Optimizing efficiency: Understanding and harnessing the potential of Thermocompressors to minimize waste

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INTRODUCTION:

Thermocompressors are widely used in numerous paper mills, primarily for recompressing and recycling blow-through steam in dryer drainage systems. Requiring minimal maintenance and utilizing both kinetic and heat energy from the motive steam, they are ideally suited for this application. However, in practice, there are considerable questions regarding the design and application of these devices.

As machines become more efficient, i.e. operating with lower blow-through and differential pressure across the dryers (DP), a significant number of improperly sized thermocompressors are observed in the market. This inadequacy compromises potential savings and machine efficiencies. In a recent machine upgrade, for instance, six existing thermocompressors lacked sufficient turndown capacity to accommodate the new conditions. They were oversized and likely worn out, resulting in compromised performance, and decreased peak efficiency. By replacing all six thermocompressors, the paper mill managed to save up to 11,400 kg/h of motive steam, achieving a return on investment in less than six months.

Additionally, there are also cases where customers are trying to utilize thermocompressors to control DP, which prevents efficient operation of most dryer sections at low pressures, produces huge steam losses on breaks and loss of control, and contributes to frequent flooding of dryers. For example, we found that a large paper machine producing containerboard grades running DP control with thermocompressors was having significant flooding events, which compromised production and lowered the reliability of the whole dryer drainage system.

As demonstrated in the cases above, and considering the increasing focus of paper mills on enhancing efficiencies, there is a pressing need to gain a deeper understanding of the utilization and sizing of this component. By identifying and rectifying inefficiencies, mills can substantially enhance their operation efficiencies, capacity, and financial returns.

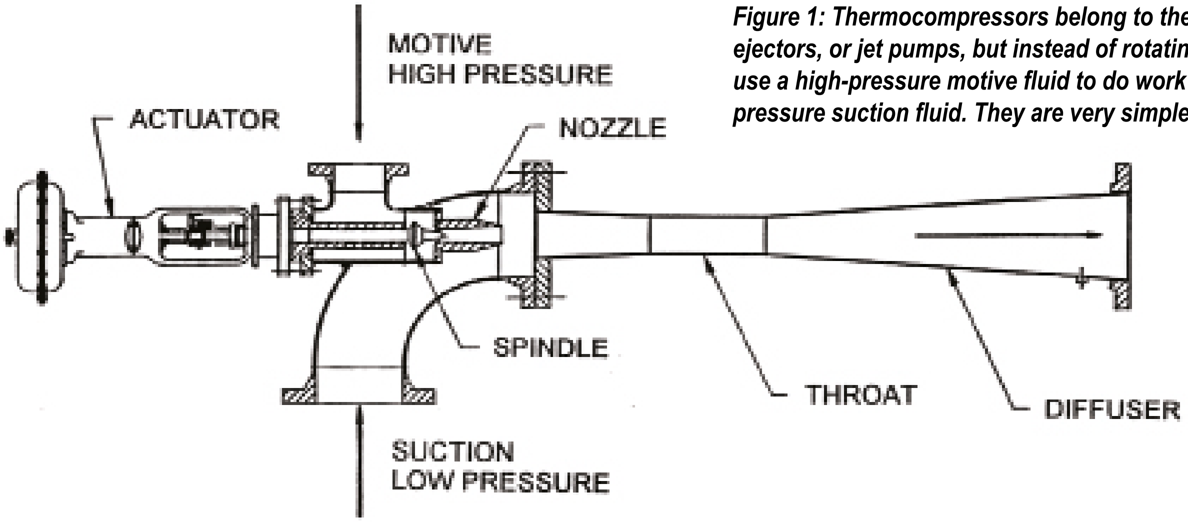


Figure 1: Thermocompressors belong to the family of ejectors, or jet pumps, but instead of rotating parts, they use a high-pressure motive fluid to do work on a low-pressure suction fluid. They are very simple in construction.

The mechanics

Thermocompressors belong to the family of ejectors, or jet pumps, but instead of rotating parts, they use a high-pressure motive fluid to do work on a low-pressure suction fluid. They are very simple in construction (Figure 1:). Essentially, it is a pipe elbow with a steam nozzle directed down the long leg. A check valve is required in the inlet approach piping to prevent back flow in case the steam jet is shut off. It is important to keep in mind the following key aspects of thermocompressors: (1) location and length of the throat; (2) the length and taper angle of the tail piece, and (3) the shape of the steam nozzle. Motive steam flow is controlled by a tapered needle in the nozzle, effectively a variable orifice rather than a pressure reducing valve. In principle, when the spindle is opened, high pressure motive steam expands at high velocity through the nozzle, the jet exiting from the nozzle entrains suction low-pressure steam which accelerates into high velocity in the throat of the thermocompressor. The resulting mixture recovers pressure as it decelerates in the tapered tail piece, being discharged at an intermediate pressure. Thus, the energy of high-pressure steam is utilized to-compress low pressure steam to a higher pressure, i.e., a steam jet compressor.

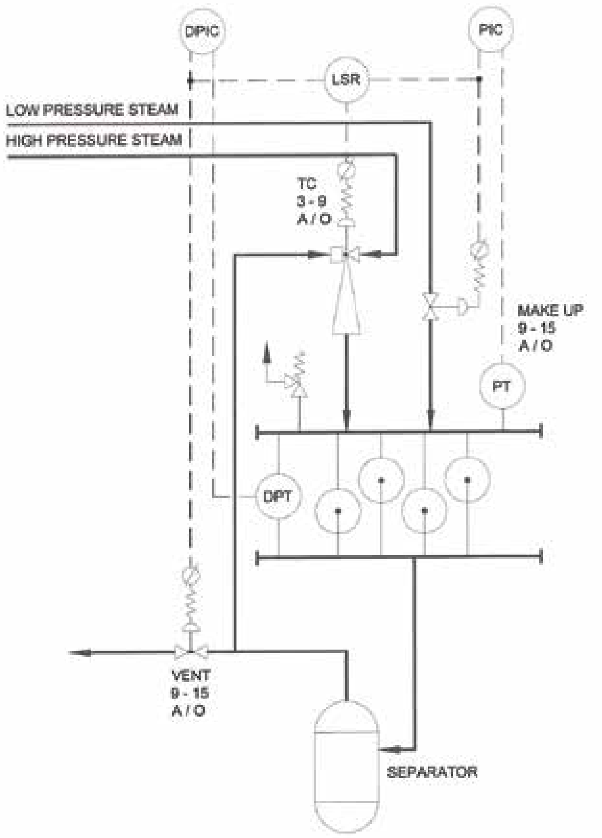
One key mistake made by end users is to treat them as "off-the-shelf" items. It is crucial to understand that the design of thermocompressors involve customizing them to a range of machine conditions and operation. The use of the specified conditions will then be applied to determine the appropriate sizing for the throat and motive steam nozzle. The throat size determines the dimension and other aspects of the body, and it is normally sized to handle the large flow volume at the lowest dryer pressure. The steam nozzle is sized to provide enough energy for the maximum work of compression at the highest dryer pressure. As paper machines typically run with a wide range of operating conditions, designing a thermocompressor can be somewhat conflicting, generating most design challenges for process engineers. The throat is normally no larger than about 47% of the discharge pipe bore. During the most efficient mode of operation, the steam jet entrains suction steam at the suction flange, and the flow volume of the mixture exactly fills the throat. One problem we typically see with poorly performing thermocompressors is that, if the steam jet flow is increased further at this point, the volume flow of the mixture becomes greater than what can pass through the throat and a reduction in suction flow occurs. This effect is called "choking" and can severely complicate control of dryer differential pressures. Another challenge for this application is that when working at the highest dryer pressure, the density and velocity of the steam are at a maximum, such that the flow volume does not fill the throat. Accordingly, the flow is subject to turbulent shock loss that reduces performance. Our proprietary software accounts for this shock loss and provides an accurate sizing of the steam nozzle. However, we have seen situations where the design of the nozzle is oversized, resulting in high gain in control loops and other problems such as the need for larger safety relief valves.

Operating Characteristics

Increasing energy costs and price volatility are key factors for the profitability of most paper mills. However, a common misconception about motive steam requirements is that by using lower motive steam pressure, the mill will save energy. The theory behind this incorrect assumption is that if motive steam is extracted at 8 bars instead of 20 bars, the difference will automatically be converted into more generated power. In a typical case where dryers operate within the 3.5 bar range, utilizing 20 bar of steam results in approximately 40% lower consumption. Therefore, the net energy cost to the mill decreases, or at worst remains unchanged, compared to using 8 bar of motive steam. In the case where 8 bars are used as a motive steam, there is little more than 50% higher than the dryer steam pressure. At this level, motive steam required rises to more than double the amount of steam being recirculated, and it may exceed the amount needed by the dryer section, resulting in major steam losses and difficulty in controlling pressures.

Some managers fear that super heat in the motive steam will in inhibit drying or wear steam joint seals. The fact is that even starting with high levels of super heat, the conversion of energy to the work of compression results in supersaturation in the throat (it's wet), and this stuff mixes with recirculated steam that has two or three percent carryover condensate. The discharge after recompression rarely has more than 10 degrees super heat.

Moreover, normally, a 6" or 8" pipe dumps blow-through steam carrying three- or four-hundred percent condensate in the form of a heavy fog into a separator tank at a velocity of much over 900 m/min. There are still plenty of inefficient, obsolete, separators in the market, which lack effective baffles (often eroded out) and the blow-through steam passes right on through without dropping out much of the condensate. From the separator it goes up to the thermocompressor, accelerates to very high velocity in the throat, and discharges back into the dryers. The wet steam erodes the throat of the thermocompressor, increases compression work by adding pipe transport and lift losses to the pressure rise and impairs compression efficiency. No separator is 100% efficient but high separation efficiency is also important to thermocompressor operations.

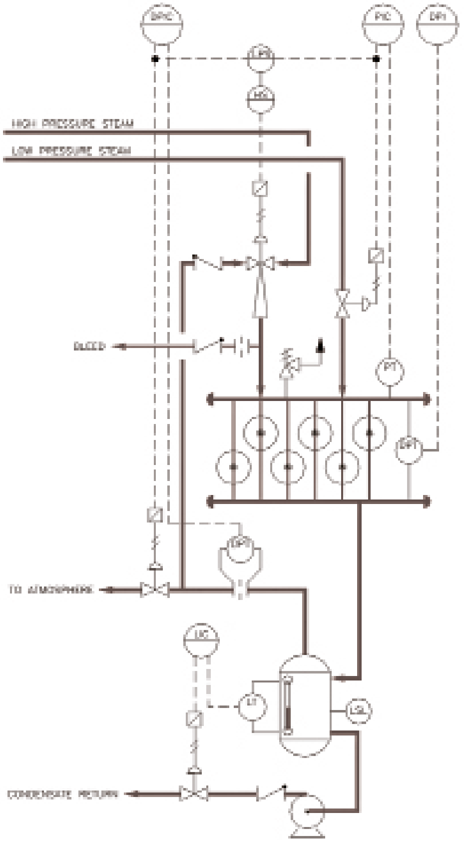


Solving the Problem

A still common method of controlling dryer drainage with thermocompressors is the recirculation system with DP control illustrated in (Figure 2:). Ideally, the DPIC (differential pressure controller) modulates the thermocompressor within the lower half range of its output signal. If the thermocompressor fails to raise the DP to setpoint after fully opening, the signal continues to rise, opening the dump valve (to waste) in the upper half range. In the event of overpressure in the dryers, the LSR (low signal selector relay) allows the PIC (pressure controller) to throttle the thermocompressor after first closing the makeup valve.

DP control systems are not optimal for coping with wide changes in condensing load. If designed to handle the maximum condensing load at maximum pressure, the exponential effects of increasing blow-through flow and pipeline pressure losses overload the thermocompressor as pressure and condensing load decrease, leading to excess blow-through steam waste. Typically, this type of system cannot operate below 1.5 bar of dryer pressure without dumping, hindering performance in paper machines. Additionally, web breaks tend to double the flow of blow-through steam, overwhelming the condenser system and flooding dryers.

The combination of blow-through control and the thermocompressor offers an effective solution. The system configuration in Figure 3 is similar to the recirculation system, but with DP control maintained across an orifice plate in the blow-through line instead of between dryer inlet and outlet headers. Under blow-through control, the range of action required of the thermocompressor is greatly reduced, as blow-through flow automatically adjusts with steam pressure and condensing rate. This results in a smaller thermocompressor throat size despite the increase in steam volume. Recent cases have shown successful operation with dryer pressures as low as 0.5 bar using thermocompressors to recycle blow-through steam. It's crucial to distinguish blow-through control from flow control. Blow-through control manages the velocity head of the blow-through steam, while flow control regulates flow in kg/hr, which may not efficiently drain dryers in various scenarios.



Blow-through control not only prevents steam loss on web breaks but also offers other technical benefits. The dryer DP drops by roughly 70% on a break, which is in accordance with the process mechanics when blow-through flow is restrained at a steady rate. The compression work is thus reduced at that time and the controller reduces the signal to the thermocompressor accordingly. The thermocompressor remains in normal control range in this case as well as in all other points of normal steaming load. Not only is the thermocompressor always in its working range at all operating conditions but a single semi-permanent blow-through control setting may be used. This is in great contrast to DP control in which compression work increases exponentially as dryer pressure is reduced or on load loss during breaks and thermocompressor chokes with the nozzle wide open.

The drying process on a paper machine involves numerous complex factors, therefore it is crucial for all components, particularly thermocompressors, to operate flawlessly for maintaining high efficiency operations. To effectively utilize thermocompressors, addressing various process and control challenges is necessary. Table 1: summarizes common process issues, their underlying design causes, and proposed solutions. Process simulation is an important part for sizing both thermocompressors and entire dryer drainage systems.

Figure 2 (Top left) and Figure 4: (Above)

Table 1

Design Problem	Process Issue	Control Response	Solution
Undersized TC body and throat	- TC choking at low pressures and on web breaks - Steam dumped to condenser/atmosphere	- DP is reduced, low signal select relay is activated thus resulting PIC controller both on DP and pressure control	- Perform system analysis - Redesign TC and system by process simulation
Oversized TC nozzle	- TC nearly closed causing unstable dynamics thus DP tends to swing	- Stiction and backlash - High control gain difficult to tune	- Perform system analysis - Redesign of TC including dynamic Loss
Quick opening spindle	- Controls oscillate	- Very high gain in DP control - cycling	- Equal percentage valve characteristic
Low motive steam Pressure	- TC Wide Open - Not able to control DP - Steam dumped to condenser/atmosphere on run	- PIC controls TC and makeup valve - High DPIC output	- Raise motive pressure - Utilize higher pressure motive steam
Dryer DP control of dryer drainage	- TC chokes at low pressure and web breaks - Steam dumped to condenser/atmosphere - Unresponsive to load surges	- Frequent switching differential control to pressure control w/ deadband - Optimum setpoint is a problem	- Blow-Thru controls
Inefficient condensate separator	- Condensate carryover - Reduces TC efficiency - Erodes TC throat - Increases DP and increases the amount of work required for the TC	- Errors in orifice flow measurement	- High-Efficiency radial type separators
Piping and dryer syphons over or undersized	- TC wide open - Dryer flooding - Steam dumped to condenser/atmosphere on run	- PIC controls TC and makeup valve - High DPIC output	- Perform system analysis and redesign TC and system by process simulation