EXECUTIVE SUMMARY

The moisture content of paper and paperboard products is controlled by adjusting the steam pressure in select dryer cylinders. During normal operation, grammage (basis weight) and exiting press moisture change very slowly and adjustment of steam pressures to meet the changing drying requirements need not be very responsive.

The change in drying requirements following grade changes, speed changes, weight changes, and similar production changes, however, are much more rapid. The moisture control loops in conventional paper machine dryer sections do not respond quickly to such changes in operating conditions and there is a resulting period of off-quality production.

During a sheet break, the dryer surface temperatures increase above their normal operating values and the moisture content of the sheet following re-threading will be much lower than it was prior to the sheet break. Further, the signal from the moisture scanner does not immediately reflect the average sheet moisture so the sheet moisture content will tend to over-shoot and oscillate if rapid adjustment of steam pressure is attempted.

To avoid the tendency for short-term over-shoot and long-term oscillation, conventional dryer section moisture control loops are normally severely de-tuned. The control loops do not respond quickly to changes in operating conditions. The paper production is off-quality until the moisture content is finally stabilized.

This paper reviews data on thermal response of a dryer cylinder to changes in heat load (sheet break simulation) and to changes in dryer steam pressures. It also shows the improvements that are possible with the application of Turbulator® bars and advanced dryer section control. This data was obtained from the pilot dryers at the Kadant Johnson Research and Development Center in Three Rivers, Michigan, USA.

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INTRODUCTION

The response of a dryer section moisture control system depends on a number of process, control, and operating parameters. There are a number of reasons why moisture control loops are often de-tuned: to allow for sheet transport lag, dryer section thermal lag, and scanner signal lag. This paper provides an introduction to the fundamentals of drying, describes the process parameters that influence the dryer steam pressure response, and then presents data on the response characteristics of the dryer section.

This paper also shows how the application of Kadant Johnson Turbulator® dryer bars can significantly increase the thermal response to changes in dryer steam pressure. This increased responsiveness can be coupled with advanced moisture control algorithms to reduce the response time following a process change or a sheet break. The improvement in responsiveness can be quite significant. Reductions in response time of four to five times are possible.

DRYING FUNDAMENTALS

The thermal response of a dryer section as well as the drying rate of the paper are directly related to thermal resistance between the steam inside the dryer and the moisture that is held by the paper fibers. There are several thermal resistances between the steam and the moisture in the paper: the condensate, scale on the inside and the outside of the dryer shell, the dryer shell itself, air that is trapped between the paper and the dryer surface, and the outer layers of fibers in the paper.

These various resistances can be lumped together, as shown in Figure 1, into three categories: the condensate, the shell, and the sheet (i.e. resistances inside the dryer, the resistance of the dryer shell, and resistances outside the dryer.) All three of these resistances are significant. All three tend to restrict the drying rate and the thermal response of the dryer section to changes in steam pressure. The following section deals with the condensate resistance.

![Figure 1: Heat Transfer Resistances](image)
CONDENSATE BEHAVIOR

As steam transfers its heat to the dryer shell, it condenses. Under normal operating conditions, this condensed steam, or “condensate”, is removed from the dryer through a dryer syphon, either a cantilevered stationary syphon or a rotating syphon that is fixed to the dryer shell.

The steam pressure inside the dryer is used to force the condensate out of the dryer. This steam pressure also forces a large volume of uncondensed steam (about 10-20% by mass) out of the dryer along with the condensate. This uncondensed steam is called “blow through” steam because it “blows through” the dryer without condensing.

Depending on the dryer speed, the condensate may be in a ponding, cascading, or rimming condition (6). These conditions are depicted in Figure 2.

If the dryer is rotating slowly, then the steam will condense directly on the dryer surface, and the condensate will run down the sides of the dryer shell and into a puddle at the bottom of the dryer. This condition is called “ponding.” Because the upper part of the shell is directly exposed to saturated steam, there is little resistance to the transfer of heat from the steam to the shell and the thermal response of the dryer is high.

As the dryer rotates a little faster, a thin layer of condensate begins to follow the dryer surface, but the majority of this condensate falls back into the puddle rather than following the surface for a complete revolution. This condition is referred to as “cascading” and it occurs at speeds up to 335-365 mpm (1100-1200 fpm).

Ponding  Cascading  Rimming

Figure 2: Condensate Behavior in a Dryer
The heat transfer resistance caused by the condensate in the cascading condition is very low because the condensate film on the upper portions of the dryer shell is very thin and the condensate layer on the rest of the surface is very turbulent. The thermal response of the dryer that is operating in the cascading condition is also very high.

Most modern paper machines operate well in excess of 400 mpm (1300 fpm). At these higher speeds, the condensate forms a thin layer that covers the entire inside surface of the dryer shell, in a condition that is called “rimming.” This thin layer of condensate is not very turbulent. As a result, there is a significant drop in temperature as the heat is transferred from the steam, through the rimming condensate, to the dryer shell. The heat transfer resistance increases both with dryer speed and with the amount of condensate in the dryer. The thermal response of the dryer is correspondingly reduced.

TYPES OF DRYER SYPHONS

Since the condensate in the dryers can significantly impede the transfer of heat and the thermal response of the dryer, the efficient removal of condensate from the dryers is a critical factor in the performance of high-speed dryers. Syphons of various designs are used to remove the condensate and to minimize its depth inside the dryer. They typically are either close-clearance rotating syphons or cantilevered stationary syphons, with somewhat larger clearances.

Kadant Johnson pioneered the development of rotating syphon shoes specifically for high-speed dryers. These close-clearance, large-perimeter rotary syphon shoes work well with non-rimming condensate as well as with rimming condensate. The syphons produce thin condensate layers so that the heat transfer rate and uniformity are kept at acceptable levels. A typical rotating syphon is shown in Figure 3.
At high machine speeds, the pressure differential required to evacuate the condensate from the inside surface of the dryer cylinder using rotating syphons can be quite high. There is also a correspondingly high amount of blow through steam that is evacuated with the condensate. To overcome these problems at high speed, stationary syphon shoes can be used. A cantilevered stationary syphon is shown in Figure 4. This syphon has been designed to be very rigid so that it has a high natural frequency and will not vibrate.

Above 1000 mpm (3280 fpm), the insulating effect of the rimming condensate can be very large, regardless of whether the dryer has stationary or rotary syphons. With stationary syphons, however, the condensate depth tends to be much larger and the resulting drying capacity is reduced and the dryer surface temperature profiles lose their uniformity.

In the late 1970's, dryer bars were developed to improve the rate of heat transfer from paper dryers with rimming condensate. Dryer bars are a series of axial bars, held against the inside surface of the dryer cylinder. When the correct number of bars is installed inside the dryer cylinder, and with the correct amount of condensate in the dryer, the dryer bars will cause the rimming condensate layer in the dryer to resonate. This resonance in turn greatly increases the rate of heat transfer, even with significant amounts of condensate in the dryer. The heat transfer can be as high in the rimming, resonant condition as in the ponding and cascading conditions, even though the condensate is still rimming and the dryers are rotating at very high speeds.

Kadant Johnson developed a unique configuration of dryer bars, Turbulator® bars, to get the maximum heat transfer rates and highest possible CD uniformity. The Turbulator bars are shown schematically in Figure 5.

![Figure 4: High-Speed Stationary Syphon](image-url)
With the development of Turbulator bars, it is possible to use stationary syphons and not have the poor heat transfer and poor drying profiles normally associated with stationary syphons. Kadant Johnson developed a high-performance stationary syphon specifically for use with Turbulator bars. A rotary joint and mounting bracket were also developed to ensure a rigid mounting for the stationary syphon.

The combination of the joint, bracket, syphon, and Turbulator bars provide high heat transfer rates, rigid mounting, and ease of installation and maintenance.

**MOISTURE CONTROL RESPONSE**

Steam pressures in paper machine dryer sections have been used to control sheet moisture for decades. Initially, papermakers adjusted the steam pressures manually, by “feeling” the moisture content of the sheet as the sheet was doctored off of the last dryer or wound onto the paper machine reel. Later, scanning systems were developed to sense the sheet moisture content, to give the papermaker a quantitative indication of sheet moisture. The scanner output was eventually connected to the control system, to automatically adjust the steam pressures and provide control of the moisture content.

The automatic control system would normally adjust the steam pressure in the main dryer section or else in a “vernier” group of dryers. Steam pressures in the adjacent wet end and dry end dryer sections would be left unchanged.
The response time of the control systems are limited by several parameters:

- Transport delay
- Thermal delay
- Scanner delay

The transport delay reflects the time between the sheet contacting a controlled dryer and the time that it reaches the moisture scanner. This time delay depends on the length of the sheet run between the controlled dryer and the scanner and the machine speed.

For example, if there are 25 dryers between the controlled dryer and the scanner, and if each dryer has a sheet path length of approximately 6 m (20 feet), and the machine speed is 1000 mpm (3280 fpm), then the transport delay would be:

\[ T = \frac{25 \text{ dryers} \times 6 \text{ m/dryer}}{1000 \text{ mpm}} \times 60 \text{ sec/min} \]

\[ T = 9.0 \text{ seconds} \]

The thermal delay reflects the thermal mass of the dryer cylinder and the internal condensate heat transfer coefficient. This delay is more difficult to estimate and is the subject of the testing reported in this paper.

The scanner delay reflects two factors: The time required for the scanner to go from the front to the back of the machine and the algorithms used for averaging the scanner readings. The time for a scanner to go from one side to the other depends on the scanner speed and the width of the machine. Typical scanner times range from 20-30 seconds. The filtering systems used to condition the scanner signals would normally reflect values that are up to 2-5 minutes old, giving the most recent signals a higher weighting.

Because of these long delays, the moisture control system is normally severely detuned. The ability to respond to the changes in the reel moisture content is correspondingly reduced.

There are a number of ways to increase the responsiveness of the dryer section steam pressure control, in spite of these inherent delays. The most significant of these ways is the reduction in thermal delay and the use of a feed-forward control system.
The performance of several stationary syphon configurations was determined using the Joco 4000 and Joco 6000 pilot dryers at the Kadant Johnson Research Center. Reported here are tests on the Joco 4000 dryer.

In the first set of tests, the steam pressure, machine speed, condensing load, and operating differential pressure were first stabilized so that the dryer outside surface temperature was stable. This simulated a dryer running under normal operating conditions. During this test, the dryer was equipped with a cantilever stationary syphon with its clearance to the shell set at 3.4 mm (0.14”). The steam pressure was set at 3.1 bar (45 psig).

All of the operating parameters were held constant, except the external cooling load. In Phase I, the cooling load (water spray) was shut off instantaneously and the response of the dryer surface temperature was then recorded. The results are shown in Figure 6.

The dryer surface temperature was 81°C just prior to shutting off the water spray system. The surface temperature then climbed steadily until it reached a value of about 122°C. This value is slightly below the saturation steam temperature, but significantly above the dryer surface temperature for normal dryer operation.

For this dryer configuration, the time required to achieve a steady surface temperature was nearly 30 minutes.
After 27 minutes, the cooling load was again applied to the dryer cylinder, to simulate the response of the dryer to the sheet being re-established on the machine. The dryer surface temperature dropped at a rate similar to the rate at which it had increased, until it reached a steady value of 81°C. The dryer took about 30 minutes to re-establish its normal operating temperature, as shown in Figure 6, for the Phase II response.

Although this test simulated the response of the dryer to a sheet break condition, it is also indicative of the dryer response to a grade change (decrease in sheet grammage or change in machine speed). The dryer response to grade changes is similar in time but lower in magnitude to its response to a sheet break.

In the next set of trials, the stationary syphon clearance was increased to 6.5 mm (0.25") and the operating conditions re-established. In order to achieve the same dryer surface temperature, the steam pressure was increased from 3.1 bar to 6.2 bar (60 psig). Once again, the dryer cooling load (water sprays) was quickly shut off and the dryer surface temperature monitored. The results are shown in Figure 7.

![Figure 7: Dryer Surface Temperature Response](image-url)
The dryer surface temperature was 81°C just prior to shutting off the water spray system. The surface temperature then climbed steadily until it reached a value of about 138°C. This is 16°C above the dryer surface temperature that occurred after the simulated sheet break with the stationary syphon clearance set at 3.4 mm. Under these operating conditions, the time required to achieve a steady surface temperature was more than 40 minutes.

Kadant Johnson Turbulator bars were added to the dryer cylinder and the above tests were repeated. The Turbulator bars significantly increase the rate of heat transfer through the condensate layer. In order to achieve the same dryer surface temperatures as in the previous tests, the dryer steam pressure had to be reduced, in this case from 6.2 bar to 1.0 bar (15 psig). The significant reduction in steam pressure required to achieve the same dryer surface temperature highlights the magnitude of improvement in heat transfer that is provided by Turbulator bars.

Once the dryer surface temperature stabilized at 81°C, the water spray system was again shut off and the dryer surface temperature was recorded. The surface temperature increased to 96°C and stabilized there in less than four minutes. This is more than five times faster than either of the previous tests in dryers that did not have Turbulator bars. These results are shown in Figure 8.
With Turbulator bars, the dryer surface temperature response is much faster and the excursion above the normal operating temperature is much less than a dryer that does not have Turbulator bars. This increase in response and reduction in surface temperature deviation helps to improve the ability of the dryer to recover from sheet breaks and for the control system to respond to changes in operating conditions.

In the next series of tests, the dryer response was measured after a simulated sheet break and dryer shutdown. A rotating syphon was used for this set of tests. The dryer steam pressure was set at 10 bar gauge (145 psig), the differential pressure was set at 0.4 bar (5.8 psi), and the dryer speed set at 650 mpm (2200 fpm). The dryer was equipped with a commercial close-clearance, heavy-duty rotary syphon (Kadant Johnson 1x1 HDRS). The dryer operation was stabilized under these conditions, then stopped quickly, with the rotating syphon pointing upward. This simulated a sheet break, followed by stopping the dryer without putting the manhole up (syphon in the puddle). The dryer was left in this position for 10 minutes, simulating the time required to remove a sheet wrap. During this time, the steam pressure was held at 10 bar (145 psig) and the differential pressure maintained at 0.4 bar (5.8 psi).

After ten minutes, the dryer was quickly accelerated back to its original operating speed of 670 mpm (2200 fpm) and the condensing load and dryer surface temperature monitored. The dryer condensing load and dryer surface temperature were monitored during this recovery period. The results are shown in Figure 9.
After the dryer had been stopped for ten minutes, the dryer surface temperature was 182°C (359°F). As the dryer speed was restored and the heat load resumed, the dryer temperature dropped, eventually stabilizing again at 171°C (339°F), about 11°C below the sheet break temperature. The condensing load also increased quite dramatically during this sheet break recovery period, from a low of 29 kg/hr (64 lb/hr) for radiation loss from a stopped dryer, to 983 kg/hr (2165 lb/hr), which was the simulated sheet drying conditions. Both the condensing load and dryer surface temperatures recovered from the sheet break in less than ten minutes.

The dryer did not flood during the dryer acceleration back to operating speed. This will be the case when the dryer is equipped with a proper rotating syphon and the steam system controls are properly tuned. In this case, the thermal response of the dryer was very fast and the resulting sheet would have achieved its target moisture content fairly quickly.

CONTROL SYSTEM RESPONSE

Advanced dryer system controls can be used to further improve the control of the sheet moisture content. There are several elements of an advanced control system that can make use of the improved dryer thermal response, improving the control of the sheet moisture content and reducing the amount of off-quality paper that is produced. Five of these elements are:

- Steam pressure adjustment for grammage changes
- Steam pressure adjustment for speed changes
- Steam system pressure control
- Sheet break pressure turn-down
- Sheet threading pressure ramp-up

Conventional moisture control systems are feedback systems. The steam pressure in a select dryer section is adjusted in response to deviations in the reel moisture from the target value. Because of the long transport, thermal, and control time delays, considerable off-quality paper is produced. Further, the adjustment of steam pressure in one group of dryers often affects the operation of dryers in the other steam groups. For dryers operating in a conventional cascade system, wet end dryers may begin flooding and dry end dryers may begin to vent steam. Also, adjustment of steam pressure in only one group will change the moisture profile in the machine direction. This can increase picking on wet end dryers and require different draws at the section breaks.

The thermal response of the dryers can be significantly improved by installing proper syphons and Turbulator bars. This improved response can be used to improve the control of the moisture content. This can be done in an advanced control system that incorporates a feed-forward
control loop to respond to changes in the dryer speed and the sheet grammage, even before these changes are reflected in changes in the moisture content at the reel.

Grammage changes. For example, if there is an increase in grammage, an advanced control system will calculate the increase in drying capacity that is required and will ramp up all of the steam pressures in advance, based on this calculation. The ramp-up period will reflect the thermal response of the dryers (long time for conventional dryers, short time for dryers equipped with Turbulator bars).

Speed changes. An advanced control system can also be used to provide feed-forward response to changes in machine speed. The increase in drying capacity that is required for the increase in speed is calculated and the steam pressures are ramped up in advance, based on this calculation. The sheet moisture content at each section break remains unchanged, the steam system remains in balance, there is no steam venting, dryers do not flood, and the amount of steam going to the vacuum condenser does not change.

Significant improvements in sheet quality and reductions in off-quality production are possible with this type of advanced control.

Steam system control. The stress-strain characteristics of paper are highly dependent on its moisture content. The speed draw must be carefully adjusted between each pair of dryer mechanical groups to maintain the required sheet tension. The optimum draw is affected by the moisture content of the sheet at that specific draw location. With an advanced control system, each of the dryer pressures can be controlled in such a way that the sheet moisture content at each draw location remains unchanged. If the machine-direction (MD) moisture content profile does not change, then the speed draws do not have to be re-adjusted. This can significantly improve the runnability of the machine.

With an advanced control system, the steam pressure adjustments can be made such that the steam and condensate system remains in balance, without steam venting, dryer flooding, or excessive amounts of steam being dumped to the vacuum condenser.

Sheet break control. In addition to handling grade changes, an advanced control system can also be used to manage the dryer response to sheet breaks. Following detection of a sheet break, the advance control system will automatically reduce the steam pressures in each of the dryer cylinders, in order that the dryer surface temperatures do not exceed their normal operating values. This requires a calculation of the steam pressure turndown amount for each dryer section.

By adjusting each dryer steam pressure by an appropriate amount, the dryer surface temperatures remain constant, the dryers do not flood,
there is no venting of steam, and the vacuum condenser is not overloaded.

Because the dryer surface temperatures remain constant, the moisture content of the tail after it is threaded is at the correct value at each position along its machine-direction path. This prevents over-drying the tail. Over-drying can result in edge cracks and sheet breaks.

Sheet threading control. Once the tail has been threaded, the signal to widen the sheet can also be sent to the advanced control system so that the steam pressures in each of the dryers can be ramped up to their normal operating values, in advance of a signal from the moisture scanner. This helps to reduce the number of sheet breaks that occur during the threading process.

By incorporating Turbulator bars in the dryers along with an advanced control system, the potential for dryer surface temperature excursion is greatly reduced, the actual amount of dryer surface temperature overshoot can be minimized, and the drying response time can be significantly improved.

After the sheet has been re-established, moisture control can continue to be handled by the advanced supervisory control system or returned to the QCS control system.

**SUMMARY OF CONTROL CONSIDERATIONS**

There are two aspects of papermaking that have inherently reduced operating efficiency and prevented rapid grade changes: The slow thermal response of the dryer section and the reliance on feedback systems for moisture control. These limitations can be greatly reduced by installing Turbulator bars in the drying cylinders and taking advantage of these improvements in dryer section thermal response with advanced control technologies.

The installation of Turbulator bars will result in increased drying capacity, improved moisture profiles, increased production capacity, reduced dryer surface temperature over-shoot following a sheet break, and increased response to steam pressure changes. The change in drying capacity is remarkable, as is the improvement in thermal response.

The combination of Turbulator bars and advanced steam and condensate system control can significantly improve the ability of the machine to recover from sheet breaks, by avoiding the dryer surface temperature over-shoot, and improve the response of the drying capacity to various grade changes.
This speed of response is essential for new, wide, fast paper machines. The enhanced response not only reduces the amount of off-spec production, but also allows the machine to make frequent grade changes to serve small or niche markets.

REFERENCES


To address the needs for improved control and response in the dryer section, Kadant Johnson has developed an advanced control system called Dryer Management System™ (DMS) control software.

DMS warms up the dryers and, under programmed control, prepares the machine at the fastest safe rate to bring on the sheet. From then on, the system automatically adjusts itself to changing machine conditions. Sheet breaks, pressure changes, grade changes, and other upset conditions are automatically handled by the system. Operators can program preset drying curves for various grades and can adjust the system upwards or downwards if needed for special circumstances.

Proper management of all energy input is ensured. Vent valves to the condenser are eliminated for almost all control sections. Supervisory logic manages all system steam pressures, flows and differential pressure setting. With this, the system design allows blow-through steam to be efficiently used within the system for all operating conditions, including sheet break. Control logic manages blow-through steam and differential pressure on a sheet break to minimize venting and loss of energy. Condensate is returned to the boiler house at low temperature for efficient energy use and good condensate handling.

**The Concept Behind DMS**

The philosophy behind DMS is that the paper machine can be divided into two distinct zones: the Quality Zone and the Production Zone. The Quality Zone focuses on the conditioning of the sheet at the wet end of the machine through accurate control of wet end drying conditions. At the early formation stages of the sheet, the drying process is a major determinant of sheet quality and characteristics. The surface properties of the sheet must be well understood in order to properly “set up” the sheet and prevent picking or cockle. This suggests that the modern steam system must have the ability to operate early dryers at sub-atmospheric pressures needed for quality control. To achieve this, there must be effective removal of condensate using stationary syphons, and a high and consistent vacuum source. The Kadant Johnson Vortec™ Vacuum Generator is used to produce vacuum levels of
Kadant Johnson is a global leader in the design, manufacture, and service of dryer drainage systems, rotary joints, syphon systems, and related equipment for the dryer section of the paper machine. For more information about Kadant Johnson products and services, email info@kadant.com or visit www.kadant.com.

- Steam and Condensate Systems
- Dryer Section Surveys
- Dryer Management System® control software
- Stationary Syphons
- Rotating Syphons
- Rotary Joints
- Turbulator® Bars
- Thermocompressors
- Desuperheaters
- Direct Injection Water Heaters
- Vortec™ Vacuum Generators
- Sight Flow Indicators
- Flexible Metal Hoses
- Installations Services