COMPRESSED AIR ENERGY THROUGH MAINTENANCE AND RELIABILITY
Opportunity Series Part 1

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Abstract

Compressed air systems can be the lifeblood of many types of production systems. However, the use of compressed air comes with significant energy costs in even a well-maintained system. When systems are not well-maintained the costs increase significantly. In this paper we will discuss the impact of maintenance related issues associated with compressed air and methods of verifying the impact through proper maintenance practices.

Introduction

Compressed air systems are an important part of most plant operations, but can be the most inefficient source of energy in a plant. To operate a one horsepower air motor, you generally need seven to eight horsepower of electrical power into the compressor in a well-maintained system. At higher than typical pressures, even more power is needed.

The overall efficiency of a typical compressed air system can be as low as 10-15%. For instance, annual energy costs for a one horsepower air motor versus a one horsepower electric motor, five days per week, two shift operation, $0.05/kWh would be $1,164 for compressed air versus $194 for the electric motor.

Leaks and other maintenance-related issues can have a more serious impact on the energy performance of a facility. A typical plant that has not been well maintained will likely have a leak rate in excess of 20% of the total compressed air production capacity. Proactive leak detection and repair can reduce leaks to less than 10% of compressor output.

In addition to being a source of wasted energy, leaks can also contribute to other operating losses. Leaks cause a drop in system pressure, which can make air tools and other equipment function less efficiently, adversely affecting production. By forcing the equipment to cycle more frequently, leaks shorten the life of almost all system equipment including the compressor package itself. Increased running time also leads to additional maintenance requirements and increased unscheduled downtime, in addition to unnecessary increased compressor capacity.

Since air leaks are almost impossible to see, other means must be used to locate them. The best way to detect leaks is to use an air born ultrasonic detector, which can recognize the high frequency hissing sounds associated with air leaks. These portable units consist of directional microphones, amplifiers, and audio filters, and usually have either visual indicators or earphones to detect leaks. Another simple method, but more time consuming, is to apply soapy water with a paint brush in areas being inspected. Additional methods include smoke sticks, candles, foam, manometers and stethoscopes.

For confirmation of impact, technologies such as Electrical Signature Analysis can be used to measure reductions in consumption in addition to the identification of defects within the compressed air system itself.

Case Study Plant: Corn Miller

In 1999, the author headed up the University of Illinois' Energy Resources Center (UIC-ERC) food processing survey which included a corn miller in central Illinois. During the survey of the facility, several common issues were determined including:

- Air pressure drop from 110 psi to 45 psi in the packaging plant;
- Air leaks in the fungi and cooking plant;
- Open blow-off valve in one high pressure (150 psi) filter; and,
- Long lengths of flexible air hose and air hoses in poor condition.

In this paper we will discuss the impacts and measurements associated with these conditions.

Packaging Plant Pressure Drop

There were a number of issues identified within the compressed air system at the starch and gluten plant. These issues included: an air pressure drop from 110 psi to 45 psi from the compressors to the end of the packaging line measured at the air regulators; the compressors did not have an opportunity to unload; compressed air is also used for the bag houses; and, the need for a compressed air strategy.

There were two 150 horsepower electric motors running in two Sullair air compressors located in the starch and gluten packaging plant. During the course of the study, these were monitored and found to operate at 90kW for a Siemens motor (AC702) and 130kW for a Lincoln motor (AC701). The Siemens motor was found to be 73.8% loaded and the Lincoln motor was 106.7% loaded. Both compressors remained online for the 48 hours of monitoring and the system was found not to unload. Total input power of the compressed air system was found to be 220kW. Due to pressure drops and air demand, the corn milling plant planned to install an additional air compressor.

Through a basic walk-through of the compressed air system, several areas were identified: a complete understanding of the demand side of the compressed air system was not readily identifiable; the bag house air lines were not found and traced for air leaks; and there was a significant pressure drop across the packaging line from 100 psi to 45 psi. For the purposes of this paper, the compressed air opportunities will focus on the packaging line with general recommendations for the remaining compressed air system.

The identification of challenges on the packaging line was through the identification in the pressure drop. A general walkdown of the packaging line identified a number of audible air leaks that could be felt and heard. The pressure drop had the following estimated impact:

Equation 1: System Air Pressure Drop

$$P_{pfl} = P_{pfl} * (0.5\% * pressure\ drop)$$

*= 220kW * (0.5%*55PSI)*

= 60.5 kW

Based on a 0.5% change in demand for every psi, the power required to maintain the pressure drop is 60.5 kW (81hp), which is 27.5% of the compressor load. The pressure drop was found to be a combination of pneumatic controls for the packaging line and air leaks. A system for correcting the existing air leaks went a long way towards correcting the losses on the packaging line. The 60.5 kW potential with the following opportunity assuming a $0.10/kWh and $10/kW demand across 6000 hours per year operation and 95% efficient motors:

Equation 2: Energy Cost Savings (consumption)

$Savings = kW * $/kWhr * hours
= 60.5kW * $0.10 * 6000
= $36,300/year

Equation 3: Energy Cost Savings (demand)

$Savings = kW * $/kW * 12
= 60.5kW * $10 * $12
= $7,260/year

The total potential savings is $43,560 of the actual cost of use based upon measured motor input of 220kW which is $158,000 per year, or a potential reduction of 28% of the operating costs and the elimination of the need for a third compressor.

One of the first issues discovered were failed compressed air system gaskets in the lines. One air leak at the compressor end of the production line was estimated at being a 3/8-inch leak. Other leaks through the system were quickly found audibly. Equation 4 – 5 relate to the losses due to the size of an air leak. Note that there are some online calculators and charts that can be referenced.

Equation 4: CFM Loss from a 3/8-inch Air Leak

$$V_f = \frac{NL * (T_1 + 460) * {}^{P_1}/_{P_i} * C_4 * C_5 * C_d * ({}^{pD^2}/_4)}{C_6 * \sqrt{T_1 + 460}}$$

$$V_f = \frac{1 * (90 + 460) * {}^{50}/_{14.7} * 28.37 * 60 * ({}^{3.146 * 0.375^2}/_4)}{144 * \sqrt{80 + 460}}$$

= 105.25 CFM

Equation 5: Power Loss Conversion from CFM

$$L = \frac{P_1 * C_6 * V_f * \left(k/_{k-1}\right) * N * C_7 * \left(\left(P_0/_{P_1}\right)^{\frac{k-1}{k*N}} - 1\right)}{E_z * E_m}$$

= 24.3hp * 0.746 kW/hp = 18.1 kW

When applied to Equations 2 and 3, the air leak relates to a cost of $13,032/year.

Table 1: Air Leak Formulae Definitions

Symbol	Definition
V_f	Volumetric flow rate of air (CFM)
NL	Number of leaks, no units
T_1	Temperature of air at inlet in F
P_1	Line pressure at leak in question, psi
C_4	Constant = 28.37 ft/sec
C_5	Conversion constant, 60 sec/min
D	Leak diameter in inches
C_6	Conversion constant, 144sqin/sqft
T_1	Average line temperature
L	Power loss due to air leak in hp
K	Specific heat ratio of air, 1.4, no units
N	Number of stages, no units
C_7	Constant, 3.03x 10^{-5} hp-min/ftlb
P_0	Compressor operating pressure, psi
E_a	0.88 for single stage recip compressors
E_a	0.75 for multi-stage recip compressors
E_a	0.82 for rotary screw compressors
E_a	0.72 for sliding vane compressors
E_a	0.80 for single stage cent. compressors
E_a	0.70 for multi-stage cent compressors
E_a	0.70 for turbo blowers
E_a	0.62 for roots blowers
E_m	Compressor motor efficiency

Additional measures could be implemented before adding compressor capacity including:

- Increase the capacity of the receiver. This would allow the compressors to load and unload (cycle) improving overall compressor system life;
- Balance the load on the two compressors. AC701 was 107% loaded and AC702 was 74% loaded. By balancing the load on the two compressors, the life of the motor and compressor components on AC701 will increase;
- Install surge tanks near the bag houses that are served by the compressor system. This also reduced the load on the compressor system as well as improved the system line pressure. Without the surge tanks in place air line pressure losses come into play based upon the air line size and distance, reducing the effectiveness and pressure of air to the baghouses.

Air Leaks at the Fungi and Cooking Plant

During the survey of the fungi and cooking plants, it was determined that there were two audible minor and one major air leaks within the compressed air system without the use of an ultrasound leak detector. The first air leak was identified at the bottom end of one of the fungi tanks and represented an ~0.25-inch opening. Using the formulae from this article, this leak put out 140.33 cfm resulting in a 30kW demand and represented $21,600 per year. The second air leak was found to be the same and the noise required hearing protection to approach them.

Throughout the course of the study at the corn miller, it was difficult to enter an area immediately below and near the fungi tanks due to excessive noise. During a second phase study, the cause of the noise was identified and determined to be a large separator following a heat exchanger and before the drier on the high pressure line (150 psi). Based upon the size of the piping, the amount of air, and the position of an open blow-off valve, this opening was conservatively determined to be 0.5 inches at 150 psi. Using the previous formulae, 561 cfm was being lost, accounting for 120 kW demand lost due to the open valve. The total cost using the numbers in this article is estimated at $86,400. The primary recommendation for this opportunity was to install an automatic blow-off valve.

Additional Recommendations

Throughout the course of the site study additional leaks and opportunities were identified. Following are a few additional recommendations for improving the compressed air system:

- Reduce long lengths of flexible compressed air hose. Such areas as the alcohol storage tanks, as well as a number of production areas, had long lengths of flexible compressed air hose. Pressure drops within hose will be significant and can be avoided through: running permanent air lines to equipment that requires compressed air; and, putting surge tanks near equipment that requires a great deal of compressed air in order to off-set additional line losses;
- Replace manual blow-off valves on compressed air filters and separators with automatic blow-off valves. This reduces maintenance requirements and ensures

that blow-off valves are not maintained in the open position; and,

- Establish a compressed air strategy to include a compressed air maintenance and inspection strategy.

Compressed Air Maintenance and Inspection Strategy

A basic compressed air strategy consists of the following points:

- Storage requirements
    - Make sure that primary storage is adequate
    - Consider strategic secondary storage for some applications (surge tanks)
- Appropriate uses
    - Evaluate each major class of compressed air end-use
    - Check end uses against inappropriate uses
- Controls
    - Periodically work with your equipment service provider to adjust individual compressor controls
    - For systems with multiple compressors, use controls to orchestrate the compressors (sequence)
    - Consider flow controllers
- Leaks
    - Get the equipment necessary to find leaks
    - Start looking in the right places
    - Learn how to repair leaks
    - Establish a leak prevention program
- Maintenance
    - Follow the maintenance guidelines for the compressor and include the compressor system in your RCM development
    - Develop a scheduled or condition-based maintenance program surrounding the compressed air system

When reviewing potential compressed air opportunities:

- Develop then review a block diagram of the system
- Develop and review system pressure profiles. Remember the nameplate horsepower is not always the true power consumption. Pressure drops across components are important in developing loss and possible opportunities for improvement
- Develop and review the demand flow profile. If possible, flows should be measured, if not economically or physically feasible, use manufacturers equipment rating, or best estimate using compressor loading when equipment is in service.

Conclusion

The relationship between reliability, maintenance and production effectiveness cannot be overstated. In this article we provided several examples of the impact of poor compressed air maintenance practices on the energy costs of a corn milling facility. These were estimated numbers and the actual before and after measurements through implementation were found to be very close. For instance, on the open 150 psi blow-off valve, the valve was closed while inspectors watched kW meters located at the co-generation facility.

While the actual energy cost numbers for the facility are not represented in this article, real numbers for consumption and demand will result in significant impact, in particular with compressed air systems. In fact, in many facilities, even the silent air leaks can justify a majority of an air leak program, including instruments and personnel.

Bio

Howard W Penrose, Ph.D., CMRP is the president of MotorDoc® LLC, a registered Veteran Owned field service and consulting company. He received 5 UAW-GM People Make Quality Happen Awards for reliability, maintenance and energy programs as a consultant for the UAW-GM joint task teams on facilities maintenance. The program implementation of the maintenance to energy programs were based upon his dissertation which was completed during his time as the senior research engineer at the University of Illinois' Energy Resources Center (UIC-ERC, 1997-1999)/Adjunct Professor, Industrial Engineering, ME Dept, and completed through Kennedy-Western University (General/Industrial Engineering) in 2000. Dr. Penrose has been involved in the design and implementation of alternative energy systems, specialty motor design for vacuum applications, and the General Motors hybrid Tahoe and Volt machines (2007-2009) and John Deere 644 and 944 hybrid construction tractors. He is a Certified Maintenance and Reliability Professional (CMRP) and the 2018 chair of SMRP. He can be contacted at info@motordoc.com.

Reference

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