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OPERATION OF THE COMPRESSED AIR PRODUCTION INSTALLATION WITH VARIABLE AIR CONSUMPTION[**]

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Abstract

This paper presents an analysis of operation the compressed air production installation under the given operating conditions on an example of conceptual solution for the process air supply to a filter press of the Filtration Facility in the Copper Mine Majdanpek. Calculation was made using an analytical method for the installation operation with variable air consumption. Also, this paper presents a layout of technological scheme of the process air supply to the filter press, as well as the technical characteristics of compressed air production installation.

Keywords: *compressed air, filter press, technical characteristics*

1 INTRODUCTION

Purchase of a new filter press of type VPA 1540-24 was envisaged for the needs of reconstruction the Filtration Facility in the Copper Mine Majdanpek in 2017. It is necessary to provide the process and instrument compressed air for the filter press operation. The parameters of process and instrument compressed air are defined by the supplier of the filter press-Metso Company. This paper gives an analysis of operation the installation producing process air for the filter press operation. The required process air quality is 2.7.1 according to ISO 8573-1. The pressure and flow rate of process air are variable during the working cycle of the filter press and their values are given in Table 3.

2 TECHNICAL DESCRIPTIONS

The compressor station operation is analyzed in this paper for the filter press operation with the following equipment:

1. Compressor unit GA75+; made by Atlas Copco [1], [2]
2. Air receiver 10 RVH 15; made by MIP Process equipment [3]

The compressor unit is a stable oil injected rotary screw one-stage air-cooled compressor with electromotor drive GA75+ – 10 with integrated refrigerant dryer IFD and heat recovery unit ER. Technical characteristics of the compressor unit are given in Table 1.

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Table 1 *Technical characteristics of the compressor unit*

Manufacturer	Atlas Copco
Type	GA75+ – 10 WorkPlace Full-Feature (with ER unit)
Installed motor power	75 kW
Maximum working pressure	9.75 bars
Nominal working pressure	9.5 bars
Capacity FAD (1 bar; 20°C)	12.6 m^3/min
Noise level	68 db(A)
Compressed air outlet	G 2 ½ "
Dimensions (L x W x H)	2290x1080x1962 mm
Weight	1680 kg

The air receiver is made of a carbon steel sheet, as horizontal. The air receiver is equipped with all the necessary connections for compressed air inlet and outlet for the safety valve, pressure gauge, command air, condensate drainage and revision.

The air receiver is equipped with the following fittings: safety valve, manometer and shut-off valve for condensate drainage. Technical characteristics of the air receiver are given in Table 2.

Table 2 *Technical characteristics of the air receiver*

Manufacturer	MIP Process equipment
Type	10 RVH 15
Volume	15 m^3
Maximum working pressure allowed	10 bars
Length	6250 mm
Height	2145 mm
Diameter	Ø1800 mm
Compressed air connections	DN150
Weight	2900 kg

The refrigerant dryer IFD, integrated into a compressor unit, produces the pressure dew point of the compressed air of +3°C. The heat recovery unit ER enables the subsequent utilization of the waste heat of compressor that can be used for heating in the winter regime. To ensure the required compressed air quality between the compressor unit and air receiver, two lines with filters for compressed air DD+, PD+ and QD+ are provided, one of which is in operation and the other in reserve. An electronic water drain EWD is used for condensate removal. The compressed air is delivered from the air receiver, placed outside next to the compressor station, in the Filtration Facility by a steel pipeline Ø139.7x4 mm. Technological scheme of the process air supply for filter press is shown in Figure 1.

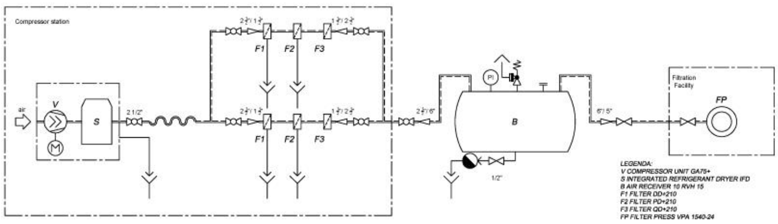

Figure 1 *Technological scheme of the process air supply for filter press*

3 CALCULATIONS

Calculation of the installation for compressed air production has for a purpose determination the process air parameters during the working cycle of a filter press and in particular the quantity of produced compressed air per unit of time defined by loaded and unloaded periods of compressor operation as well as the working pressure values in the compressed air installation. The calculation was done for the following operating conditions adopted:

1. Compressor in operation i.e., loaded ("switched on") compressor produces constant quantity of air per unit of time of $\dot{V}_c = 12{,}6 \left[\frac{m^3}{min}\right]$. This quantity of air per unit of time represents the volumetric flow rate for free air delivery conditions (FAD) and it corresponds to the mass air flow rate of $\dot{m}_c = 15{,}12 \left[\frac{kg}{min}\right]$ (for the air density of $\rho = 1{,}2 \left[\frac{kg}{m^3}\right]$).

2. When pressure in the air receiver rises up to the set value of the unloading pressure compressor switches to the mode of operation when it is unloaded ("switched off") and then there is no air output. The unloading pressure amounts $p_{isklj} = 9{,}2[bar]$.

3. When pressure in the air receiver drops down to the set value of the loading pressure compressor switches to the mode of operation when it is loaded ("switched on"). The loading pressure amounts $p_{uklj} = 8{,}2[bar]$.

4. Maximum pressure in the net is $p_{max} = 10[bar]$.

5. Minimum pressure during the working cycle in the net is $p_{min} = 7[bar]$.

6. Air temperature in the net is constant and amounts $t = 20[°C]$.

7. Volume of the pipeline is neglected, i.e., the volume of installation is equal to the volume of air receiver and amounts $V = 15[m^3]$.

8. All losses due to system leaks are ignored.

In Table 3, the required parameters of process air are given by the stages of one working cycle of the filter press according to [4] and [5].

Table 3 *Required parameters of process air*

Number	Stage of the cycle	Duration of the stage of the cycle	Air pressure at filter press downstream of the control valve	Minimum air volumetric flow rate	Maximum air volumetric flow rate	Average air volumetric flow rate	Air volume consumed in the stage of the cycle
	-	min	bars	Nm^3/min	Nm^3/min	Nm^3/min	Nm^3
1.	Filtration	1.90	-	0	0	0	0
2.	Compression	0.50	8	2	2	2	1
3.	Air blow	4.03	7	6	22	14	58
4.	Top blow (technical time -first part)	0.083	4	60	60	60	5
5.	Washing (technical time - second part)	0.083	-	0	0	0	0
6.	Top blow (technical time - third part)	0.083	4	60	60	60	5
7.	Technical time - fourth part	3.05	-	0	0	0	0

According to [4] the normal working conditions refer to the temperature of $t = 20[°C]$ and pressure of $p = 1{,}013[bar]$.

The following calculation formulas were used in the calculation:

1. $\rho_1 = \frac{p_{1aps}}{R_g \cdot T_1} \left[\frac{kg}{m^3}\right]$- air density at the beginning of respective stage of compressor operation

where:

$p_{1aps}[Pa]$- absolute air pressure at the beginning of respective stage of compressor operation

$R_g = 287 \left[\frac{J}{kg \cdot K}\right]$- individual gas constant for air

$T_1 = 293[K]$- absolute air temperature at the beginning of respective stage of compressor operation

2. $m_c = \dot{m}_c \cdot \tau_T[kg]$- air mass produced during the respective stage of compressor operation

where:

$\dot{m}_c = 15.12 \left[\frac{kg}{min}\right]$- air mass produced per unit of time during the respective stage of compressor operation

$\tau_T[min]$-duration of the respective stage of compressor operation

3. $m_p = \int_{\tau_1}^{\tau_2} \dot{m}_p d\tau \, [kg]$- air mass consumed during the respective stage of compressor operation

where:

$\dot{m}_p = \dot{m}_p(\tau) \left[\frac{kg}{min}\right]$-air mass consumed per unit of time during the respective stage of compressor operation

$\tau_1[min], \tau_2[min]$-time of the beginning and the end of the respective stage of compressor operation

4. $\Delta m = m_c - m_p[kg]$- difference between produced and consumed mass of air during the respective stage of compressor operation

5. $\rho_2 = \frac{\rho_1 \cdot V + \Delta m}{V} \left[\frac{kg}{m^3}\right]$-air density at the end of the respective stage of compressor operation

where:

$V = 15[m^3]$-volume of the air receiver

6. $p_{2aps} = \rho_2 \cdot R_g \cdot T_2[Pa]$- absolute air pressure at the end of respective stage of compressor operation

where:

$T_2 = 293[K]$-absolute air temperature at the end of the respective stage of compressor operation

Using the formulas from 1. to 6. and taking into account the compressor loading and unloading pressures, a compressed air production diagram can be determined, i.e., the periods of loaded and unloaded compressor operation as well as the working pressures in the installation during one working cycle of the filter press.

The results of analysis are given on diagrams in Figure 2.

4 DISCUSSIONS OF CALCULATION

When sizing a compressor to work with variable air consumption, there is an option of selecting a compressor with a lower capacity than the maximum air consumption, since in periods when air consumption is higher than production, the required amount of air is provided from the air receiver. If the air consumption in relation to time is known it is possible to determine both the required compressor capacity and required air receiver volume meeting the required air parameters during the working cycle.

In this example, the consumption of process air as well as the required process air pressure during the working cycle are determined by the technological requirements (see Table 3). During the first stage of the working cycle (filtration) there is no air consumption, the pressure in the installation is equal to the unloading pressure of 9.2 bar and the compressor is switched off. During the second stage of the working cycle (compression) the air consumption is constant and amounts 2.4 kg/min and pressure at the filter press is 8 bar.

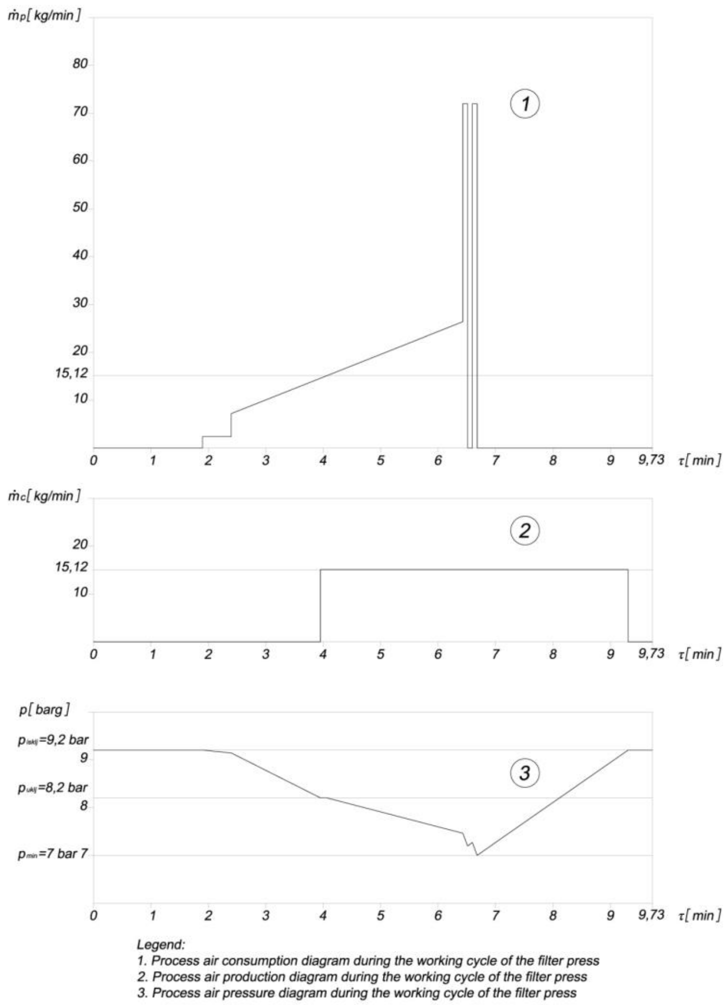

Figure 2 *Process air parameters during the working cycle of filter press*

At the same time the compressor is switched off so the pressure in the installation drops to 9.14 bar. During the third stage (air blow) air consumption changes from the minimum which amounts 7.2 kg/min to the maximum which amounts 26.4 kg/min and pressure at the filter press is 7 bars. At this stage, during the 93.1 sec time with the compressor switched off, the pressure drops to 8.2 bar. After that, with the compressor switched on for a period of 6.6 sec the pressure remains approximately the same since the air production is approximately equal to the consumption. Finally, at the end of the third stage for a period of 142.1 sec with compressor switched on, the pressure drops to 7.46 bar due to the fact that the air consumption is higher than production. The remaining working cycle time is technical time. During the first part of the technical time for a period of 5 sec top blow is carried out with the air consumption of 72 kg/min and pressure at the filter press is 4 bar. The pressure drops to 7.197 bar. At the second part of the technical time, for 5 seconds, washing is performed and there is no air consumption, so the pressure increases to 7.266 bar as the compressor is switched on. The third part of the technical time has the same parameters as the first part of the technical time and, at the end of it, the pressure drops to 7 bar. At the fourth part of the technical time, there is no air consumption, so that at first for a period of 157.6 sec the pressure rises to the unloading pressure of 9.2 bar, and pressure remains the same. The compressor is switched on 55% of working cycle duration of the filter press. The total cycle time of the filter press is 9.73 min. At no time, the pressure in the installation does not fall below the minimum pressure value for the respective stage in the working cycle of filter press. The scenario analyzed here is the most unfavorable case i.e., the case when the lowest pressure in installation is achieved, because at the moment when the system goes into a part of diagram where the consumption is higher than production (243.7 sec from the beginning of cycle) the pressure in the installation is equal to the loading pressure of 8.2 bar. In the next part of the cycle, the pressure can only fall because the air production is less than consumption and at one point it reaches a minimum value. The minimum value of the pressure in installation for the entire working cycle is at the end of stage 6 according to Table 3 (top blow - the third part of the technical time). However, after that begins the stage when there is no air consumption and when there is enough time for pressure in installation to rise to the unloading pressure of compressor before beginning the next stage when the cycle repeats.

5 CONCLUSION

The exposed methodology of calculating the operation of installation for compressed air production with variable air consumption represents an analytical method for determining the operating parameters of compressed air under given operating conditions. When choosing a compressor beside the capacity, the other parameters are taken into account, such as the loaded and unloaded period of compressor operation, achievement of the required air quality, possibility of cooling and utilization of waste heat. When determining the capacity, the addition for losses, reserve for additional consumers and addition due to the calculation errors, are also taken into consideration [6]. In this case, the air receiver is selected according to the requirement that system works without unallowable pressure drops during the consumption spikes, realizing all the other functions that an air receiver has in the compressed air installations. The most optimum solution is found analyzing various variants from which one variant is represented in this paper. Compressor and air receiver are important but not the only equipment in the compressor station. More detailed considerations of the design of compressor stations in Flotation plants are given in the paper [7].

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