Compressed air is an expensive utility and managing the air system reduces costs. However, it may be possible to reduce your plant’s total energy consumption by recovering the heat air compressors produce. The electric motor—or other prime mover—puts energy into the air stream through the compression process. Heat and work are two different methods of transferring energy.

It is possible to extract, by heat transfer, an amount of energy from the compressed air that is equivalent to the amount of energy that the electric motor placed into the compressed air. This may appear to be a paradox, but it confirms the first law of thermodynamics and the principle of the conservation of energy, which states that energy can neither be created nor destroyed; it can only change form. The air entering the compressor at atmospheric pressure has a base level of energy content. After the compression process increases the air pressure and raises its temperature, energy is available for transfer. Heat must be removed to maintain the compressor tolerances and clearances, and the compressed air cooled to make it suitable for the intended use. The compressed air still contains sufficient energy to do useful work after the heat has been removed. The air compressor increased the pressure and proportionately reduced the volume. The energy of the original entering air is now at an elevated pressure, ready to do work down-

Air compressor heat recovery is a hot topic

Done wisely, it’ll yield a cool bundle of cash

By William Scales, P.E.

Figure 1. General arrangement of a compressor room.
stream in the compressed air system. The heat energy is usually rejected to the atmosphere or the cooling water.

One of the better methods for improving the overall efficiency of any compressed air system is to recover the rejected heat. However, the availability of the heat and the opportunity to recover and use it are two different matters. Depending on the compressor type, radiant heat losses and cooling method, it’s possible to recover fifty percent to ninety percent of the total energy input in the form of heat. The most common uses for the recovered energy include process heating, supplemental space heating, heating water or preheating boiler make-up water. The applications are limited only by the imagination and possible opportunities, even in northern or colder environments.

**How much heat is available?**

Motor power can be quantified as kilowatts or BTU per hour. One horsepower is the equivalent of 2,545 BTU per hour. Although most rotary screw and reciprocating air compressors are sold in nominal horsepower sizes, they generally can operate at loads 10 percent above the motor nameplate rating to achieve rated compressor discharge pressure and full capacity output. The horsepower at the compressor shaft, also referred to as brake horsepower (bhp), can be 10 percent above motor nameplate horsepower and consume most of the motor’s 1.15 service factor safely. Therefore, a 100-horsepower compressor (110 bhp) converts electricity into almost 280,000 BTU per hour at full load. In addition, a motor having an assumed efficiency of 93 percent dissipates an additional 19,600 BTU per hour.

The heat balance differs by
Compressors

compressor type. Presently, the most common compressor found in manufacturing plants is the lubricant-injected, rotary screw unit supplied as a packaged compressor, a fact that makes it easier to recover the heat. In these compressors, approximately eighty percent of the heat is rejected in the lubricant cooler. Most of the remaining heat is rejected in the aftercooler, with a small percentage rejected in the form of heat radiated from the compressor housing and lubricant separator receiver. In a two-stage lubricant-free rotary screw compressor, almost all the rejected heat is divided evenly between the aftercooler and intercooler. In two-stage, water-cooled reciprocating compressors, the intercooler and aftercooler each may each reject 40 percent of the heat, while the cylinders account for 20 percent. A centrifugal compressor may have each intercooler and aftercooler share almost equally in the heat load. Given these facts, consider the possibilities of heat recovery from an engine-driven air compressor.

Some heat recovery projects

Consider a rather small compressor room with three 50-hp, air-cooled compressors, each of which is operating at full capacity to maintain the required air pressure. One production line requires compressed air for a special milling machine and an associated robot, while the final stage uses compressed air for cleaning and drying parts. Increased production requires an additional manufacturing line, so management is considering the addition of a fourth 50-hp or 100-hp compressor.

At a consultant’s recommendation, an inexpensive flow meter determined the milling machine and robot production line required approximately 95 cfm (almost 25 hp), 55 cfm for the process and 40 cfm for the parts drying. The parts dryer on the new milling machine process was replaced with a two-kW blower.

However, the existing compressors didn’t have any spare capacity. In the event of a malfunction, some production process would be interrupted. Because no more compressor room space is available, the alternative is a 25-hp air-cooled, rotary screw compressor installed at the drying end of the new milling machine line.

Recovering the heat from the air-cooled compressor and directing it at the parts to be dried eliminates 40 cfm of consumption. The excess capacity from the 25-hp compressor can feed back into the main plant air system. This solution, combined with other measures, reduces compressed air consumption to the point that one 50-hp compressor can be shut off. The solution negates the need to purchase a larger compressor. In addition, a simple heat recovery system installed in the main compressor room is used for supplemental factory space heating in winter. Both projects have short payback periods.

For many years, hot air from the compressor discharge prior to the aftercooler had been used to reheat
the compressed air after initial cooling or drying. This adds additional energy to the air. However, care must be taken to ensure the end uses can accept the elevated temperature. Also, all piping should be insulated to reduce heat lost through radiation and, more importantly, to protect personnel who might touch exposed pipes. Air from the discharge of non-lubricated rotary screw compressors or from centrifugal compressors, prior to the aftercooler, can be used to regenerate the desiccant in heat-of-compression regenerative dryers.

Compressed air from lubricant-free rotary screw compressors or from upstream of the aftercooler on centrifugal compressors can be used to regenerate desiccant in heat-of-compression regenerative dryers.

**Supplemental space heating and ventilation**

Improper ventilation in compressor rooms can result in elevated operating temperatures that reduce equipment life, generally increase maintenance and repair cost and yield an unreliable air compressor system. The initial cost of a good ventilation system is usually far less than the cost of a hot operating environment. It’s advisable to consult with HVAC experts to ensure proper ventilation and to evaluate possible heat recovery opportunities. However, remember to keep installations as simple as possible.

When considering heat recovery for supplemental space heating, the expense of properly sized ductwork and booster fans can be significant, but the payback also can be substantial. The compressor ventilating system design should consider its effect on the rest of the plant’s ventilating system, including heating, air conditioning and possible negative pressures. Balance savings against installation cost and evaluate payback using life cycle cost analysis before proceeding with any project.

**Case studies**

A company that packaged pharmaceutical products operated two 100-hp, air-cooled, rotary screw compressors at full capacity for 8,000 hours per year. Occasionally, when a special process was in operation, a third compressor was necessary; for this example, only the two compressors will be assumed to be running. The brake horsepower (bhp—measured at the compressor shaft) is 110, and the motor efficiency is 0.93; the fan motor has an efficiency of 0.90 and requires 5 bhp. The conversion factor is 2,545 BTU per hour per bhp.

Energy input = \((110/0.93 + 5/0.9) \times 2,545 \times 2 = 630,320\) BTU per hr., of which only 80 percent, or 504,000
For natural gas costing $0.50 per therm and a heating season of 4,000 hours, the annual saving is:

\[ \text{504,000 BTU/hr} \times \frac{\$0.50}{100,000 \text{ BTU}} \times 4,000 \text{ hr./yr.} = \$10,080/\text{yr.} \]

Many applications require deducting the energy cost of operating additional ventilating or booster fans from the savings. Figure 1 shows the general arrangement of the compressors within the plant and warehouse area. Plant personnel were able to add an outside louver and wall fan without needing any ductwork. In winter, plant air is heated and discharged to the warehouse. During warmer months, the heated air is directed outside.

Another manufacturer has multiple 350-hp and 150-hp, water-cooled, rotary screw compressors in two plant areas. The original compressor area in the boiler room has no additional space available. The second area in the middle of the plant has no outside walls. A plant expansion required an additional 350-hp compressor and a larger cooling tower. The compressor vendor proposed an air-cooled compressor. The heat recovered in winter was sufficient to heat the entire section of the plant in which the compressor was located. In summer, heat was ducted through the roof. The initial estimate of annual fuel savings was $28,000.

**Recovery tips**

Louvers and ductwork create restrictions to the flow of ventilating air and may impede the necessary fan airflow to effect proper cooling. In some cases booster fans may be necessary, and the cost of their operation should be considered. Size the louvers for minimum restriction and maintain an air velocity between 10 ft./sec. and 15 ft./sec. Follow the compressor and dryer manufacturer’s recommendation for maximum static pressure.

Introduce cooling air at a relatively low point, but not low enough to pick up dirt or dust. Dusty environments require generously sized air panel filters. Keep the filters, louvers and cooler surfaces clean for best compressor performance and reduced maintenance costs.

Direct the cooling air toward the compressor, dryer fan inlet and through the cooling surfaces across the compressor and dryer. Exhaust warm air from the room at a level above the compressor or other air-cooled equipment. In multiple compressor installations, ensure that warm air from one compressor or dryer isn’t directed towards the fan inlet of another.

In most rotary screw compressors, the air leaving the coolers can be 20°F to 40°F warmer than the inlet air; therefore, recirculated plant air can be used for supplemental heating. However, recovered heat won’t warm sub-freezing outside air to a temperature that will reduce heating fuel costs.

Water-cooled compressors are also a potential source of heat recovery. The warm outlet water can be directed through either a liquid-to-liquid heat exchanger to heat a fluid or a water-to-air unit to warm the loading dock or manufacturing area. These heat recovery systems are available as
packaged units and include the pumps and controls for simplified installation and economical operation. Motor losses, however, are not easily recovered, but this heat will be rejected to the area in which the compressor is located.

Using imagination
In one case, a manufacturer used natural gas to heat wax used in its end product. The plant engineer designed a system of coils that used the heat from the lubricant of a nearby water-cooled rotary screw compressor to help melt the wax and substantially reduce the plant’s gas consumption.

In a food processing plant, the jacket water from an engine-driven compressor liquefied chocolate and sugar. Passing the hot lubricant from the air compressor through multiple heat exchangers could have achieved similar results.

The opportunities are excellent. Use your imagination to recover air compressor heat and reap the benefits of reduced energy consumption and lower operating costs. ☛

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Figures: Scales Air Compressor Corp.