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Purpose & Design Factors – Compressed Air

The use of compressed air in the milking center is a relatively recent addition to the array of equipment employed to harvest milk. Compressed air is able to provide the pneumatic force to operate a variety of devices that have been developed to further automate milk harvest. Its primary advantages are the ability to deliver controlled force to assist animal movement without injury and elimination of potential sources of electric shock in a wet environment.

Examples of equipment that is currently utilized on California dairy farms that use compressed air as an energy source include:

- Holding area crowd gates.
- Parlor stall entry and exit gates.
- Parlor stall rapid exit “reels” and other gang exit systems.
- Control indexing and positioning brisket rails in parlor stalls.
- Operate dairy cattle sorting gates
- Operate milker claw detacher systems.
- Operate wash valves in some CIP systems.
- Operate “flush” valves for waste removal in parlor and freestall

Electricity provides the power source to produce compressed air that is used to operate air-powered equipment in the milking center. The air compressors utilized are common commercially available systems, employing various types of compressors, storage tanks, air treatment and delivery systems and an extensive range of end-use devices. Maximum system efficiency is derived from careful selection of all air handling components.

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Equipment – Compressed Air

Air Compressors

Reciprocating Compressors

Reciprocating compressors utilize a piston, crankshaft and connecting rod to transform rotary power input (from electric motor or engine) to linear motion to compress air. They can be configured in single or multiple cylinders to provide required air flow (cfm) and pressures (psi). Generally classified as single stage (95 psi or less) and two-stage compressors (100-175 psi) depending on operating pressure required. See Figure 7-1.

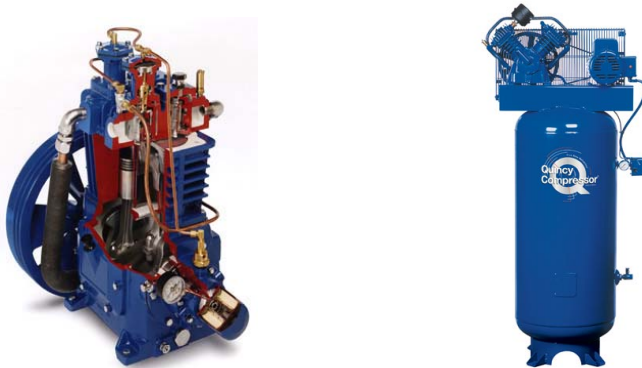


Figure 7-1. Reciprocating compressor (Quincy)

Rotary Screw – lobe style rotor

A rotary compressor uses two intermeshing rotors to compress air. As the rotor turns, their configuration compresses the air trapped between them. This simple process lowers the operating temperatures approximately 50% (as compared to reciprocating designs), increases efficiency and delivers a clean air supply. A rotary compressor uses a coolant to cool its internal components. This allows the compressor to operate in a fully loaded, continuous duty cycle. See Figure 7-2.



Figure 7-2. Rotary screw – lobe style rotor (Kaeser)

Air driers – Compressed Air Treatment

An essential part of any compressed air system is the air treatment equipment. Compressed air will contain water vapor, oil, dirt particles and other contaminants. If not removed these contaminants can interrupt operation, damage equipment and controls, and reduce operating life.

Depending on the air quality requirements of the end use, a wide array of air treatment options is available. The amount of air treatment needed is driven by the air quality requirement of the end use device. In general contaminant removal is divided into main line and point-of-use air treatment products.

Mainline air treatment usually takes place directly after compression and treats all or a major portion of air used. Typical equipment employed includes are discuss below.

Air or Water-cooled Aftercooler An air cooled aftercooler is shown in Figure 7-3. These units remove 75% of the water and 70% of the oil.



Figure 7-3. Air or water-cooled aftercooler (Thermal Transfer)

Refrigerated Dryer These units use mechanical refrigeration to chill the compressed air to 35 to 50°F. The exit air is saturated at this dew point temperature. Up to 96% of water vapor and 40% of oil from compressed air is removed. As the air is heated the relative humidity decreases and a dry air is produced.



Figure 7-4. Refrigerated dryer (Kaeser Compressors, Inc.)

Regenerative Desiccant Dryer – Compressed air flows through beds of desiccant material, which absorbs water vapor. Produces -40°F pressure dew point for ultra-dry air (removes up to 99.9% of water). Use of oil removal filter upstream is recommended to prevent contamination of desiccant material. Requires upstream aftercooler to pre-cool incoming air. A unit is shown in Figure 7-5.



Figure 7-5. Regenerative desiccant dryer (Hankison)

Three-In-One Dryer – The unit shown in Figure 7-6 is a refrigerated dryer that incorporates an aftercooler and reheater. It handles high inlet temperatures without the need for separate aftercooler, condensate separator and drain.



Figure 7-6. Three-in-one dryer (Speedaire)

Automatic-Electric Drain Valves – The unit shown in Figure 7-7 drains liquid water from air compressor receiver tank, aftercooler, and other air system components.



Figure 7-7. Automatic, Auto-electric drain valve (Wilkerson)

Point-of-use treatment takes place immediately before the end use and treats only the air used by that device. See Figure 7-8. Options include:

- **Air Line Filter** – Removes dirt particles and some liquid from compressed air
- **Oil Removal Filter** – Reduces oil content of air to very low levels for critical applications.
- **Manual Desiccant Dryer** – Desiccant material absorbs any remaining water vapor in compressed air.
- **Lubricator** – Provides proper amount and type of lubricant to operate air tools, motors and other pneumatic equipment requiring lubrication.

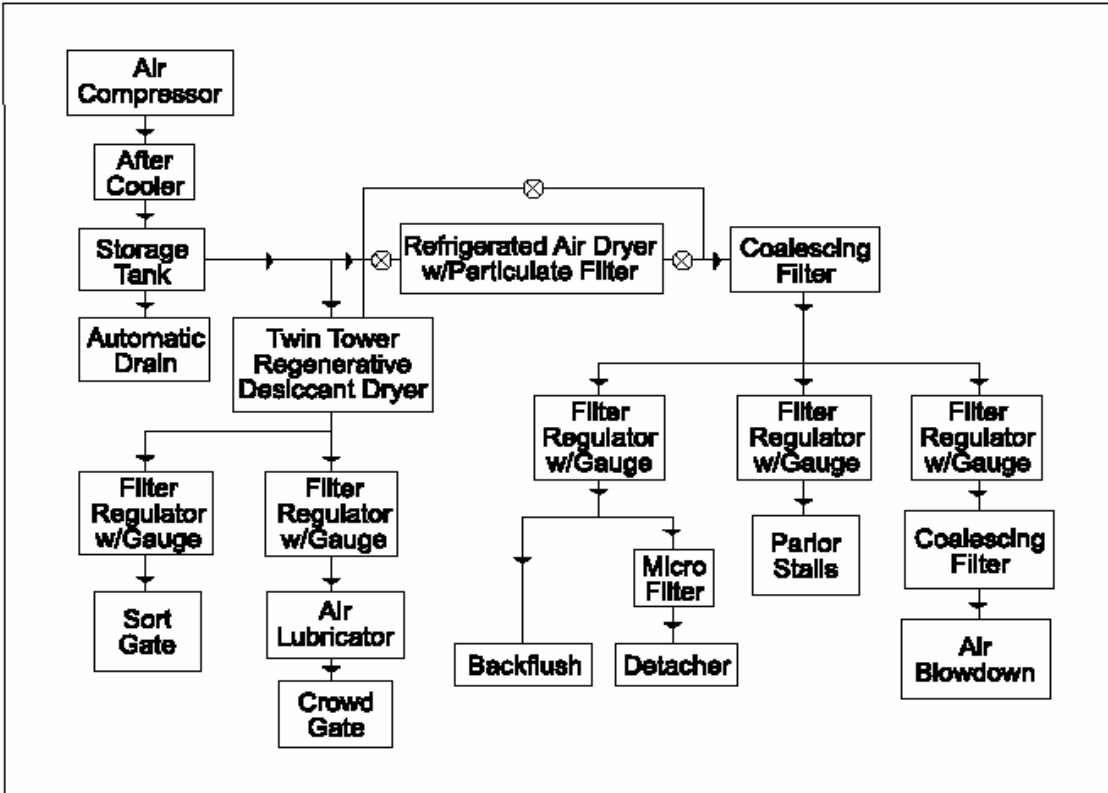


Figure 7-8. Point-of-use air treatment options (8a,d – Campbell Hausfield; b – Speedaire; c - Wilkerson)



Figure 7-9. Compressed air system (Westfalia Surge)

A typical air handling system of a milking parlor is shown in Figure 7-10.



(Source: Westfalia-Surge LLC – September 1999, web site – www.westfaliasurge.com)

Figure 7-10. Typical Parlor Air Supply System

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Compressed Air Energy Utilization Indices (EUIs)

The majority of electrical energy used to provide compressed air on the dairy farm occurs within the milking center, mainly in the milking parlor. The adaptation of compressed air operated equipment to the milking parlor has increased the total level of automation and allowed increased labor efficiency of milk harvest.

Electric energy used to produce compressed air on California dairies is controlled by:

- Air volumes (cfm) consumed by end use devices.
- Greatest operating pressure (psi) required by end use device.
- Proper design, sizing & selection of compressed air system.
- Pressure losses and leaks within air delivery piping.
- Efficiency (cfm/watt) of compressor/motor package.
- Operating schedule of milking parlor equipment.

General levels for compressed air EUIs will commonly range from 15 to 50 kWh per cow-year on most California dairy farms. EUIs on the lower end of the range may suggest very efficient compressed air systems or low levels of animal handling automation. EUIs on the upper end of range can indicate milking parlor systems using a high level of air-operated equipment, or a poorly maintained leaky compressed air system.

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Compressed Air Energy Conservation Measures (ECMs)

Motor Selection

In selecting an air compressor, there are two components to consider: the air-end and the motor. In some applications, the air-end and the motor are sold as a package. Often, however, the buyer can select one of several motors to be installed on the air-end. Long-term energy savings can be locked in for the life of the equipment by selecting the most efficient motor available.

Equally important is choosing the correct size of motor. Motors that are not large enough may have to operate above their rated load, forcing them to run at elevated temperatures, which shortens their operating life. Motors that are much larger than required not only cost more, but also suffer efficiency loss when the operating load falls beneath about one-half of the motor's rated load. For further discussion of selecting an energy efficient electric motor, see The [General Information](#) section, "Energy Efficient Motors".

Variable Speed Drive - Compressed Air Application

Variable speed drive provides one of the newest available control options to reduce energy consumption of compressed air systems. Variable speed drives can be more efficient than conventional stop/start or load/unload control systems when:

- Varying flow conditions are present. VSDs can provide constant pressure control, and vary or stop the compressor to match system use.
- As a suitable retrofit on oversized compressors to reduce speed and energy use.

Although the primary benefit of a VSD is energy reduction they are also able to:

- Reduce need for other air compressor control equipment.
- Provide soft start & stop, which allows a reduction in starting loads and stresses to both compressor and motor, increasing wear life.

High Efficiency Compressors

An indicator of relative energy efficiency for an air compressor is the output of air (cubic feet per minute) delivered at a specific pressure per input watt of electrical power to the motor (cfm/watt). This data will vary widely dependent on the following:

- Operating pressure
- Efficiency of electric motor
- Efficiency of compressor

These figures are not verified or published by an independent testing lab but derived from manufacture's testing. Cfm per watt can provide a guide for comparing compressor performance if they are tested under equivalent conditions. When comparing the cfm/watt delivered by two compressors, the unit with the greater value provides superior energy efficiency.

Some manufacturers will express the efficiency of their compressors in terms of horsepower per 100 cubic feet of air produced (Hp/100 cfm). In this instance the compressor with the lower value will be the most energy efficient.

Efficient Dryer Applications

Compressed air drying applications are tied to the dew point temperature requirements of end use devices. The dew point temperature is simply the temperature at which water vapor contained in the compressed air condenses to liquid form and can cause damage or operating problem in air operated equipment.

To prevent liquid water from forming in air lines, the drying equipment selected should be able to produce a dew point below the lowest temperature to which your pneumatic equipment requires. As the need for higher levels of air-drying, energy requirements to achieve those levels also increase. The lower the dew point temperature needed the more expensive the dryer will be to purchase and operate.

To evaluate the most cost effective compressed air drying system for your application, consider the following factors:

- Determine maximum acceptable dew point temperature necessary to operate your system, and do not exceed this.
- Select drying equipment to meet dew point requirements.
- Consider dryer energy operating costs and maintenance costs.
- Use appropriate filters on driers to maintain efficiency and performance.

The best opportunity for energy reduction in air-drying hinges on the selection of an appropriate level of dew point reduction. A knowledgeable, experienced supplier, familiar with dairy applications, should be retained to assist in selection of this equipment.

Outside Air

An assessment of the ambient conditions in the utility room where the compressor draws air from should be performed. Air compressors work more efficiently and run cooler when the intake air is clean, cool and dry. Compressors that are located inside equipment utility rooms must compress warm inside air.

Installing an outside air intake will allow the compressor to use cooler outside air, which is easier to compress. If the intake air comes from a hot, humid and or dusty utility room, consider ducting the intake to the outdoors. This measure will also reduce the noise level in the utility room. Generally a 5-6°F reduction in air intake temperature will provide a 1% reduction in energy use.

Reduction of System Operating Pressure

The level of system operating pressure and energy consumption are directly related. Maintaining system pressures at levels greater than required to operate end use devices only serves to increase energy usage. A rule of thumb for systems operating around 100 psi is that for every 2-psi increase in operating pressure, energy costs will increase 1%. If operating pressure could be dropped 20 psi, a 10% reduction in energy costs will occur.

Reducing system-operating pressures will also provide supplemental benefits such as reducing leakage rates, increasing system capacity, and longer life of components and equipment due to reduced stress at lower pressures.

The majority of equipment that operates on compressed air requires an article pressure of 80 psi or less. System pressures tend to be operated at higher than the end use requirements due to a number of factors. These include:

- The belief that the extra pressure provides a buffer against pressure sags.
- To compensate for pressure drop in the distribution system and for undersized regulators, hoses and other distribution system restrictions.
- Comparatively wide control band employed on most air compressors that are operating without adequate control storage capacity in the system.

Pressure drop is the loss of air pressure that occurs as air travels from the compressor, through the distribution and air treatment systems on its way to the actual end use. A properly designed system will have a pressure loss of much less than 10% of the compressor's discharge pressure.

Utilizing a higher system pressure than required at the end devices creates an "artificial demand" on the compressed air system. The best way to illustrate this concept is to consider the following. Suppose an air cylinder requires 75 psi to operate a device 1 time per minute with a displacement of 1 cubic foot. Based on these parameters, the cylinder should use 5 cfm of compressed air (1 cubic foot times 5 atmospheres of pressure). Now consider what happens when this cylinder is operated with a supply pressure is 105 psi. The cylinder will still perform adequately, but now the air consumption will be 7 cubic feet per stroke (1 cubic foot displacement times 7 atmospheres of pressure) or 7 cfm to do the same job. This represents an increase in compressed air use of 40 percent, simply because the pressure is higher than required.

Undersized regulators, hoses and other distribution system restrictions may cause low working pressure at the end uses, particularly during periods of highest airflow. The wide control band found on most air compressors creates low working pressure during the tank

pressure drop before the air compressor turns on. The typical solution to low working pressure is to raise the storage tank pressure, resulting in increased air usage, decreased compressor capacity, increased electric consumption and increased thermal and mechanical stresses on the compressed air system.

Minimizing pressure drop within a compressed air system is an effective way to counter elevated operating pressures and associated energy costs. Effective measures to minimize pressure drop are as follows:

- Have air distribution system properly designed instead of a “hodgepodge” of components that have grown and been added to over time.
- Operate and maintain air filters and drying equipment to keep interior of piping system clean and free of corrosion.
- Select air treatment components (aftercoolers, separators, dryers and filters) that produce the least possible pressure drops.
- Provide the shortest possible path for air to travel within the distribution system from the compressor to the end use.

When system pressures can be successfully reduced and controlled, adjustment of compressor control set points can be fine tuned to obtain greater efficiency. Through the use of control storage tanks and intermediate controllers or regulators, the pressures maintained in distribution headers can typically be reduced to approximately 85 psi. The storage tank pressure should be set such that the compressor starts before the tank pressure drops to the level of the regulated, distributed air pressure. In addition to reducing air consumption, the lower distributed pressure will reduce fatigue on cylinder and valve seals and reduce the amount of air lost through system leaks. The overall reduction in total airflow thru the system will also improve the effectiveness of air dryers.

Improve End Use Device Efficiency

Select individual end use components that have lowest cfm requirements to perform a particular function. Carefully evaluate and investigate air motors, cylinders, and other air consuming devices to obtain lowest possible compressed air consumption rates. Utilizing the most efficient end use devices will ensure energy savings for the entire operating life of the compressed air system.

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Operator Level Checks –Compressed Air

Compressed Air System Leaks

The existence of air leaks in a compressed air delivery system can represent a significant source of wasted energy. A very poorly maintained system may likely have a leak rate equal to 20-30% of the total compressed air production capacity. Conversely, a well maintained system with timely leak detection and repair can reduce leakage to much less than 10% of compressor output.

Besides wasting input energy, air leaks can also be a factor for inefficient operation of end use devices, increased running time, shortened equipment life, and can lead to greater periods of unscheduled downtime.




While leakage can occur in any part of the system, the most prevalent sources are:

- Couplings, hoses, tubes, pressure regulators and fittings.
- Open condensate traps and shut-off valves.
- Pipe joints, disconnects, and thread sealants
- Air using equipment left in operation when not needed

There are two common methods that can be used for the detection of leaks. The more sophisticated technique utilizes an ultrasonic acoustic detector. These devices employ directional microphones, and amplifiers, to locate high frequency sounds associated with air leaks. The operator is directed to the leak location with either a visual display or thru earphones. The ultrasonic acoustic detector is fast, accurate and able to detect very small leaks, but relatively expensive to justify on small compressed air systems.

The second simpler method is to apply a soapy water solution to suspected leak locations with a brush. Then observe formation of air bubbles to pinpoint leaks. Although this method is cheap and reliable, it can be time consuming when looking for generalized leaks in a system.

Since small air leaks are almost impossible to see or recognize before they become so large that they are readily audible, it is important to have a systematic approach to leak detection. Leaks are usually inexpensively and easily repaired, but allowing a leak to persist can be very costly and inefficient as indicated in Figure 7-11. With energy prices at \$0.10 per kWh, the energy that could be saved by reducing the cross section area of air holes (leaks) by 1/8 inch could approach \$4,000.

	Size	Cost per Year
	1/16"	\$523
	1/8"	\$2,095
	1/4"	\$8,382

Costs calculated using electricity rate of \$0.05 per kWh, assuming constant operation and an efficient compressor.

(Source: Compressed Air Challenge – Fact Sheet #7, April 1998)

Figure 7-11. Costs of Leaks Per Year

Common locations for leaks to be found in a compressed air system:

- Condensate traps
- Pipe work
- Fittings and flanges
- Flexible hoses
- Filters
- Pneumatic cylinder seals
- Hose connections and controls to tools
- Instrumentation

Estimating Amount of Leakage

The following is fairly straightforward method for estimating the amount of leakage for compressors that use start/stop controls. This method can be performed during parlor down time, when compressed air is not needed.

- First ensure that all air operated end-use equipment is turned off and not functioning.
- Make certain the air compressor itself is on and operating.
- Release air at a convenient location until the compressor cycles on.
- Record the average times the compressor is running and stopped.

The compressor will stop and start as the pressure drops from air escaping through leaks in the system. Total leakage (percentage) can be determined as follows:

$$\text{Leakage (\%)} = [(T \times 100) / (T + t)]$$

Where: T = Ave. time compressor is running (minutes)
t = Ave. time compressor is stopped (minutes)

Leakage will represent the percentage of compressor capacity that is lost. Leakage in a well-maintained system should be 10% or less. Poorly maintained systems can have losses as high as 20-30%, and represent excessive waste of air and electricity.

The following example illustrates how significant these losses can be. A 20 hp air compressor is found to be running 6 minutes (T) and stopped for 24 minutes during a half hour cycle when no air is being used.

$$\text{Leakage (\%)} = [(6 \times 100) / (6 + 24)]$$

$$\text{Leakage (\%)} = 20\%$$

This amount of unnecessary air leakage corresponds to an annual kilowatt-hour use of 13,000 kWh and cost of \$1,300 just to push air through leaks.

Verify Distributed Pressure

Pressure higher than 90 psi uses more air, runs compressor hotter and uses more energy, and exceeds the design operating pressure of most equipment.

Monitor Compressor and Motor Operating Temperature

Check temperature of compressor and motor with self-adhesive recording strips. High temperatures can mean a drift upward in system pressure, restricted intake air filter, lubrication problem, or other compressor problem. The intermittent nature of the air compressor means higher temperatures may result from longer run times associated with air leaks or higher air consumption

The following check list, Figure 7-12, is a check list that could be useful in maintaining a compressed air system.

Basic Maintenance Checklist

- Inlet Filter Cartridges.** Inspect and clean or replace per manufacturer specifications. Required frequency is often related to operating conditions. Dirty filters increase energy consumption.
- Drain Traps.** Clean out debris and check operation periodically.
- Compressor Lubricant Level.** Inspect daily and top-off or replace per manufacturer specifications. Change lubricant filter per manufacturer specifications.
- Air Lubricant Separator (Lubricant-injected Rotary Screw Compressors).** Change per manufacturer specifications, or when pressure drop exceeds 10 psid, whichever is less.
- Lubricant Selection.** Select compressor and electric motor lubricant per manufacturer specifications.
- Belt Condition.** Check belts for wear and check/adjust tension per manufacturer specifications.
- Operating Temperature.** Verify that operating temperature is per manufacturer specifications.
- Air Line Filters.** Replace particulate and lubricant removal elements when pressure drop exceeds 2 to 3 psid. Inspect all elements at least annually regardless of pressure drop indication.
- Water Cooling System.** For water-cooled systems, check water quality (especially pH and total dissolved solids), flow, and temperature, and clean/replace filters and heat exchangers per manufacturer specifications.
- System Leaks.** Check lines (especially joints), fittings, clamps, valves, hoses, disconnects, regulators, filters, lubricators, gauge connections, and end-use equipment for leaks.
- System Cleanliness.** Check system for compressor and motor lubricant leaks and cleanliness.

Source: Compressed Air Challenge – Fact Sheet #5, April 1998)

Figure 7-12. Basic Maintenance Checklist

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Glossary of Air Compression Terms

Air Pump (Compressor Head): The part of compressor that compresses the air.

Single-stage – for applications requiring operating pressures of 95 PSI or less.

Two-stage – for applications requiring operating pressures of 100-175 PSI. Has two or more cylinders in series. The first cylinder compresses air into the next, which compresses it further and then pumps to the air tank.

Air Tank (Receiver): Stores compressed air produced for peak loads or intermittent use.

Air Treatment: Removal of contaminants (water vapor, oil, dirt, other particles) contained in air produced by the compressor.

Main line air treatment – devices that treat all air produced by the compressor between the air tank and end use devices.

Point-of-use air treatment – apparatus that only treats air used by a single end use device.

Automatic Tank Drain Valve: Installed at bottom of air tank; opens briefly during each pumping cycle to release moisture condensed from the air.

Duty cycle: The percentage of time in an hour that the compressor should be allowed to run. E.g. If a compressor has a 50/50 duty cycle and is going to run in a 10 minute cycle, it should be run for a combined maximum of 5 minutes ON and 5 minutes OFF.

CFM: Cubic feet per minute of air flow at a designated pressure that a compressor can deliver or an end use device consumes to operate.

Check valve: Allows air to flow one way only, from pump to tank. When compressor stops, this valve closes, preventing loss of air from tank or damage to pump valves.

PSI: Pounds per square inch of pressure that a compressor can deliver or are required by end use devices to operate properly.

Relief valve: Vents the tank if excess pressure builds up to prevent damage.

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