Figure 1. Screw compressor natural gas installation.

The modifications from the original compressor skid are in magenta color. The electro-compressor is equipped with an oil injected screw compressor.

The skid chassis is a metallic structure from carbon steel profiles welded together and its purpose is to sustain the other components of the equipment like: electrical driving, engine, gas – oil separation system, oil installation, etc. Another important role is to fix the equipment to the ground. The frame is equipped also with an oil tank for the oil installation. The compression unit is produced by GHH-Ingersoll Rand and is equipped with screws with asymmetric profile. These are complex equipment, with high efficiency and with multiple possibilities to adapt to various technological schemes, maintaining a delivery pressure. The electrical engine is of asynchronous type, with anti-fire protection and air cooling. The oil installation contains all the circuits that ensure the lubrication of the bearings and the cooling of the compressor. Fine and coarse filters for the oil entering the compressor are also included in the injection system. The heat exchanger - or the oil cooler is an air-cooling unit. The cooling fan speed is variable and it has the purpose to maintain the oil temperature constant at the entrance in the compressor.

Through this are avoided the thermal shock on radiator and the electrical energy consumption is minimized and is according to the atmospheric temperature.

Air cooling is better than the one with water (does not need treated water, cooling tower, pumps, etc.). The oil-gas separation system is a pressurized vessel and it is used to separate the cooling oil from the compressed gas. This system it is also an oil tank. The oil-gas separation system is made of two separation stages: one centrifugal and one inertial. The connection section with flexible element connects the screw compressor exhaust area and the admission of the oil-gas separation system. The section has a flexible metallic hose. This element is necessary to take the axial movement of the connection pipe, movement that appear due to dilatations caused by the hot gases. Also, the metallic hose is a good vibration isolator between compressor and oil-gas separation system. The gas admission filter is used to keep the impurities from the natural gas. The oil pump is used to keep the oil level constant in the separation vessel. This working sequence is automatic. The exhaust pipes contain the connections between the compression equipment and the common pipe with compressed gases from the field. Also are included the protection elements of the equipment like: overpressure and sealing valve. The compression equipment is an automatic compression equipment. The product is completely automatic, without surveillance personal. All the commands included in the automatic program are supervised by a programmable automate (PLC). The equipment stops automatically is the function parameters reach values outside the imposed limits. The main electrical engine starters systems according to the beneficiaries needs the starting procedure it can be made in two ways:

- Frequency converter;
- Soft starter.

3. Gas compression and oil injection processes

Due to the operating parameters of the screw compressors, a value of over 4.5 bar of discharge pressure is required for the oil injection in the compression process. In the most cases, the discharge pressures in the natural gas compression installations are below this value and in order to reach it, a pressure regulator is required when discharging from the installation or a manually operated valve that closes gradually, until the desired discharge pressure. By choking the compressor discharge, the electricity consumed by the electric motor to achieve the compression desired pressure in the compressor also increases. At the same time, before the modernization of the compressors, the starts were made without pressured oil injection, what led to the degradation of the surfaces of the rotors and also to the degradation of the compression unit. In order to prevent the above mentioned, a lubrication pump with a 4kW electrical motor (see figure 2), was installed on the oil lubrication system that works automatically depending on the discharge pressure and which ensures a pressure in the oil installation higher than the discharge one, so that the compressor can be lubricated regardless of its discharge pressure. As a result of these changes, the electricity consumption decreases considerably due to the fact that the compression unit is no longer overloaded and implicitly neither the electric drive motor.

Figure 2. Geared pump with magnetic coupling and the 4kW electrical motor, used for energy-saving process.

Gear pumps are of special construction and can operate with high suction pressures. For safety, two identical pumps are installed, one of which is in operation and the second in reserve. Also, to ensure an energy saving, long life exploitation and environment safety for the new modernized compressor installation, the following technical solutions were implemented:

- Effective filtering of compressed gas to reduce the oil content of compressed gas from the compressor skid by installing demisters in the oil-gas separation vessel;
- Installation of the aspiration discharge system which significantly reduces the emissions of gases into the atmosphere;
- Installation of check valves and electric valves on the suction and discharge of the compressor for automatic and safe operation of the compressor assembly;
- Additional parameters are monitored to ensure a safe operation and minimize the number of staff required to operate them at the station, with the possibility of data transmission and remote control;
- New generation of PLC and a touch display ensures an easy to use interface to view all the functional parameters, alarms and eventual errors during the operation of the equipment;
- Monitoring the electric motor parameters (temperature and absorbed current intensity) to protect him from overheating and overload;

3. Energy saving and power consumption calculation.

Notations:
Q - gas flow [Nm^3/day]
m - mass flow [kg/s]
R - universal gas constant [J/kg/K]
K - adiabatic transformation coefficient [-]
T_1 - suction temperature
p_1 - suction pressure [bara]
p_2 - discharge pressure [bara]
$P_{cons.}$ - power consumption [kW]
$P_{cons.Case\ I.}$ - power consumption in Case I [kW]
$P_{cons.Case\ II.}$ - power consumption in Case II [kW]
E_{r_saved} - Energy rate saved per year [kW]
E_{year} - Energy saved per year [kWh]
$Price_{year}$ - total economy per year [Euro]
kWh_{price} - estimated price per kWh [Euro]

In order to be able to make a comparison between the two different working regimes, depending on the discharge pressure, the following input data from the table 1, will be taken into account:

Table 1. Two cases studied

Parameters			Unit
	Case I	**Case II**	
Q	30.000		Nm^3/day
p_1	1.2		bar abs.
p_2	3	5	bar abs.

The main equation used in the calculation procedure used in COMOTI is the consumed power equation.

$$P_{Cons.} = mRT_1 \frac{k}{k-1}\left[\left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}} - 1\right] \text{[kW]} \quad (1)$$

Adding the data in the calculation procedure used within the COMOTI institute, we have the following results as seen in figure 3.

CASE I

For methane gas, Pa=1.2 bara, Pr=3 bara			
Kappa	k	1.4	
Molweight	Mol	16.04	kg/kMol
Suct. press., abs.	**p1**	**1.2**	bara
Pressure gauge	Pa,g	0.2	barg
Normal volume flow/day Requeste	**Qz**	**30000**	Nm^3/zi
Normal volume flow/hour	Qh	1250.0	Nm^3/h
Suct. Temp.	t1	15	°C
Term A	A	1.06	
Term B	B	0.84	
Succion volume flow	V1	1105.4	m^3/h
Discharge press., abs.	**p2**	3	bara
Compresion ratio	pi	2.50	
Mass flow/h	m	894.7	kg/h
Mass flow/day	md	21472.6	kg/day
Suct. Temp.	T1	288.15	K
Mass flow/s	Ma	0.249	kg/s
R = 8314,3 / Mol			
Gas const.	R	518.35	J/kgK
Cp = k * R / (k - 1)			
spec. heat @ const. press.	Cp	1814.2	J/kgK
F=k/(k-1)		3.5	
(k-1)/k		0.3	
Lc = Cp * T1 * (pi ^ ((k - 1) / k) - 1)			
	Lc	156444.9	J/kg
P_s = Lc * Ma / 1000			
Isentropic power	P_s =	38.88	kW
Consumed power, effic.ad=0,75	**Pcons.**	**51.8**	**kW**

CASE II

For methane gas, Pa=1.2 bara, Pr=5 bara			
Kappa	k	1.4	
Molweight	Mol	16.04	kg/kMol
Suct. press., abs.	**p1**	**1.2**	bara
Pressure gauge	Pa,g	0.2	barg
Normal volume flow/day Requeste	**Qz**	**30000**	Nm^3/zi
Normal volume flow/hour	Qh	1250.0	Nm^3/h
Suct. Temp.	t1	15	°C
Term A	A	1.06	
Term B	B	0.84	
Succion volume flow	V1	1105.4	m^3/h
Discharge press., abs.	**p2**	5	bara
Compresion ratio	pi	4.17	
Mass flow/h	m	894.7	kg/h
Mass flow/day	md	21472.6	kg/day
Suct. Temp.	T1	288.15	K
Mass flow/s	Ma	0.249	kg/s
R = 8314,3 / Mol			
Gas const.	R	518.35	J/kgK
Cp = k * R / (k - 1)			
spec. heat @ const. press.	Cp	1814.2	J/kgK
F=k/(k-1)		3.5	
(k-1)/k		0.3	
Lc = Cp * T1 * (pi ^ ((k - 1) / k) - 1)			
	Lc	263175.2	J/kg
P_s = Lc * Ma / 1000			
Isentropic power	P_s =	65.41	kW
Consumed power, effic.ad=0,75	**Pcons.**	**87.2**	**kW**

Figure 3. The two cases of calculation with the different discharge pressures.

In the figure 3 above, we simulated the parameters of the compression process of a screw compression installation for the same type of compressor, with a COMOTI developed software.

The power rate at the two cases presented is as follows:

$$P_{cons.Case\ I} = 51.8\ (Case\ I) + P_{cons.pump} = 51.8 + 4 = 55.8\ [kW] \quad (2)$$

$$P_{cons.Case\ II} = 87.2\ (Case\ II)[kW] \quad (3)$$

In the "Case I", in order to produce a gas flow of 30,000 Nm^3/day (about 0.249 kg/s), and creating sufficient pressure for the oil flow, with a 4kW electric motor pump, a power consumption of 55.8 kW is required. In the "Case II", for the same gas flow, the calculation with the increased discharge pressure is presented so that the oil flow can be done through the separator vessel. In the case II, the power consumption required to achieve the oil flow is 87.2 kW. Therefore, the energy rate saving by using a lubricating oil pump is approximately E_{r_saved}=31kW, between the two cases.

The electricity price produced provided by the OMV-Petrom, that is also an electricity supplier, considering that the offer is for medium voltage (6kV to 20kV), the offer from [8] for the electricity price from 01.06.2020, taking into consideration an IC consumer (500…2000 MWh) [9] is about 570.75 RON, or at the average 4.97 RON/euro in the next 12 month, the price is 114.84 euro/MWh. For a more general view, the estimated energy saved in one year (approximated to 8,000 hours, eliminating downtime for revisions and technical issues) for a screw compressor installation is:

$$E_{year} = func.hours \cdot E_{r_{saved}} = 8{,}000 \cdot 31 = 248{,}000 \left[\frac{kWh}{year}\right] = 248 \ [MWh/year] \quad (4)$$

$$Price_{year} = E_{year} \cdot kWh_{price} = 248 \cdot 114.84 = 28{,}480 \ [Euro] \quad (5)$$

4. Conclusions

For the compression of a gas flow of 30,000 Nm3/day (about 0.249 kg/s), having the suction pressure and the other parameters unchanged, and for ensuring the oil flow necessary for its injection in the compressor without the need to have the discharge pressure above 4.5 bar, adding a 4 kW lubrication pump is a viable solution and ensures a reduction of the electricity power rate with approximately 30 kW, according to the calculations performed.

The present paper shows how a gas compression skid using an oil-injected screw compressor was upgraded after 80,000 hours function. In addition to the constructive modifications of the skid to comply with the current standards in the oil and gas industry and the health and safety requirements, the aim was to optimize the energy consumption of the entire assembly. This goal was achieved by adopting a lubrication system equipped with a geared pump with magnetic coupling. Also, the paper presents the estimated calculation of the power consumed by the compressor with and without the modernized lubrication system.

After a simple calculation, the estimated energy savings represented in euro is approximately 28,480 euro/year/compressor skid improved. The return of investment done by the modifications is approximately two years, and for 2 modified compressor skids, we will have approx. 60,000 euro/year saved by energy improvement investigations.

R E F E R E N C E S

[1] *V. Teleaba, M. Crețu, R. Mirea*, „Lubrication Optimization of a Screw Compressor Used for Natural Gas,", TURBO, vol. **IV** (2017), no. 1

[2] *M. Cretu, R. Mirea*, „The Influence of Natural Gas Composition on Screw Compressor Oil,", TURBO, vol. **V** (2018), no. 2.

[3] *M. Nitulescu, V. Silivestru, N. Toma, C. Slujitoru, V. Petrescu, A. Serban, I. Malael*, „Design, measurements and performance calculation of a high pressure screw compressor", International Conference on Compressors and their Systems, London, Great Britain, 2017.

[3] *V. Petrescu, C. Slujitoru*, „Development of a Screw Compressors Family with Oil Injection, for High Discharge Pressure (45 bara),” 6th CEAS Air & Space Conference Aerospace Europe, - Young Persons Poster Presentation - Bukarest, Romania (2017)

[4] *M. Niţulescu, C. Slujitoru, V. Petrescu*, „Case Study regarding the test of the new screw compressor with high delivery pressure - 45 bara - on the test bench (with air),”, INCAS Bulletin 4(4):151-159, DOI: 10.13111/2066-8201.2012.4.4.14.

[5] *V. Silivestru, D. Ifrim*, „COMOTI asigură dezvoltarea competitivă a compresoarelor cu şurub pentru gaze naturale,”, (“COMOTI ensures the competitive development of screw compressors for natural gas”), Revista (Magazine) - Market Watch Nr. 143/ 15.03-15.04.2012.

[6] *V. Silivestru, Gh. Fetea, S. Tomescu*, “Instalatie de comprimare gaz natural pentru alimentarea Statiei Cogenerative Suplacu de Barcau,”, (“Natural gas compression installation for supplying the Suplacu de Barcau Cogeneration Station”), Revista (Magazine) - Market Watch Nr. 143/ 15.03-15.04.2012.

[7] *A. Mitru, C. Dumitru, R. Iorga*, “Solutions for Antiex Protection Intended on a Full Automation Encased Screw Compressor,”, International Symposium on Occupational Health and Safety - SESAM 2015, 7th edition.

[8] https://www.omvpetrom.com/services/downloads/00/omvpetrom.com/1522151985716/Oferta_standard.pdf

[9] https://www.anre.ro/download.php?f=fq99gQ%3D%3D&t=vdeyut7dlcecrLbbvbY%3D