ETM0002

Energy saving Measures for Air Compressor: A Case study for Plastic Bottle Manufacturer

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Abstract

The operating of a compressor gently affects the cost of compressed air. A compressor consumes more power at higher pressures .This higher pressures leads to excessive wear and increasing air leak in the system. Heat generated by operating compressor continuously, dissipates to compressor room leading to hot air intake. This results in higher energy consumption. The volumetric efficiency of a compressor is also less at higher delivery pressures and higher inlet air intake. The objective of this research is to finding the energy saving measures for air compressors in the plastic bottle manufacturer. The electric energy consumption of compressed air system for this manufacturer was 1,632,986 kWh/year in 2014. which is considered as a large amount. The research is carried out by analyzing theoretically the energy saving measures then applied to the manufacturer. The data were measured at the compressor room consisting of compressor room temperature, ambient air temperature, compressor pressure setting, storage air tank pressure and electrical energy consumption, for automatic load control of a multiple compressors both using typical electric sequence control and microprocessor control. Four energy saving measures were recommended as a guideline as followings: 1) The inlet air temperature to the compressor is not higher than the ambient air temperature by 3 ^{o}C resulting in energy saving of 1.2 % 2) The storage tank air pressure is not higher than the equipment required pressure by 1 bar resulting in energy saving of 8.4 % 3) The pressure drop across inlet air filter is not higher than 2.5 kPa resulting in energy saving of 1.6 % 4) For multiple compressors, The electric sequence control is replaced by the microprocessor control resulting in energy saving of 10.8 %

***Keywords**:* Compressor, Energy saving, compressor control

Introduction

The running cost of a compressed air system is higher than the cost of a compressor itself. Energy savings from system improvements can range from 20 to 50 percent of electricity consumption as shown in figure 1.

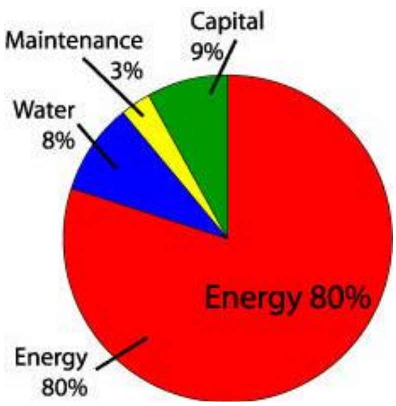

Figure 1 Cost components in a typical compressed air system [1]

A properly managed compressed air system can save energy, reduce maintenance, decrease downtime, increase production throughput, and improve product quality. The Compressed air system consists of following major components: Intake air filters, inter-stage coolers, after-coolers, air-dryers, moisture drain traps, receivers, piping network, filters, regulators and lubricators as shown in figure 2.

The operating of a compressor gently affects the cost of compressed air. A compressor consumes more power at higher pressures .This higher pressures leads to excessive wear and increasing air leak in the system. The hot air intake to a compressor also results in higher energy consumption. The compressor generates heat dissipated to compressor room leading to hot air intake. The volumetric efficiency of a compressor is also less at higher delivery pressures and higher inlet air intake. Moreover, in the multiple compressor system, the automatic

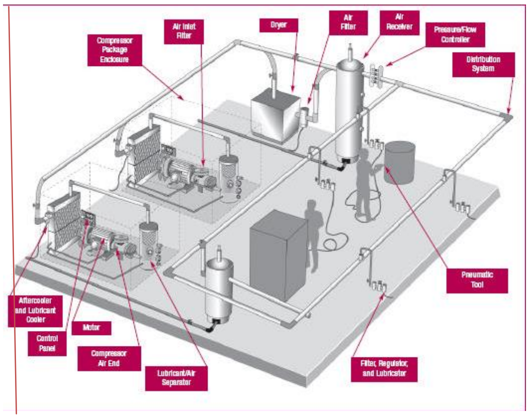

Figure 2. Compressed air system (US DOE)

process load control will reduced the delivery air pressure to the optimum value. The objective of this research is to finding the energy saving measures for air compressors in the plastic bottle manufacturer.

Compressor Performance

The ideal PV diagram of the reciprocating compressor as shown in figure 3. Starting with air was compressed from a pressure P_1 to pressure P_2, discharged from P_2 to P_3, expanded from P_3 to P_4, and suctioned from P_4 to P_1 to complete the ideal compressor cycle.

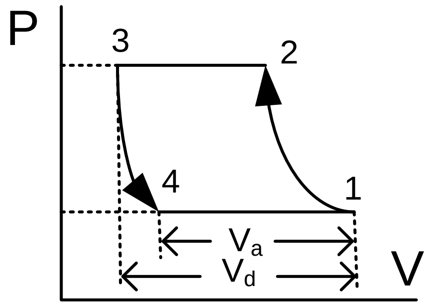

Figure 3 PV diagram of compressor with clearance

The isentropic work can be obtained from equation (1)

$$W_{isen} = \frac{kP_1V_a}{(1-k)}[(\frac{P_2}{P_1})^{\frac{k-1}{k}} - 1] = \frac{km_aRT_1}{(1-k)}[(\frac{P_2}{P_1})^{\frac{k-1}{k}} - 1] \quad \cdots (1)$$

Where

W_{isen} - isentropic work, J
k - specific heat ratio
P_1 - inlet pressure, Pa
P_2 - discharge pressure, Pa
m_a - actual delivery mass, kg
V_a - actual delivery volume, m^3
V_d - displacement volume, m^3
R - universal gas constant, J/kg.K
T_1 - inlet temperature, K

The isentropic work is the minimum theoretical work. The actual exit temperature is also higher than the isentropic exit temperature due to the irreversible process. The isentropic work is increases with pressure ratio and inlet temperature.

The isentropic efficiency can be obtained from equation (2)

$$\eta_o = W_{isen} / W_{shaft} \quad \ldots (2)$$

Where
W_{shaft} - actual mechanical shaft work
The isentropic efficiency is usually used to compare the performance of the compressors.

The volume air flow rate in the pipe line varies with temperature and pressure due to its compressibility while the mass air flow rate is constant along the pipe line. However, The volume air flow rate is usually used in practice by converting to standard temperature, T_s and pressure, P_s at 20 ^oC and 101.3 kPa respectively. The standard volume air flow rate is obtained from equation (3)

$$Q_s = Q.\frac{P}{P_s}.\frac{T_s}{T} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where
Q – actual air flow rate, m^3/h
Q_s - standard volume air flow rate, Nm^3/h

The performance index is defined as specific power which is the ratio of the electric power and the standard air flow rate as in equation (4)

$$P_s = P/Q_s \quad \ldots (4)$$

Where
P_s - specific power, kW/m^3/h
P - electric power, kW

The volumetric efficiency of a reciprocating compressor with clearance volume can be obtained from equation (5)

$$\eta_V = \frac{V_a}{V_d} = 1 + c - c(\frac{P_2}{P_1})^{\frac{1}{k}} \quad \ldots. \quad (5)$$

Where
V_a - actual air volume, m^3
V_d - piston displacement volume, m^3
C - clearance volume ratio

The higher the compression ratio the lower the air volume flow rate.

Automatic Load Control

The typical automatic load control for multiple compressor system is electric sequence control. The control action is two positions or ON/OFF. When the delivery air flow rate from the storage tank increases, the delivery pressure is decreases. When this pressure is below the low pressure setting at the controller, the compressor is turned off and turned on again when the delivery pressure is above the high pressure setting. The difference between the high and low pressure setting, ΔP_1 is called a dead band or differential of the controller. Each compressor has its own pressure controller and set point, SP as shown in the figure 4.

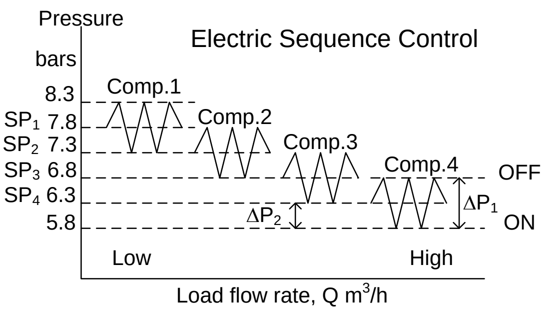

Figure 4 The electric sequence control

At low load demand only compressor 1 is run at set point SP_1 while at high load demand all four compressors are run. Between each step, there is a difference pressure, ΔP_2 to prevent all compressors run on and off at the same time. Thus, the operating system pressure is between 5.8 and 8.3 bars which is high above the required pressure to operate the machines. When the load flow rate is low, only compressor No.1 is turned on and off between pressure of 7.3 and 8.3 bars. When the load flow rate is high, compressor No.1 to compressor No.3 are turned on and compressor No.4 is turned on and off between between pressure of 5.8 and 6.8 bars. Thus the compressor efficiency at low load is lower than the efficiency at high load. When the microprocessor control is used, there is the pressure transmitter that sent the signal to the controller and this signal comparing with a set point. When there is an error the controller sends the corrected command to turn on or turn off the compressors depending on the load. The run compressors may sequence in by rotating or by priority with first on and last off. The differential is 0.5 bars as shown in figure 5. Thus the system pressure is lower than the electric sequence control.

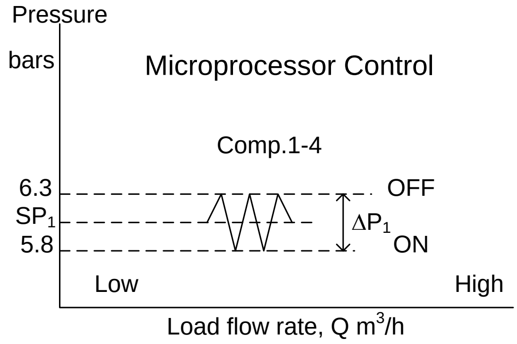

Figure 5 The microprocessor control

Data acquisition

The data were taken at the compressor room in the plastic bottle manufacturer. The inlet air temperature, ambient air temperature pressure setting, storage air tank pressure and electrical energy consumption were measured for a multiple compressors using both typical electric sequence control and microprocessor control.

Energy saving measures

The electric energy consumption of compressed air system for this manufacturer was 1,632,986 kWh/year in 2014. which is considered as a large amount. For the purpose of comparison, the operating condition of compressor were the ambient temperature, the inlet pressure, the outlet pressure were 38.3^{o}C, 1 bars, and 8 bars respectively. The compressor clearance ratio was 0.05. The specific heat ratio and universal gas constant were 1.4 and 287 kJ/kg.K respectively.

The first energy saving measure is reducing the inlet air temperature. The inlet air temperature to the compressor is not higher than the ambient air temperature by 3 ^{o}C. For inlet air temperature was 33.7 ^{o}C the W_{isen} was equal to 254 kJ/kg. while the ambient air was 38.3 ^{o}C the W_{isen} was equal to 251 kJ/kg. Thus W_{isen} was reduced by 3 kJ/kg or 1.2 % for decreasing inlet air temperature by 3^{o}C. this measure can be done by increasing the room ventilation rate.

The second energy saving measure is reducing the storage tank or delivery pressure. The storage tank air pressure is not higher than the equipment required pressure by 1 bar. For example, the air pressure ratio before and after were 8 and 7 bars respectively. W_{isen} were equal to 254 and 232.7 kJ/kg. respectively. Thus W_{isen}

was reduced by 21.3 kJ/kg or 8.4 % for decreasing pressure of 1 bar.

The third energy saving measure is cleaning inlet air filter. The pressure drop across inlet air filter is not higher than 2.5 kPa. For example, the pressure drop before and after were 5 and 2.5 bars respectively. W_{isen} was equal to 246.7 and 242.7 kJ/kg. respectively. Thus W_{isen} was reduced by 4 kJ/kg or 1.6 %

The fourth energy saving measure is using microprocessor control. The electric sequence control is replaced by the microprocessor control. The actual data were measured for two weeks at the plastic bottle manufacturer. For the electric sequence control, the average pressure, the energy consumption, and the specific power were 7.65 bars, 686,677 kWh/yr, and 7.39 kW/Nm^3/min. respectively. For the microprocessor control, the average pressure, the energy consumption, and the specific power were 7.08 bars, 612,218 kWh/yr, and 6.86 kW/Nm^3/min. respectively. Thus the energy saving was 74,459 kWh/yr or 10.8 %.While the specific power was reduced from 7.39 to 6.86 kW/Nm^3/min, or 7.2 % as shown in table 1

Table 1 A comparison of electric and microprocessor control

List	Electric	Microproc.	Difference
Average Pressure, bar	7.65	7.08	0.57
Energy consumption kWh/yr.	686,677	612,218	74,459 (10.8%)
Specific Power kW/Nm^3/min	7.39	6.86	0.53 (7.2%)

Conclusion

The Compressors should be operated efficiently by using the energy saving measures as followings.

1. The inlet air temperature to the compressor is not higher than the ambient air temperature by 3 °C resulting in energy saving of 1.2 %

2. The storage tank air pressure is not higher than the equipment required pressure by 1 bar resulting in energy saving of 8.4 %

3. The pressure drop across inlet air filter is not higher than 2.5 kPa resulting in energy saving of 1.6 %

4. For multiple compressors, The electric sequence control is replaced by the microprocessor control resulting in energy saving of 10.8 %

For the plastic bottle manufacturer, energy saving measures number 2 to 4 had already been implemented.

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