Compressed Air:
An Operations Perspective

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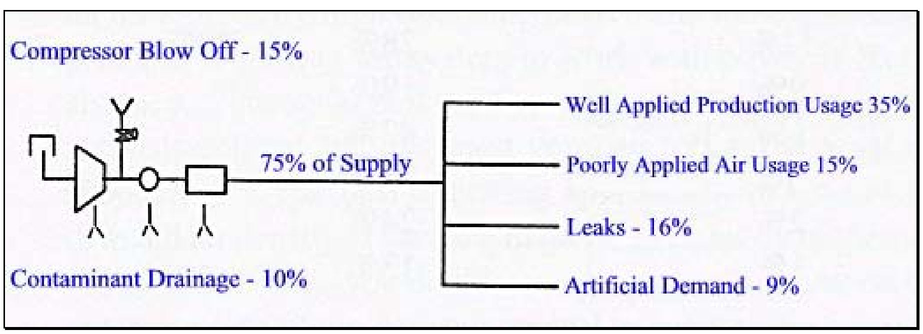
General Concepts:

Compressed air represents one of the most critical power resources in most modern manufacturing and process environments. It ranges between seven to forty percent of the total electrical usage in most plants. If the pressure drops beyond an acceptable level, production is interrupted. If the contaminant level of the compressed air varies significantly in terms of moisture, lubricant, or dirt, production quality is affected. In terms of wire to work, it represents the most inefficient means of transmitting power in the plant. A relatively well designed compressed air system with little waste will produce approximately eleven percent of the input energy in the form of work at the point of use. At $.06 per kwh, three shifts a day, seven days a week production, every 100 cubic feet per minute costs approximately $15,000 per year to operate. If your plant produces 10% pretax profit, you must generate $1,500,000 in production revenue to support 1,000 cfm of average usage per year. Despite this information, well intended production personnel give little thought to the use of compressed air and actually think that "more is better", more pressure, …. more volume, …. more dryness, …… more whatever is good!!!

In one textile manufacturing plant, the production manager was interviewed during an audit regarding his use of compressed air. His expressed attitude was "We take it. You make it. What more needs to be understood?" The following illustration was developed specifically for his benefit showing the cost value relationship of compressed air and his investment.



Since production paid for compressed air, but it was presented only as part of a large bucket of cost called overhead, they had no idea what if any impact it had. They also had no idea whether it was a good investment. In this case, he received 75% of what was produced, but only directly benefited from 35% of his total investment. With actual financials to support the constituents of demand, the production and maintenance managers came to an agreement as to what each of them had to do to get the best return on investment. They also both committed to accountability and education for their personnel.

Most manufacturing facilities have no idea how much compressed air they actually use or need. At best, they may know the minimum acceptable pressure and air quality required experientially. This information has probably been handed down like a legacy from previous operating personnel. There is probably some significant fudge factor between the perception and the reality.

It is highly unlikely that anyone knows specifically what the compressed air costs, and there are no rules for the use of it on the production side of the system. Production installs new compressed air usage on a regular basis with no discussion with facilities personnel and no idea what impact this change may have on other production applications, systems reliability, or the system's operating cost. In the average facility, this expensive and critical utility is used as though it is a limitless resource. If this approach were taken with any other utility, such as electricity, the voltage, amperage, and power quality would be so influenced that production could not an would not tolerate it for a day.

Operating Approach:

Are you operating this utility with good business practices?

With no one in facilities, production, or management understanding these previously mentioned issues, the rules of engagement in the operation of the compressed air system are normally as follows:

1. **Production can use air in anyway they choose with no communication or accountability.**

2. **All problems on the production side of the system will be corrected on the supply side of the system with no problem definition. All problems should be interpreted as insufficient supply or treatment. If leaks or inappropriate usage become excessive, without definition or investigation, facilities is expected to increase the supply of compressed air to more than correct the results of the situation. One would liken this approach to jacking up the taps on the substation to correct ground faults in the electric distribution system.**

3. **If production is unhappy and wants more compressors or clean up equipment purchased to correct any poorly defined symptom which shows up in production, money will be appropriated immediately withy no consideration for the impact on operating cost or justification required. On the other hand, if the same problem can be corrected by applying production needs differently or the system can be retrofitted at lower operating costs with the production problem corrected, and money is needed, stringent return on investment requirements must be met. Even if these financial hurdles can be met, you will still have to compete with production for capital. In most facilities, competing with production for anything is typically a losing exercise. All of this occurs while management is demanding a reduction in the facilities operating budget.**

4. **After surviving these unwritten rules for any period of time, facilities and maintenance management simplifies the operating protocol as follows:**

   "Do whatever it takes in operating the compressed air system so that they won't call".

The telephone becomes the instrument of choice to validate performance. If they don't call, life is good! No reasonable manager can look at this typical operating situation and believe that this makes any sense at all. Part of the problem is that plant management has never seen this perspective in its entirety. In every instance, where production has been exposed to this information quantitatively, appropriate assignment of responsibility is corrected. Even production management cannot condone this approach, when faced with the financial and qualitative results.

Constituents of Demand:

Is your use of compressed air getting the best value for our investment?

Five years ago, a concerned consortium of users and utilities asked that a number of quantitative systems audits be combined to see what the typical situation would look like. In an analysis of

forty two systems which were audited, on the average, less than 50% of the total compressed air produced in these facilities represented reasonable usage which contributed to productivity. The following represents the constituents of demand which were found in these forty two plant compressed air systems on the average.

Constituent of Demand	Average % of Total Use	Highest %
1. Well Applied Uses for Compressed Air	45%	53%
2. Leaks	18%	38%
3. Misc. Uses Which Should be Other Than Air[1]	11%	28%
4. Artificial Demand[2]	9%	19%
5. Open Blowing – Production[3]	8%	42%
6. Open Blowing – Drainage[4]	5%	31%
7. Dryer Purge Air[5]	2%	24%
8. Attrition on Wearing Orifices and Nozzles[6]	1%	13%
	100%	

1 There were many uses, which fell into the inappropriate user category other than those listed in the constituents of demand. They included vacuum generators, sparging, aspirating, vibrating and atomizing liquid. All of these uses could be accomplished more effectively using an alternative form of power such as vacuum, mechanical pumps or blowers.

2 Artificial demand is the volume of air, which is gene3rated by operating users at higher pressures than is necessary to achieve the desired results. It would also be described as the volumetric difference between the volume at the actual pressure versus the volume that would be consumed at the lowest acceptable operating pressure.

3 The open blowing applications were primarily applications, which could have been better applied with blowers. AT least they should have been applied with high efficiency nozzles or amplifiers. The bulk of these applications were for wiping, item cooling, personnel cooling, and parts or scrap ejection.

4 Drainage was represented primarily by solenoid or motorized valves and direct open blowing. Despite the fact that the percentage of volume was relatively little at an average of 5%, the impact that these drains had on the system was quite significant. In a majority of cases, although the volume was small, the rate of flow relative coupled with the low system's capacitance caused sufficient momentary pressure drops to prevent at least one compressor from unloading or timing out in the systems.

5 The reason for dryer purge representing such a low average percentage was the fact that few of the systems had desiccant dryers. Of those, which had these types of dryer, only a percentage were air reactivated or heatless. Where heatless dryers were in use, the impact on the system was significant not only relative to volume, but event pressure drops, which occur on the tower switch over.

6 There were only five systems where nozzle wear or attrition applied. The applications included wear on jet looms in textile plants and nozzle inserts on sandblast equipment. Slight increases in nozzle size can increase the air consumption appreciably.

Financials:

Do you understand the impact that compressed air has on our bottom line?

The systems that were audited in the above analysis tended to be larger systems averaging 1760 kw of on board power including compressors, dryers, pumps and fans. The average compressed air usage was 8,130 cfm at 103 psig. The average cost of electricity was $.048 per kwh. The

average hourly usage per year was 7,760 hours. The average annual cost for electricity was $655,564.80.

The cost of make up water, water treatment, operator labor, maintenance, outside labor parts inventory cost, depreciation, insurance, property tax, administration, and supervisory cost added an average of $375,825.40 per year to the electrical cost. The total annual operating costs averaged $1,031,390.20. Consistently, the individual plants did not know what their compressed air costs were. Those that speculated on their costs underestimated it typically by more than 50%.

You cannot make reasonable business decisions, when you can not accurately determine the financial consequences. If we divide the total cost by the operating hours per year, we have $132.91 per hour. When we divide the cost per hour by the units of 100 cfm, we have 132.91/81.30 units or $1.63 per 100 cfm per hour of operation. In doing this exercise we have quantified a unit value for compressed air that production can work with in estimating the operating cost of an application and evaluating the best alternatives. If we were to take the average quantity of leaks of 18% and multiplied it times the total average volume of 8,130 cfm, we would have 1,463 cfm. If we multiply the unit cost of $1.53 times 14.63 units, we would have an hourly cost of $23.85 for leaks. Multiply this times the hours of service and we have an annual cost of $185,052 for yearly leaks. If someone in production is going to apply a 1/5" open nozzle at 90 psig to dry or wipe a wet article somewhere in the production process, it would consume 94 cfm. .94 units of air times the hourly cost of $1.63 per hour times 7,760 hours per year generates an estimated annual operating cost of $11,890. You could perform the same function with +/- ½ hp positive displacement blower. The open blow nozzle cost nothing to apply compared to perhaps as much as $750 for the blower and installation. The annual cost of operation for the blower would be $140.20 per year to operate.

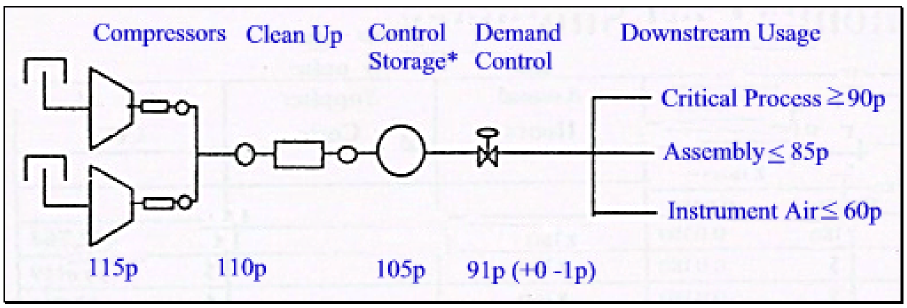
The question is whether a little extra effort and up to $750 in expense is worth more than $10,000 in operating cost. The answer should be obvious, but it is not unless there is a clear understanding of unit cost, accountability for operating cost, and a mandate form management to treat the use of compressed air as a business decision. The use and installation of all other utilities is carefully applied and reviewed. This is primarily because of code and operating personnel who understand both the financial and operating personnel who understand both the financial and operational consequences of poor applications. I think that it is interesting that a $10,000 business decision in most plants requires several signatures, yet anyone in production can make such a decision with no discussion at all. Please see below for an example of a detailed breakdown of operating cost for an actual compressed air system. You want management to show an interest in opportunities and issues.

Compressor System Economic Cost Summary						
Cost Item	**Equipment Book Value**	**Current Profile**	**Current Rate**	**Annual Hours**	**Supplier Costs**	**Annual Cost**
Compressor Equipment	**$250,000**					
Electric Power Cost:		1,330 kw	$0.0380	8,760		$442,764
Compressor - Avg. kw		1,208 kw	$0.0380	8,760		$402,119
Dryers - Avg. kw		66 kw	$0.0380	8,760		$22,003
Cooling Tower Pumps - Avg. kw		44 kw	$0.0380	8,760		$14,647
Cooling Tower Fans - Avg. kw		12 kw	$0.0380	8,760		$3,995
Ventilation Fans - Avg. kw		8 kw	$0.0380	8,760		$2,663
Water & Sewer Cost:						$27,457
Cooling System Make-Up Water/1,000 Gals		19 gpm	$2.01	8,760		$20,073
Blowdown Water Sewer/1,000 Gals.		5 gpm	$2.81	8,760		$7,385
Maintenance Cost:						$257,300
Routine Labor (Internal)		$38	1.6	521		$32,031
Unplanned Labor (Internal)		$38	1.6	80		$4,923
Administration (Secretarial)		$14	1.6	80		$1,846
Supplier Labor (PM Contracts)					$28,000	$28,000
Unplanned Supplier Labor (Report)					$20,800	$20,800
Routine Maintenance Parts & Lube					$16,740	$16,740
Unplanned Repair Parts & Lube					$41,640	$41,640
Water Treatment Chemicals					$7,000	$7,000
Disposal Costs (Lube)					$1,500	$1,500
Insurance (Equipment)		$250,000	50%			$1,250
Personal Property Tax (Equipment)		$250,000	50%			$750
Compressor Rental & Fuel					$100,820	$100,820
Other						
Total Operating Cost						$727,521
Equipment Depreciation						
Original Purchase Price		$875,000	14%			$125,000
Total Economic Cost						$852,521

Quality:

Do you measure compressed air as assigned or unassigned cause as it impoacts production quality?

There are a number of things that can cause off quality relative to compressed air. The most prevalent is the least obvious. This is when one intermittent application at a high rate of flow causes a critical pressure user to drop in pressure. One seldom determines the cause of the problem. Instead we tend to treat the effect. The problem doesn't report itself, only the result. The normal diagnosis is insufficient supply. Chances are you operate the system at a high enough supply pressure that when the event occurs, the pressure does not drop into the critical user. The size of the additional compressor that is operating to service this approach will determine the degree of pressure fluctuations, which will occur. The result is the lack of repeatability at the point of use at an unnecessarily high operating cost. The most significant problem of forcing the system to work with power is inconsistency. You are far better off being consistently wrong than inconsistently right. At least you can figure out what the problem is. The best operating approach is to control the demand air density at variable mass independently of the supply system. When you do this, you can store clean air on the upstream side of the demand control to support the transient events instantaneously. This will allow you to regulate demand at the lowest pressure all of the time. By controlling demand independently, supply can be operated at the best independent pressure where we can optimize compressor performance. You get accuracy at the lowest required pressure and optimum supply performance at or near the isothermal design of the compressors. Point of use quality at the best operating efficiency.



* Control storage allows for ≤ 14 psi of pressure drop with no change in demand psig. The capacitance of control storage should be equivalent to the largest event for the allowable pressure drop for the ≥ the time required to get the next available compressor to support the transient change in demand. Supply changes to adapt to demand without any change in demand pressure. We have generated transparency, the ideal utility configuration. In most systems, supply energy is relatively constant with demand changing in pressure and air quality constantly.

Leaks, dirty point of use filters, and increased air flow across installation components all cause the article pressure to drop on production using equipment. Since differential pressure increases as a square function of flow increases, even a small leak can cause the pressure to drop affecting quality. Most point of use filters are seldom monitored for dirt loading or cartridge change. In fact most plants have no point of use filter cartridges in the stores department. One would think that in the absence of measurement, erratic operation of use equipment would assume first that the filter might need service or a leak test needs to be done.

Unfortunately the problem is normally diagnosed as insufficient supply energy. When the point of use regulator can no longer be increased, the phone call is made to the compressor room operator. Another problem is when applications increase their cycles per minute or the rate of flow is increased. Both of these situations require resizing some or all of the installation components so that there will not be a decrease in point of use pressure. If production anticipates increasing cycles, rate of production, or air consumption, the installation needs to be reevaluated. Typically, we force the system to overwhelm the symptom.

Another problem that causes off quality is contamination in the system. There are all kinds of perceptions for this. To make things simple, you need to provide the following in order to maintain your clean up system:

- **Size the filtration and drying equipment for the heat load and mass flow at density.**
- **Maintain a consistent temperature into the equipment within the design parameters.**
- **Design and maintain a superior drainage system. Don't cut corners or go cheap.**
- **Store enough clean dry air on the downstream side of the clean up equipment to support transient events in demand without generating a velocity across the clean up equipment.**
- **Control the water flow and temperature across all heat exchangers.**
- **Provide adequate monitoring equipment to observe process results. Benchmark and trend approach temperatures relative to ambient and cooling temperatures. The equipment will eventually foul and fail the system doesn't have to, if you provide a predictive maintenance approach.**

  The most critical component of air quality is the temperature of the air at various control points. A 10^{o}F rise in temperature can alter the clean up equipment performance by 26%.

Reliability:

Do you have a risk management plan to prevent production downtime with compressed air?

Most concerned buyers of com0pressed air equipment attempt to differentiate equipment based on how it may influence the reliability of the system, ie., better stuff reduces risk of interruption or minimizes down time. There isn't any perfect, if that is what we are looking for. This is rotating equipment. It will fail. The premature failure will likely be as a result of how you operate the system and the equipment in it, rather than what you choose. What would be more important to find out about the shortcomings of the equipment and how it fails? Please find below information that would help you in learning what is important relative to reliability and reducing risk in the system. Armed with this information, you can select equipment and design the system to control risk and minimize downtime. Some other basic information, which will improve the reliability of the system, includes:

1. **Don't select compressors that are so large proportionate to the total demand that the failure of one of them can cause the system to fail.**

2. **Make sure that you take the time to write a failure scenario in a supply, demand, pressure, storage and time algorithm. Request and test the permissive response time to start all compressors from a cold start to full load with the motor and the compressor off. Measure the capacitive storage of the system expressed in cubic feet per psig. This information is essential to automatically back up the failure of a compressor or an unusually large demand event without achieving an unacceptably low pressure.**

3. **Smaller, faster, more automation friendly compressors will support risk more effectively than larger, slower units that back up other large units.**

4. **Parallel as much individual compression and clean up equipment as possible, so that if you lose a compressor or piece of clean up equipment, you do not lose the entire train of equipment. Too many systems are designed with a number of parallel trains with a**

compressor, aftercooler, filter, and a dryer. You can have one compressor from one train and a dryer from another train down for service and lose both trains from service.

5 Trend and benchmark all systems variables and deltas against design performance. You can anticipate maintenance in advance of failure. If your system is large or critical enough, a central management information system may serve you well.

6 Develop a failure plan for demand side of the system. In the event of a supply side equipment failure, manually or automatically limit the least important use sector so that you hold the required pressure in the balance of the system. If you prioritize the demand usage by sector, you could automatically limit or adjust the least important to the most important until the system was stable. The greatest risk of interruption will be experienced when you have three or fewer compressors on line and no demand side risk management program.

Summary:

With compressed air being the most poorly designed and managed of all the industrial utilities, there is certainly a great deal of opportunity to improve productivity while reducing operating cost. We have reviewed the highlights of a reasonable perspective on managing the compressed air system. When we say "system", we mean the supply, the demand and the in-between. If you treat production usage as a black hole, which must be satisfied at any cost, you have stepped outside the bounds of reason. Your cost will skyrocket, while performance declines. With the current demands from management for more effective use of our assets, this area of the compressed air certainly can be categorized as low hanging fruit.

Reliability Questions:

Reliability is certainly an important issue. There are many questions that you should ask regarding the compressors and their relative maintenance. Here are just a few:

1 How much running maintenance downtime is required per year?

2 Does the manufacturer require annual inspections? Can you train in-house people to do this work?

3 Will anything that can occur as a result of normal wear and tear or fouling cause the performance of the machine to degrade? How does this occur? What kind of performance loss is possible?

4 What trendable information or tests can be done to anticipate this degradation?

5 What is the expected life between major overhauls or repairs? What do most overhauls cost in today's dollars?

6 What is the anticipated downtime required for a particular type and brand of compressor when major work is anticipated, and it will be?

7 Does your servicing dealer maintain an inventory of parts beyond normal running maintenance parts?

8 What can go wrong with this type of compressor and how long does it take to get parts to pull this type of maintenance or overhaul?

9 If you have to change any major components or perform an overhaul, what are the risks associated with changing the performance of the compressor? Will the unit need to be tested before and after to determine that you are still making the performance?

10 Everyone has good references. Talk to some people who have had problems with a particular brand and type of equipment. Make sure that you talk to users with at least 8 years operating experience. There are compressors that are wonderful for the first few years. After the first airend replacement or major overhaul, the users opinion may be different.

There isn't any perfect out there. Get familiar with the down side of the equipment. Tell the sales representative that you want the good and the bad. It's not an unreasonable request. It will help you with instrumentation and maintenance planning.

Reprinted with permission from R. Scot Foss, president of Plant Air Technology, Charlotte, N.C., a company specializing in system auditing and design. This article is based on his book, "Compressed Air System Solution." A portion of the proceeds from sales of the book is donated to children's charities. To order a copy of the book, please contact Southern Corporation.