Dryer Condensing Loads Following Sheet Breaks

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When a wet end sheet break occurs on a papermaking machine, the heat load on the dryer cylinders is removed and the condensing load decreases. When the sheet is re-threaded and again passes over the dryers, the heat load is restored and the condensing load increases, eventually back to the rate at which steam was condensing before the sheet break occurred.

Many papermakers believe that not only does the condensing load increase when production is restored, but also the condensing load increases significantly more than the rate that existed prior to the sheet break. This perception is incorrect.

There are three distinct rates: The rate at which steam is condensing in the dryers, the rate at which the condensate is drained from the dryers, and the rate at which condensate is drained from the downstream separator tanks. During normal steady-state operation, these three rates are identical. During sheet breaks, these three rates can be distinctively different, particularly if the steam control system is unstable, poorly tuned, or out of control.

Tests were conducted at the Kadant Johnson Research Center in Three Rivers, Michigan USA to directly measure the rate of condensate evacuation from dryers with different control strategies in response to a sheet break and recovery. Three conditions were tested: In the first, the dryer steam pressure is unchanged during the sheet break. In the second, the dryer steam pressure is turned down using an appropriate supervisory control strategy. And in the third, the dryer steam pressure is turned down by a much larger amount. These results were compared to a theoretical analysis.

These tests and analysis show that after a short delay following a sheet break, the condensing load starts to decrease. It continues to decrease until it reaches a minimum, or until the sheet again passes over the dryers. The condensing load then increases until it reaches the rate that existed prior to the sheet break.

If the dryer steam pressure is reduced during the sheet break by an excessive amount, the condensing rate will be higher than the pre-break rate, but only by a few percent and only for a brief period of time.

However, if the steam control system is unstable or poorly designed, the differential pressure across the dryers may be insufficient during the sheet break to maintain the drainage rate and condensate will start to build up in the dryers. Then, when the differential pressures are finally restored, the rate at which condensate is being drained from the dryers will greatly exceed the rate at which the steam is condensing in the dryers.

Further, if the separator tank level control is poorly tuned, the rate at which condensate is drained from the separator tank will not closely follow the rate at which condensate is entering the separator tank and the level will rise and fall by large amounts. This is often, but incorrectly, thought to be a reflection of a significant increase in condensing rate inside the dryers. It is, however, a reflection of inadequate steam system design or steam system control.
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INTRODUCTION

Paper is dried by passing the wet web over a series of steam heated cast iron drying cylinders. The wet web on the outside of the dryer cylinders provides the “heat sink” for the hot steam inside the dryers. The steam inside the dryer cylinders condenses as it transfers heat to and through the dryer shell and to the wet web on the outside of the dryers. The rate at which the steam condenses depends on a number of factors, including the steam temperature, web temperature, thickness of the dryer shell, thermal contact between the dryer surface and the wet web, type of syphon used to drain condensate from the dryer, and performance of internal dryer bars.

When there is a wet end sheet break, there is no longer a wet web on the outside of the dryer cylinders. The dryer surface temperature increases and the rate at which the steam condenses decreases. These changes, however, do not happen instantaneously. It takes time for the loss of the outside heat sink to be “seen” by the steam inside the dryer. The length of time required for the dryer to respond depends on many of the same factors that determine the rate at which the steam condenses. More on that later.

To recover from a sheet break, a narrow strip of paper is trimmed from the front edge of the wet web and this “tail” is threaded through the dryer section to the end of the paper machine, then widened to once again be a full-width web. After the sheet is widened to full width, the heat load is established on the dryer cylinders and the steam condensing rate increases again.

The rate at which steam condenses inside the dryer cylinder before the sheet break occurs, after the sheet break occurs, and following the widening of the sheet is the focus of this study.

A typical papermaking dryer cylinder is shown in cross-section in Figure 1, for reference.

Also for reference, a dryer section elevation drawing is shown in Figure 2.
Figure 1: Paper Dryer with Stationary Syphon and Turbulator Bars.

Figure 2: Paper Machine Two-Tier Dryer Section.

**HEAT TRANSFER ANALYSIS**

The thermal response of the dryer cylinder can be modeled as a transient temperature response of a long hollow cylinder subject to a step change in external convective boundary conditions. The internal convective boundary conditions can be fixed or varied, depending on whether the dryer steam pressure is adjusted when a sheet break is detected and how much of an adjustment is made.
A typical dryer arrangement is shown in cross-section in Figure 3. The shell transfers heat to paper from point “a” to point “b” (counterclockwise in this figure) and to the environment from point “c” to point “d”. A full time-dependent description of the energy transfer from the shell would require consideration of these areas and their individual characteristics. The transfer of heat from the drying cylinder, however, is dominated by the transfer of heat to the paper, between point “a” and point “b”, so a simplified model that treats the entire surface of the cylinder as transferring heat to the sheet is considered here.

A typical section of the dryer cylinder is shown in Figure 4 in which the heat transfer resistances are identified between the steam inside the dryer and the wet paper web on the outside of the dryer.
The temperature of the steam inside the dryer depends on the cylinder steam pressure. As the steam transfers its heat to the paper, there is a temperature drop across the condensate layer inside the dryer, another temperature drop across the dryer shell and any scale that may be in the inside surface, and yet another temperature drop across any scale, air gap, or paper fibers between the outside surface of the dryer and the water that is carried by the paper in contact with the outside surface.

This is for steady drying conditions. During a sheet break and recovery, these temperatures change with time in response to the change in boundary conditions. The most significant of these changes are reflected in the response of the dryer shell temperature.

The changes in temperature of the dryer shell during sheet break and recovery are described by the following one-dimensional transient heat transfer equation:

$$\frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial T}{\partial r} \right) = \frac{1}{\alpha} \frac{\partial T}{\partial t}$$

where:

- $\alpha = \frac{k}{(\rho C_p)}$
- $\alpha$ = thermal diffusivity of the shell
- $k$ = thermal conductivity of the shell
- $\rho$ = density of the shell
- $C_p$ = heat capacity of the shell
- $T$ = shell temperature
- $t$ = time
- $r$ = shell radius

The time-varying boundary conditions for the inner and outer surfaces are described below.

For the outer surface, there are two separate conditions, one for sheet in contact with the dryer surface and the other representing a sheet break when the paper is not in contact with the dryer surface. When the sheet is in contact with the dryer surface:

$$-k \frac{\partial T}{\partial r} + h_t (T - T_p) = 0$$

Where $h_t$ is the sheet contact coefficient when the sheet is in contact with the dryer and $T_p$ is the temperature of the sheet. Typical values for $h_t$ range from 200 to 600 W/m²/C.

When the sheet is not in contact with the dryer surface:
At \( r = r_2 \) \[-k \frac{\partial T}{\partial r} + h_a (T - T_a) = 0\]

where \( h_a \) is convective coefficient when the sheet is not in contact with the dryer surface and \( T_a \) is the temperature of the air in the hood. Typical values for \( h_a \) range from 10 to 20 W/m²/C.

The boundary condition for the inner surface is:

At \( r = r_1 \) \[-k \frac{\partial T}{\partial r} + h_c (T_s - T) = 0\]

where \( h_c \) is the condensate coefficient and \( T_s \) is the temperature of the steam in the dryer.

The condensate coefficient depends on thickness of the condensate layer. Dryer bars reduce the sensitivity to variations in thickness and significantly increase the coefficient at rimming speeds. Typical values for \( h_c \) range from 300 to 3400 W/m²/C.

Note: \( T_s \) is the saturated steam temperature and is a function of time if the dryer steam pressure is adjusted during the course of the sheet break.

The solution to the above one dimensional transient heat transfer equation is generally found numerically, either using a commercially available heat transfer analysis program or by using a custom finite element analysis program, as was done for this study.

The step change in the sheet contact coefficient that occurs during a sheet break results in a gradual increase in the outside surface temperature of the dryer shell. Figure 5 shows a typical response of the dryer outside surface temperature to a sheet break when the steam pressure in the dryer is held constant.

![Figure 5. Shell Temperature and Time](image_url)
The time for the shell temperature to increase and the magnitude of this increase depend primarily on the condensing rate before the sheet break, internal condensate coefficient, and thickness of the dryer shell. For commercial dryers, the typical time response will be between 3 and 25 minutes and the typical temperature change will range from 10 to 50 °C.

As the shell temperature increases, the heat flow and the corresponding rate of condensation of steam decreases. When the sheet is re-established on the dryer, the condensing rate returns to its steady state value, as shown for a typical dryer in Figure 6.

![Figure 6. Condensate Formation Rate versus Time.](image)

There are several process delays that occur between the formation of condensate on the inside surface of the dryer shell and its return to the boiler. There is a delay as the condensate film thickness inside the cylinder increases to its original thickness. There is a second delay as the condensate flows through the drain piping to the separator tank. And there is a third delay as the separator tank level control reacts to the change in the rate at which condensate is flowing into the tank. Each of these individual delays is typically longer than the time required for the condensate formation rate to stabilize.
The dryer steam drainage rate was measured directly on a research paper dryer to confirm the above analytical results. The Joco 6000 pilot dryer at the Kadant Johnson Research Center in Three Rivers, Michigan was used for these tests. This dryer is 1.8 m (72”) in diameter with an 8.76 m (345”) face width. The dryer is rated for 11 bar (160 psig) steam pressure. It has a maximum operating speed of 2000 mpm (6560 fpm). And it has a condensing rate capacity of approximately 50 kg/hr \( \cdot \text{m}^2 \) (10 lb/hr-ft\(^2\)).

For the tests in this study, the dryer was equipped with a set of Turbulator® Tube™ bars. The steam was supplied to the dryer through a Kadant Johnson 9800 PTX® rotary joint and the condensed steam and blow-through steam were evacuated from the dryer through a cantilever stationary syphon. A photograph of this dryer is show in Figure 7.

The heat load of the sheet was simulated in these tests by spraying a fine, uniform mist of water on the outside surface of the dryer. The water flow rate was adjusted to achieve the desired condensing load to simulate the drying of paper at a particular rate.

Turning the water shower off simulated a sheet break.

Turning the shower on again simulated the sheet recovery.
TESTING PROCEDURE

For each set of tests, the steam pressure, machine speed, condensing load, and operating differential pressure were set and the dryer was allowed to run until the outside dryer surface temperature and steam condensing rate were stable. This simulated a dryer running under normal operating conditions.

For all tests, the steam pressure was initially set at 8.6 bar (125 psig), dryer speed was set at 915 mpm (3000 fpm), condensing load was set at 1590 kg/hr (3500 lb/hr), and differential steam pressure set to maintain the blow-through steam flow rate at 10%.

After the dryer was stabilized at these operating conditions, the steady steam pressure, dryer surface temperature, and steam condensing rate were recorded.

The cooling load (water spray) was then shut off instantaneously and the response of the dryer surface temperature was recorded along with the rate at which the condensate was being drained from the steam separator that was located downstream of the dryer.

After the dryer surface temperature stabilized, now at a higher level, the cooling load was turned back on, simulating the re-threading and widening of the sheet. The dryer surface temperature and the rate at which the condensate was drained were continuously recorded until the dryer surface temperature was again stable.

The above test was then repeated, but this time the dryer steam pressure was reduced in response to the simulated sheet break. The amount of steam pressure set back was determined by the Kadant Johnson Dryer Management System® supervisory control. For this set of operating conditions, the set-back pressure was 0.7 bar (10 psi). That is, the dryer steam pressure was reduced following the sheet break from 8.6 bar (125 psig) down to 7.9 bar (115 psig).

This test was then repeated again, but this time the dryer steam pressure was reduced by 1.7 bar (25 psi) in response to the simulated sheet break. This steam pressure set-back was higher than the amount determined by the Dryer Management System supervisory control.
The dryer surface temperature was stable at 154°C (310°F) just prior to shutting off the water spray system. This temperature level indicates effective steam system operation and dryer hardware performance.

After shutting off the water spray system, the surface temperature climbed steadily until it reached a value of about 170°C (338°F). This value is slightly below the saturation steam temperature, but significantly above the dryer surface temperature for normal dryer operation. It took about 7-8 minutes for the dryer surface temperature to stabilize at this level (a time period that is normally less than the average break time on a board machine). The rate at which the dryer drainage decreased, however, was significantly slower. It took a few minutes for the condensate drainage rate to change at all, then it dropped continuously, from 1590 kg/hr (3500 lb/hr) down to about 450 kg/hr (1000 lb/hr). This took nearly 20 minutes.

After 19 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 154°C (310°F). The dryer surface took about 6 minutes to re-establish its normal operating temperature.

The drainage rate, however, took much longer to recover to its stable rate of 1590 kg/hr (3500 lb/hr). It took several minutes for the drainage rate to change at all, then it took 16 minutes before the drainage rate was back to 1590 kg/hr (3500 lb/hr).

These results are shown in Figure 8 (Graph I).
In the next set of tests, the dryer steam pressure was reduced during the sheet break time by an amount calculated by the Dryer Management System supervisory control. The set-back was 0.7 bar (10 psi) for this set of operating conditions.

Prior to the simulated sheet break, the dryer surface temperature was stable at the same level as in the previous test: 154°C (310°F). After shutting off the water spray system, the dryer steam pressure was reduced from 8.6 bar (125 psig) to 7.9 bar (115 psig). The dryer surface temperature climbed steadily until it reached a value of about 166°C (330°F). This value is less than the dryer surface temperature from the previous test. It took about 4 minutes for the dryer surface temperature to stabilize at this level (less than the time required for the previous test). As in the previous test, it took a few minutes for the condensate drainage rate to change at all, then it dropped continuously, from 1590 kg/hr (3500 lb/hr) down toward about 450 kg/hr (1000 lb/hr).

After 12 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 154°C (310°F). The dryer surface temperature took about 4 minutes to return its normal operating temperature. For these
In the final set of tests, the dryer steam pressure was again set back during the sheet break, but this time by 1.7 bar (25 psi), an amount that was larger than that calculated by the Dryer Management System supervisory control.

The condensate drainage rate, however, again took much longer to recover to its stable rate of 1590 kg/hr (3500 lb/hr). In fact, it continued to decrease even after the dryer surface temperature had already recovered. It took about 22 minutes for the drainage rate to return to 1590 kg/hr (3500 lb/hr). The drainage rate increased only slightly (about 6%) over the 1590 kg/hr (3500 lb/hr) stable rate before returning to 1590 kg/hr (3500 lb/hr).

These results are shown in Figure 9 (Graph II).

In the final set of tests, the dryer steam pressure was again set back during the sheet break, but this time by 1.7 bar (25 psi), an amount that was larger than that calculated by the Dryer Management System supervisory control.

Prior to the simulated sheet break, the dryer surface temperature was stable at the same level as in the previous test: 154°C (310°F). After shutting off the water spray system, the dryer steam pressure was reduced from 8.6 bar (125 psi) to 6.9 bar (100 psig). The dryer surface
temperature climbed steadily until it reached a value of about 159°C (318°F). This value is less than the dryer surface temperature from the previous test. It took about 20 minutes for the dryer surface temperature to stabilize at this level. This was more than the time required for the previous test because it took longer for the steam pressure to drop by 1.7 bar (25 psi). Again, it took a few minutes for the condensate drainage rate to change at all, then it dropped continuously, from 1590 kg/hr (3500 lb/hr) down to about 230 kg/hr (500 lb/hr).

After 12 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 steam pressure was ramped back to 8.6 bar (125 psig) and the dryer surface temperature took about 7 minutes to return its normal operating temperature, but with a 1.7 bar (25 psi) set-back to the dryer steam pressure, the dryer surface temperature first dropped below its normal operating temperature, then increased back to its original value.

The condensate drainage rate also increased after the simulated sheet break recovery. After 10 minutes, the drainage rate had reached over 1820 kg/hr (4000 lb/hr) and was still increasing. This is because in the dryer shell had cooled off more and required additional heat from the steam simply to get back to the operating temperature.

These results are shown in Figure 10 (Graph III).
CONCLUSIONS

During normal operation, there is a near-linear temperature drop through the thickness of the shell. The inside surface of the dryer shell is hotter than the outside surface temperature. When a sheet break occurs, the outside surface temperature immediately begins to increase as the heat continues to flow from the dryer shell. If the steam pressure remains constant, the dryer surface temperature increases until it reaches a stable value. This value depends on a number of dryer configuration, felting, and process variables, but it is predictable. The condensing rate decreases during the time the sheet is off the dryer. When the sheet is again passing over the dryers, the condensing rate slowly increases back to the rate that existed prior to the sheet break.

If the steam pressure is reduced during the sheet break, the dryer surface temperature does not increase as much. A set-back that is too large, however, results in a longer time for the dryer surface to stabilize, the dryer surface temperature drops below its normal operating value when the sheet is again passing over the dryers, and the condensing rate slightly exceeds the rate for normal operation.

If, during the sheet break, the dryer steam system controls respond too slowly, too quickly, or inappropriately, the dryer differential pressures that are critical for dryer drainage can be too low, condensate can start to build up inside the dryer cylinders, and eventually, the dryers will be flooded. When the differential pressures are finally restored, which may be at values significantly higher than required during normal operation, the condensate inside the dryer cylinders will drain at an excessively high rate. This can overload the separator tank, particularly if the separator control is unable to maintain the level of the condensate in the tank.

If the steam pressure is reduced during the sheet break by the correct amount, the dryer surface temperature increases by just enough to provide the heat to recover quickly, without an undershoot in dryer surface temperature and without causing the steam condensing rate to exceed the normal rate. This provides for stable steam system control and greatly reduces the risk of condensate carry-over from separator tanks that are marginal in size.

REFERENCES

To address the needs for improved control and response in the dryer section, Kadant Johnson developed an advanced control system called Dryer Management System® supervisory control.

The Dryer Management System supervisory control warms up the dryers and, under programmed control, increases the steam pressures to the operating values at the fastest safe rate. During operation, the system determines the correct set points for all control parameters (pressures, differential pressures, flow rates, etc.). 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.

All drying energy steams can be monitored and controlled. Vent valves to the condenser can be eliminated for almost all control sections. Supervisory logic manages all system steam pressures, flows and differential pressure settings. 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.

Dryer Management System Concept

The philosophy behind the Dryer Management System concept is that the dryer section can be divided into two distinct zones: the Quality Zone and the Production Zone.

The Quality Zone conditions the sheet at the wet end of the dryer section through accurate control of wet end drying conditions. In the early drying stages, the drying process is a major determinant of sheet quality. Steam pressures must be properly set to prevent picking and cockle. In many modern dryer sections, the early dryers must operate at sub-atmospheric pressures. To achieve such low pressures, 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 -0.95 bar (28″ Hg), which allows the wet end dryers to operate at pressures as low as - 0.50 bar.

The Quality Zone varies with the grade being produced. Different grades and weights have different Quality Zone requirements. A particular machine will have a number of different Quality Zone drying strategies, depending on the grade structure.

The Production Zone is used to complete the drying process, proving the maximum capacity and maximum flexibility possible. A modern steam system uses a specific drying curve for the given grade being...
produced. System pressures are automatically adjusted based on the drying curve. Production Zone dryers can be made to operate at maximum dryer pressures for drying limited weight grades and at sub-atmospheric pressures for lightweight grades, without the need to valve out dryers.

Unique Dryer Management System Features

- Robust regulatory control
- Intuitive graphic interface
- Remote diagnostics system
- Effortless supervisory control
- Pre-established drying curves
- Automatic system pressure adjustments
- Push-button system control
- Automatic differential pressure adjustments
- Sheet break turndown logic
- Valve condition monitoring
- Press moisture monitoring
- Monitoring of total water evaporation
- Energy balances and reports
- Drying rate analysis
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