Applications of AIRMaster+ in Real Industrial Facilities

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ABSTRACT

The U.S. Department of Energy has been developing a suite of analytical tools to assess various technologies present in industrial facilities of which AIRMaster$^+$ is a fairly recent addition. AIRMaster$^+$ is a Windows-based software tool used to analyze industrial compressed air systems intended to enable users to model existing compressed air systems, evaluate system upgrades, and assess savings. The software provides a systematic approach to investigate inefficiencies in compressed air systems. The software itself is well documented and training programs are provided through the Department of Energy's Compressed Air Challenge Program.

This paper focuses on real world experiences and the overall process of applying the AIRMaster$^+$ analytical tool to actual industrial facilities and applications. We will outline the overall approach to obtain the necessary field data required as inputs to the software. This will include discussions of the data collection methodologies employed and the process of incorporating field data into the software to generate the compressed air assessments. This will include presentation of the processes required to establish the supply and demand side profiles and components of the systems, and how to develop scenarios for energy efficiency measures. Case study of an actual facility will be incorporated to provide clarity in discussing the process. Advantages and limitations of the software will be clearly described. The overall objective of the paper is to provide experiential perspectives on the application of the AIRMaster+ software in industrial facilities, and to discuss the associated benefits and potential enhancements of this powerful tool.

Introduction

In the U.S., compressed air systems account for approximately 90 billion kWh per year, which translates into $1.5 billion per year in energy costs. Compressed air systems account for ten percent of all electricity and roughly sixteen percent of U.S. industrial motor system energy use. Seventy percent of all manufacturing facilities in the United States use compressed air to drive a variety of equipment. It is likely that many of the industrial plant air systems have large energy savings potential with relatively low project costs. In small to medium-sized industrial facilities, approximately 15 percent of compressed air system usage can be saved with simple paybacks and in larger facilities these savings could range from 30 to 60 percent of current system usage. In addition to energy benefits, optimized compressed air systems frequently offer corresponding improvements in system reliability, product quality, and overall productivity.

Many industries use compressed air systems as power sources for tools and equipment used for pressurizing, atomizing, agitating and mixing applications. Compressed air is considered industry's fourth utility, but is seldom considered as contributing to the cost of production. Most of the industrial facilities view compressed air as something that is free and readily available. However, on the contrary, generation of compressed air requires a huge amount of energy and is anything but free. Evaluation of compressed air systems requires a systems approach, with attention to match demand with the supply. Several issues tend to reduce the efficiency of compressed air even further, such as leaks, mismatched supply/demand, and inappropriate uses. This often results in wasted energy, poor reliability, reduced productivity, and higher operating costs. An efficient compressed air system can increase productivity and ensure better product quality.

To better understand the dynamics of compressed air system efficiencies, Department of Energy (DOE) provides funding for various efforts, one of which was to develop tools (AIRMaster$^+$) for analyzing industrial compressed air systems for system improvements and to assess the cost benefit of various efficiency measures. The DOE, under the Best Practices initiative of the Office of Industrial Technologies (OIT), provides an assortment of analytical tools, one of which is the AIRMaster$^+$, as well as training resources to help industrial end users achieve efficiency improvements and related cost savings. In addition, DOE provides the technical support for improving compressed air systems through the Compressed Air Challenge (CAC). The mission of the CAC is to develop and provide resources that educate industry on the opportunities to increase net profits through compressed air system optimization.

Compressed air systems inherently have poor overall efficiencies. Given this characteristic, it is important to match the supply of compressed air to the demand requirements in any given system. A compressed air system is comprised of the supply side (compressors, dryers, filters, drains and receivers) and the demand side (distribution piping, pneumatic equipment and related enduse, blow offs, leaks etc.). As an industrial facility grows or shrinks, the balance between the supply and the demand side also changes, potentially resulting in greater inefficiencies. Therefore, in today's industrial facilities, a full understanding of the compressed air system is imperative to minimize inefficiencies in the system. A complete assessment of the compressed air system is helpful in achieving this understanding. A typical assessment is comprised of:

1. *Initial interviews* with plant staff to obtain basic operating parameters.
2. *Facility walk through* to observe the application of compressed air in different equipment, noting observations and collecting name plate data of the compressors and dryers and operating set points.
3. *Installation of data loggers* to monitor power draw, as well as flow and pressure if possible, for at least a one-week period to establish operating profiles.
4. *Detailed investigation* for potential areas identified for improvement to establish consumption and pressure data locally and to establish pressure drops at various locations in the distribution piping.
5. *Analytical assessment* of the compressed air system, such as with AIRMaster$^+$.
6. *Report generation* with energy efficiency recommendations.

As indicated above, a compressed air system assessment includes data collection and data analysis components. AIRMaster^{+} can be used in both the data collection and the analysis phase of a project assessment - this will be described in later sections of this paper. Some of the significant capabilities of AIRMaster^{+} software are listed below:

1. Analysis of multiple facilities and compressors can be conducted.
2. Simulation of existing and modified compressed air system operation, including compressor replacement (using actual compressor performance values or values of generic compressors from the database) and end use recommendations is possible.
3. Hourly-metered airflow or power data for each compressor and various day types can be input for analysis. Logged energy data can be input into the software to calculate airflow, or logged airflow can be used to calculate energy usage.
4. Modeling part load system operation for interconnected multiple-stage lubricant-free or lubricant-injected rotary screw, reciprocating, and centrifugal air compressors operating simultaneously with independent control strategies and independent operating schedules are possible.
5. Evaluation of energy savings potential from eight Energy Efficiency Measures (EEM) considering interactive effects of the EEMs is possible.
6. Life cycle analysis can be performed.

AIRMaster^{+} is a powerful tool for modeling "what if" scenarios for possible improvements to compressed air systems. It is intended to enable auditors to model existing and future improved system operation, and evaluate savings from energy efficiency measures. AIRMaster^{+} is not intended to replace an experienced auditor in the evaluation of a compressed air system.

AIRMaster^{+} Modules

This section discusses the various inputs for the first seven modules of AIRMaster^{+} that need to be collected during the site visit. Figure 1 below shows the main menu of AIRMaster^{+} upon starting the application.

Figure 1. Main Menu of AIRMaster^{+} Software

Input Screens

To develop an analysis that evaluates a compressed air system using AIRMaster$^+$, the user needs to follow a logical path for data input. The first seven modules depicted in the figure above are primarily used in the required order to establish the analytical model. The user would provide inputs sequentially into each module, moving to the next only after the previous module has been completed. In this fashion, the information collected by the auditor during the site visit is entered in the program modules to define the analyses. A brief description of each module is presented below.

Company. Information pertaining to the facility being audited such as name, industry type, SIC code, address and contact information are entered in this module.

Utility. Information about the utility company such as name, utility code, address, contact name and phone, and their associated rate schedules are entered in this module. Under the rate schedules, kW and kWh rates for two seasons can be entered, facilitating the use of seasonal or time-of-the-use rates.

Facility. Information in this module is similar to that entered in the Company module. However if the company has several facilities, then this module can be used to create a common database of the compressed air systems. This module contains the overall facility information and the utility assignments.

System. Information regarding the operation of the existing compressed air system(s), such as operating pressures, receiver storage capacities, sequencer types and corresponding set points, production day types and a list of end uses are entered in this module. The day types tab in the module helps simulate weekends or any abnormal production day from the remaining operating days. The end uses tab in the module can be used to create an inventory of the significant air users in the facility. This module is also useful for entering information for multiple compressor plants.

Compressor. The compressor module incorporates Nameplate, Controls, Performance and Totals tabs. The first three tabs are used to enter the performance and operating information for all the compressors in the facility, such as the full load operating pressure, full load SCFM rating, location, cooling fan size if applicable, unload points, unloading sump pressure, air inlet temperature, discharge pressure and power draw, etc. At the heart of AIRMaster$^+$ is a compressor catalog of generic compressors ranging from 1-3,500 HP capacities. The compressors available from the catalog are single and two-stage lubricant injected rotary screw, two-stage oil free rotary screw, single and two stage reciprocating and multiple stage centrifugal compressors. The compressor capacity control types available are inlet modulation with and without unloading, variable displacement with unloading, load/unload and start/stop. The compressors matching closest to the plant compressors are selected from the catalog and then modified to suit the plant operating conditions. The modified compressor information can be copied to the compressor catalog, and thus can be used for future use. Therefore, a powerful database of compressors from different manufacturers can be created for future use. Figure 2 below shows the compressor catalog form used to define and select the appropriate compressor from the AIRMaster+ database. It is very important during the site visit to cycle a compressor through various load points and measure the power and discharge pressure to use as inputs into AIRMaster+. The software then generates a performance curve based on the entered data that is used to calculate the power draw for the existing compressor. Figure 3 below shows a performance profile curve generated for a single-stage lubricated rotary screw compressor that has inlet modulation without unloading control.

Figure 2. Compressor Catalog Selection Menu

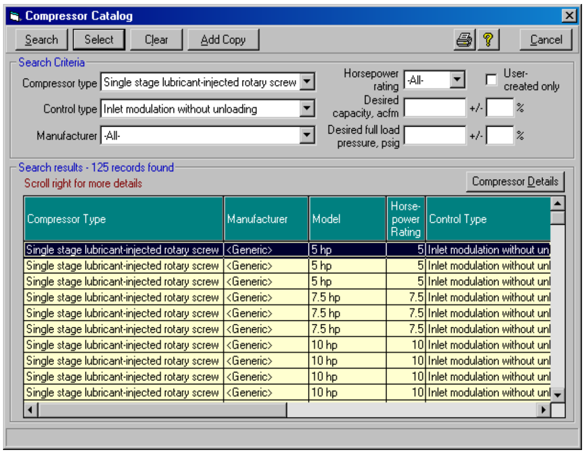
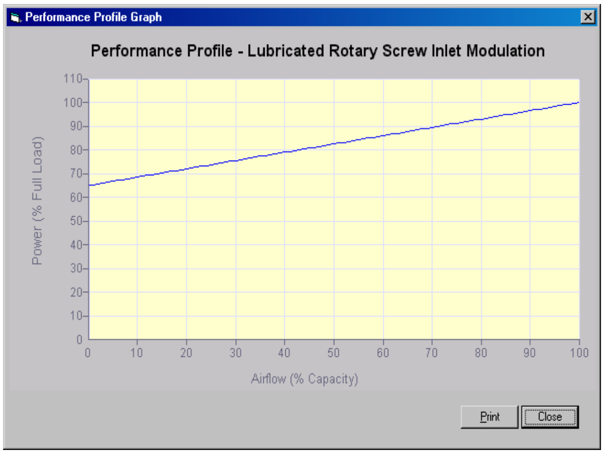


Figure 3. Compressor Performance Profile Curve



Profiles. The hourly input information in the profiles module for a given compressor can take any of the following forms: power (kW), airflow (% capacity), airflow (acfm), cycle time or volt/amps. Compressed air systems are dynamic systems and the ideal set of data would include simultaneous power, airflow and pressure readings to characterize a compressed air system. However, this is costly and is used only in longer duration studies involving higher capital costs. Monitoring power (kW) or current draw (Amps) is the most commonly used data logging technique.

Efficiency measures. At this stage of the analysis, the existing compressed air system has been characterized. Attention should be given to check the energy associated with the existing compressors. Based on site observations associated with inappropriate uses, leaks, set points and performance characteristics, the proposed system enhancements can be analyzed in the Energy Efficiency Measures module. The following measures can be analyzed using this module:

1	Reduce Air Leaks	5	Adjust Cascading Set Points
2	Improve End Use Efficiency	6	Use Automatic Sequencer
3	Reduce System Air Pressure	7	Reduce Run Time
4	Use Unloading Controls	8	Add Primary Receiver Volume

These measures can be assessed individually or interactively using this software. Each of these measures can be evaluated based on the auditor's observation of the existing system and plant operations. Proposed energy, airflow and dollars savings are quantified for each measure.

Maintenance. The Maintenance module can be used to keep track of the maintenance performed on the compressed air system. This option provides a single location to track maintenance activities, schedules and costs for the entire compressed air system.

Catalog. Catalog option of AIRMaster$^+$ can be used to view information for generic air compressors of various ratings. The modified compressors in the Compressor module can be added to the catalog to be used in future projects and analysis.

Life cycle. This module can be used to view financial calculations for a project, such as after-tax return on investment, net present value, and benefit to cost ratio.

Print data input forms. AIRMaster$^+$ has input forms for each module described above. The input forms can be modified for a project and then printed to collect information to be entered in the AIRMaster$^+$ modules. The data forms allow recording information in the format that can be easily entered in AIRMaster$^+$ modules.

Integrating AIRMaster$^+$ in an Industrial Assessment

As discussed earlier, a compressed air assessment involves several steps. This section describes the type of information, methods and equipment used to collect pertinent information during the site assessment, and how these procedures should be conducted in order to use AIRMaster$^+$ as an analysis tool for the assessment. It should be noted that AIRMaster$^+$ has a series of data collection forms that can be printed and taken to the site for use in recording system data.

- *Site Visit.* A scheduled time is arranged to meet with the facility staff for an initial walk through and interview. As a part of the interview process, information regarding the plant-operating schedule, utility rate schedule, production levels, required plant pressure, compressor and dryer information and types of compressed air end users is collected. This information is used as inputs for the *Company*, *Utility* and *Facility* modules.
- *Initial Walk Through.* Subsequently, a walk through the site is conducted starting with the compressor plant, where the compressor operating parameters like the discharge pressure(s), nameplate data and the operating pressure band(s) is recorded. As a part of the walk through, all the significant compressed end uses are visited and noted. Inappropriate end uses, such as open blowing, sparging, inefficient nozzles, vacuum generation is noted for further investigation. The distribution pipe sizes, receiver capacities and their locations are noted. This information forms the inputs for the *System* and *Compressor* modules.
- *Data Logging.* Next, data loggers to monitor power of the compressors and dryers are installed. The setup of data logging equipment is a potential area where special care needs to be taken to avoid errors because different compressors behave differently.

For example, the way an inlet modulation machine reacts to changes in loads is different than a load/unload compressor. These factors affect the selection of the data-sampling rate for monitoring. As a part of this process, compressor control strategies are determined before selecting the appropriate data-sampling rate. As a rule of thumb, a minimum of 3 data points per demand event provides a good snap shot of the system being monitored. A demand event would be the loading time or unloading time of a compressor. During the installation of the data loggers, the compressor operating parameters – such as the discharge pressure and power draw at full load and no load - are measured. These measurements will be used as inputs in the *Compressor* module. Typically, the loggers are set to record power draw at the determined sample rate for a period of one week or more.

- *Final Site Visit.* Either on the same day as the initial site visit or on another suitable day, the final site walk through is conducted. This walk through is focused on locating the leaks and potential end use issues identified in the earlier site visit. Ultrasonic leak detection equipment is used to locate leaks in the compressed air distribution network and near end-use connection fittings. Located leaks are tagged and marked on a data collection leak sheet. The leak list is then entered in to a compressed air analysis tool to calculate the total leak CFM load. End uses like blow offs, pneumatic pumps; air motors are characterized either by measuring or noting the air pressure on the gauges and the corresponding discharge orifice diameters. At the end of all the on-site data collection, potential measures are identified and discussed with the facility staff.
- *Analysis.* AIRMaster$^+$ requires data in hourly bins and subsequently the monitored data is averaged on an hourly basis to form an input for the *Profile* module. The Profile module accepts hourly inputs of various data (kW, Volt-Amp, CFM) as discussed above and the one that is available and measured should be input. The identified measures are then analyzed using the *Efficiency Measures* module of AIRMaster$^+$. The *Efficiency Measures* module can be used to investigate eight supply and demand measures for energy saving potential. Some of the measures require calculation of the flow using discharge equations outside AIRMaster$^+$ for the analysis. The most commonly investigated measures like reduce air leaks, reduce pressure set point and improve end use efficiency on the demand side and reduce run time, add primary receiver volume, etc. on the supply side are available in the *Efficiency Measures* module. A brief discussion of the most commonly used measures and their inputs is presented below.
- *Reduce Air Leaks.* As discussed above, the leak load in CFM can be calculated from the ultrasonic leak detection equipment. This measure can be analyzed to investigate the energy saving potential of fixing all or fraction of all the leaks that are identified during the site visit.
- *Improve End Use Efficiency.* This measure can be used to investigate savings from replacement of inappropriate uses of compressed air with better alternatives or shutting un-used equipment off. This measure option can calculate savings using either a constant CFM load or a variable CFM load. Some of the common measures investigated using AIRMaster+ would be replacing blow offs with blower system, installing efficient nozzles, turning off unused equipment and replacing air motors.

CFM associated with inappropriate uses is calculated using flow equations for the observed blow off diameter and pressure. Electric kW demand of substitute tools is estimated based on discussions with product vendors and engineering judgment, which then is input to AIRMaster+ for accurate computation of the energy savings.

- *Reduce System Air Pressure.* If the pressure in the system is unnecessarily high (based on the pressure gauge measurements taken at various locations in the distribution network during the site visit), system pressure reduction should be investigated as an efficiency opportunity. As a part of the process, the facility staff is asked about the minimum pressure required by the equipment and if determined that the pressure is unknowingly set high then this measure can be used to show the saving potential of reducing the existing high pressure set points. Care should be taken as a part of this investigation to look into distribution pipe sizing, plugged filters and dryers. As a part of this investigation, legitimate high-pressure end users can then be identified and appropriate methods can be adopted to supply the necessary high pressure. This analysis requires the inputs of the pressure reduction potential in psi and the associated cost of implementing the measure.
- *Reduce Run Time.* As a part of this measure, shutting off unused compressors or replacing the existing compressors with a new efficient compressor can be investigated. This measure is mostly investigated as an interactive measure involving the fixing of leaks, improving the end use efficiencies and then installing a new smaller sized compressor plant for the reduced overall demand. AIRMaster+ uses the CFM load for the existing compressors as the inputs for the analysis of the new proposed compressors. For accurate economic analysis, performance and cost details for the replacement compressor (s) are obtained from the compressor vendors.
- *Add Primary Receiver Volume.* This measure is applicable for lubricated compressors operating under load/unload control. As a part of the site visit, the size of the existing receivers is noted and compared against the Compressed Air Challenge recommended range of 3 to 5 gallons per CFM. If less receiver capacity is present, then the savings analysis can be performed for adding additional receiver capacity. This measure requires the capacity of the new additional tank in gallons or cubic feet and the cost of installation for the analysis.

Based on ERS' experience of using AIRMaster+ for analyzing compressed air systems in various industrial facilities, we have identified the following comments about applying AIRMaster+ as an analysis tool for compressed air assessments.

Strengths

1	Provides a good central location for entering information for various compressor installations that can be easily referenced for future use.
2	Excellent database of compressors along with performance curves.
3	Provides the ability to run comparative scenarios.
4	Provides standardized analysis software for compressed air assessments that is user-friendly and easy to use.
5	Easily facilitates interactive analysis of compressed air measures.
6	The results of the analysis are available in easily printable reports.
7	Offers calculator's for receiver capacity, cycle times, and CFM conversions.

Suggestions for Improvement

1	AIRMaster+ assumes that every compressed air system is perfect. AIRMaster+ is a static analysis tool and not a dynamic one. Any dynamic event issues identified in data logging affecting the operation of the compressors cannot be analyzed using AIRMaster+.
2	Currently, Variable Frequency Drive compressors (VFD) are not available as an option in the database of compressors. However, there is a work around solution to simulate a VFD compressor. This is somewhat cumbersome.
3	Cannot analyze compressed air dryers as a measure option.
4	Complicated rate structures are hard to simulate in the utility module.
5	Does not have the option of analyzing flow controllers.
6	Compressor performance curves are generic and specific compressors from different manufacturers are not available.
7	The software algorithms are not described in the manual, and hence there is no clear understanding of savings analysis methodology.

Case Study

Allegheny Rodney Metals

The plant is a 120,000 square foot facility in southern Massachusetts that manufactures thin metal sheets. ERS worked with the facility personnel and NSTAR Electric to determine ways for the company to reduce their compressed air energy usage. The facility operates three shifts per day, 7 days per week and has three Gardner Denver variable displacement rotary screw air compressors (only two operate at any given time, while the third acts as backup). A 125 HP machine is the primary machine while one of the two 100 HP compressors serves as the trim machine. The compressors are not equipped with network controls but are controlled based on system pressure. Figure 4 below shows a picture of the 125 HP lead compressor at the facility.

Figure 4. Allegheny Rodney Primary 125HP Rotary Screw Compressor

A refrigerated dryer rated at 1,000 scfm provides dry air to the plant. Flow controllers do not exist in the distribution network. Two distributed receivers totaling approximately 1,200 gallons were identified during the facility walk through. The compressed air end uses consist of pneumatic actuation and controls for all the milling machines, furnaces, slitting machines, tension levelers and cleaning lines. Additionally, the furnaces and milling machines use compressed air for particulate removal from the sheets of metal. Therefore, through the initial interview process and site walk through we collected information for the *Company, Utility, Facility, System* and *Compressor* modules. During the initial walk through data loggers were installed at the compressors to determine the compressor power draw over a period of one week. To obtain the energy use of the compressed air system at the facility ERS used Onset Computer Corporation's HOBO loggers. A separate visit was then scheduled to remove the loggers and perform a limited compressed air leak survey using UE Systems Ultraprobe air guns. End use opportunities identified earlier were also characterized during the second visit. The data from the retrieved loggers was then downloaded to a computer and averages for one-hour periods were established for input into the *Profile* module. The volts/amp option was used to enter data in the *Profile* module to characterize the compressors. This established the load profile of the compressed air system and was used as a baseline for future analytical purposes. The energy efficiency measures identified during the site visits were then investigated using the *Efficiency Measures* module of AIRMaster^{+}. The measures analyzed are presented below:

Summary of Recommended Energy Efficiency Measures (EEMs)

Seven Energy Efficiency Measures (EEMs) were recommended for implementation at this facility. The savings and costs associated with each measure are listed in Table 7 below. It should be noted that EEMs 1 through 6 are presented as independent measures while EEM 7 presents an interactive analysis. Installation costs are vendor supplied for each measure. Brief descriptions of each of the measures are contained in the paragraphs that follow Table 1.

Table 1. Summary of Recommended Energy Efficiency Measures

Energy Efficiency Measures	Energy Savings (kWh)	Demand Reduction (kW)	Installed Cost ($)	Annual Cost Savings	Simple Payback (Years)
EEM-1 Reduce Compressor Pressure Set Points	64,970	7.4	$0	$5,894	0.0
EEM-2 Install Efficient Compressed Air Nozzles	130,936	14.9	$260	$11,879	0.0
EEM-3 Install Solenoid Valves on Furnaces and Milling Machine	26,817	0.0	$500	$2,226	0.2
EEM-4 Replace Pneumatically Driven Pumps	20,846	3.7	$1,500	$1,977	0.8
EEM-5 Repair Tagged Compressed Air Leaks	46,453	5.5	$1,725	$4,307	0.4
EEM-6 Install Blower Air-Wipe Systems	248,247	30.3	$8,444	$22,633	0.4
EEM-7 Compressed Air System Optimization	739,918	84.6	$78,129	$73,208	1.1

EEM-1 reduce compressor pressure set points. ERS collected pressure readings at the compressors and at various locations in the distribution network throughout the facility. The observed pressures were higher than required by the equipment. Based on discussions with the facility staff, a 10-psi reduction in pressure was feasible. *Reduce System Air Pressure* measure option was used to analyze the savings of reducing the pressure on an average by 10-psi at the compressors.

EEM-2 install efficient compressed air nozzles. Particulate removal from the sheets of metal on the furnaces and milling machines is achieved using compressed air blow offs with a steady stream of high velocity compressed air. The compressed air is currently delivered through a variety of orifice openings. Data was collected to characterize the compressed air flow by noting the discharge orifice diameters, discharge pressures, quantities and operating hours. This information was then used to calculate the CFM use for each nozzle. The installation of efficient air nozzles would meet the process requirements but with significantly reduced compressed air consumption. This measure was analyzed using ERS' compressed air analysis tool because of the easy availability of the discharge equations and the need to provide a more specific analysis format. However, this analysis could also have been conducted using AIRMaster$^+$, *Improve End Use Efficiency* measure option in the *Efficiency Measures* module once CFM values were calculated.

EEM-3 install solenoid valves on all furnaces and milling machines. During non-production periods it is a common practice to leave the compressed air on resulting in un-necessary compressor run times. Installing interlocked solenoid valves in the air supply lines to these machines will shut off compressed air supply during non-production periods. Based on discussions with machine operators, the non-production hours were determined and the compressed air discharge was characterized as a part of this analysis. We again opted to use our custom compressed air analysis tool because of the easy availability of the discharge equations and better report format for this measure. However, this analysis could also have been conducted using AIRMaster$^+$, *Improve End Use Efficiency* measure option in the *Efficiency Measures* module once CFM values were established.

EEM-4 replace pneumatically driven pumps. There are several areas within the facility where pneumatic pumps are used to transfer chemicals. We investigated replacing those pumps with electrically driven equivalents where possible. As a part of this analysis, the quantity, type, media being transferred and model numbers of the pneumatic pumps were noted to quantify the compressed air usage. Using performance curves for the pneumatic pumps and their operating points we estimated the compressed air usage. We opted for our custom compressed air analysis tool because of the reasons cited in the measures above. However, this analysis could also have been conducted using AIRMaster$^+$, *Improve End Use Efficiency* measure option in the *Efficiency Measures* module.

EEM-5 repair tagged compressed air leaks. Leak detection was done using a UE Systems Ultraprobe UP100 air gun. Several leaks were identified and tagged during the site walk through. The majority of these leaks were located at connection points of fittings, filters, lubricators, regulators, control valves, and hand blowguns. We used our custom compressed air analysis tool to estimate the total leak load (cfm). Analysis was performed using the *Reduce Air Leaks* measure option to investigate fixing only 50% of the tagged leaks.

EEM-6 install blower air-wipe systems. The facility currently uses compressed air nozzles at various locations for particulate removal. Installation of regenerative blowers with supply air knives to eliminate compressed air usage was investigated. Data was collected to characterize the nozzle flow by noting the discharge orifice diameter, discharge pressures, quantities and operating hours. This information was then used to calculate the CFM usage for each nozzle. A blower vendor was contacted to size the replacement systems and provide the system costs. This information was then input to the *Improve End Use Efficiency* measure option to analyze the measure economics.

EEM-7 compressed air system optimization measure. An interactive analysis was performed to analyze installation of a new 125 HP variable frequency drive (VFD) compressor after fixing the leaks and installing blower wipe system to replace use of compressed air. Other end uses were not considered in this analysis. The analysis was accomplished by selecting and prioritizing designated measures: 1) *Reduce Air Leaks*, 2) *Improve End Use Efficiency* and then 3) *Reduce Run Time*. AIRMaster$^+$ proved to be a very effective tool in performing interactive analyses.

Conclusion

AIRMaster$^+$ software provides a useful and efficient tool to help analyze compressed air efficiency measures in industrial facilities. A wealth of performance information is contained in the integral database facilitating the development of an analytical model. The software is easy to use and provides interactive measure analysis based on hourly profiles for different daytypes. We found that for some of the end use analyses, AIRMaster$^+$ could not be easily used as a stand-alone tool, but was useful once a level of preliminary calculations had been completed. ERS chose to use proprietary analysis software due to the complexity in the end use analyses and ease of result presentation. It does not mean that AIRMaster$^+$ could not have assisted in the analysis. Augmentation to the software is recommended to include specific end-use analyses options (nozzles, blower alternatives, etc.) as well as for dryers and VFD compressors. Additionally, analysis methodology and supporting algorithm documentation should be made available. Overall, we believe AIRMaster$^+$ is a powerful tool that provides a standardized methodology for compressed air analysis.

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