Equipment for measurement of cylinder surface temperatures

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Accurate measurement of the cylinder surface temperature provides an indication of the performance of the condensate removal system. This is a necessity to maintain maximum productivity levels on modern high-speed machines. Flooded dryers would have much lower condensate heat transfer coefficients resulting in a substantial decrease in the cylinder surface temperatures. Normally this is checked at regular intervals at the mill by the plant engineer. Accurate, reliable, safe, and easy-to-use hand-held instrumentation is required for this evaluation.

Figure 1 shows the predicted surface temperatures at different condensate heat transfer coefficients for cylinder No. 15 in a printing paper machine equipped with 37 drying cylinders. The calculations were performed with the simulation tool developed by Wilhelmsson and Stenström *(1)*. The condensate coefficient for cylinder No. 15 varied from low to very high values while the coefficients for all the other cylinders were kept at 1450 W/m^2°C. The steam temperature in this section was 141°C.

Based on a condensate heat transfer coefficient of 1450 W/m^2°C, the temperature of cylinder No. 15 was calculated as 119°C. Assuming that inefficient condensate drainage results in a coefficient of only 400 W/m^2°C, the surface temperature is reduced to 104°C. Thus the difference in surface temperature between a normal and a poor operation of the condensate system in this machine would be 15°C. This indicates that instrumentation for cylinder surface temperature measurements must be able to detect differences on the order of a few degrees.

Different designs have been used for the measurement of the cylinder surface temperature. The most common instrument is sold by Swema, Sweden, and is based on the measurement of the temperature in a small cavity inside a wagon sliding on the cylinder surface. This meter was originally developed by Carlander and Jordansson *(2)* in the 1950s and has since become a standard instrument for measurement of cylinder surface temperatures. In their investigation the cylinder velocity ranged between 35–175 m/min, which is far below the velocities used on modern paper machines today. IR-meters are available but dryers with a well-polished surface have undefined low emissivities that render these measurements inaccurate. Indirect IR-meters with an emissivity converter are also available; however, the IR-sensor is very sensitive to the surrounding air temperature, which requires air or water cooling techniques that render this method less practicable for measurements inside the dryer hood.

Hamel and Dostie *(3)* investigated three different designs for the measurement of surface temperatures in calender stacks. The designs used were an indirect IR-meter measuring the temperature of a Teflon band in contact with the surface, a direct IR-meter, and a contacting thermocouple. Over the temperature range studied (<200°C), the three instruments were in good agreement with an estimated accuracy of ±2°C. In this work the meters were used on a pilot calender without a humid atmosphere; thus, the results are not directly applicable for measurements inside a paper dryer hood.

In this work, a new instrument based on the measurement of the temperature of a thin Teflon band sliding in contact with the cylinder surface is presented. Different sources of error of the instrument are considered, both convective heat losses and frictional heating at the interface between the cylinder and the Teflon band. Further, the response time is evaluated for the instrument.

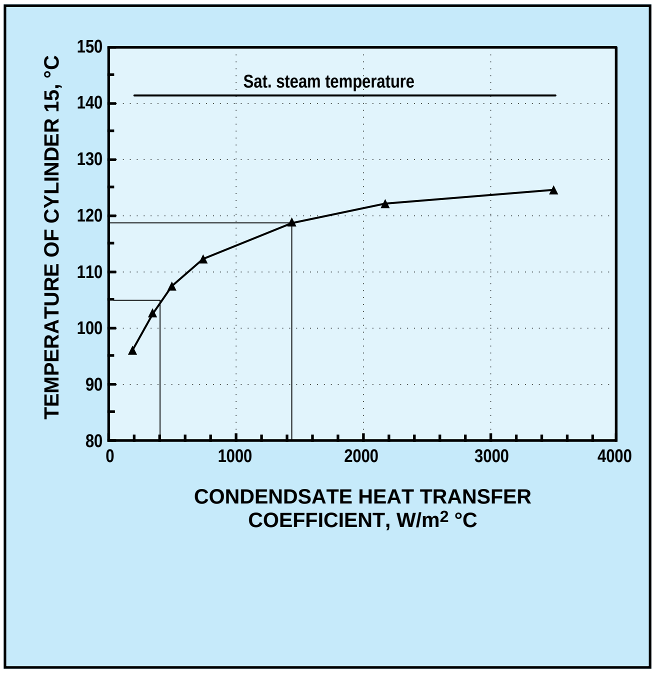
Experimental

The *new design* is a development of a meter manufactured by Heimann in Germany. The infrared sensor in the original instrument was replaced by a thin Pt-100 Kapton foil, which was attached to the back of a Teflon band by an adhesive Kapton tape. The Teflon band was mounted on a spring blade so that it readily followed the cylinder curvature. The meter is shown in Fig. 2. The meter is fastened to the end of a wooden rod.

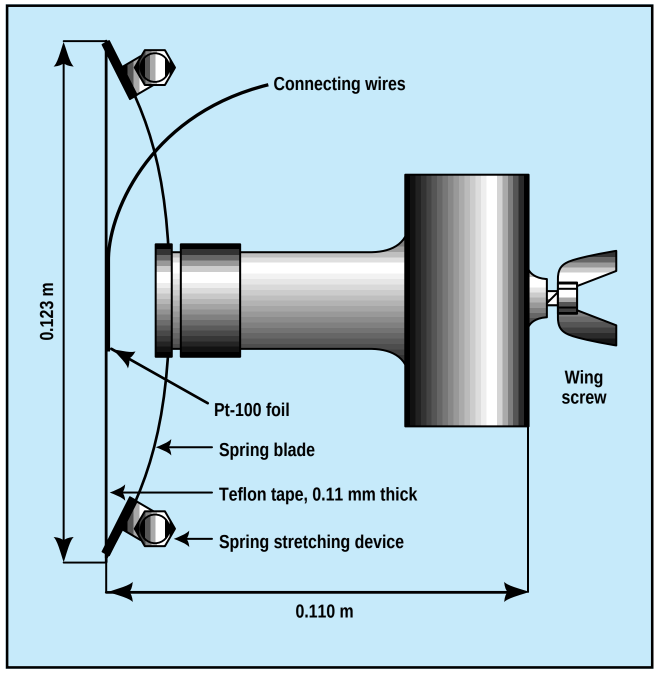
Two sources of error can be distinguished with this design:

- *Convective losses* from the backside of the Teflon cools the Pt-100 element resulting in too low temperatures
- *Frictional heating* at the interface between the cylinder and band heats the Teflon causing too high measured temperatures.

1. Temperature of cylinder no. 15 for different condensate heat transfer coefficients



2. Cylinder surface temperature meter



These effects were studied with a finite difference heat conduction computer program.

The calculations were performed for a cast iron cylinder with a shell thickness of 25 mm, divided into five equally thick elements. The heat conductivity of the cast iron was taken as 45 W/m°C. In the real cylinder the radial temperatures right below the meter will be equalized by heat conduction to surrounding cast iron material. This was included for the five elements in the cast iron. The total thickness of the tape and the Teflon band is d = 0.36 mm, divided into three equally spaced elements. The heat conductivity of Teflon is k = 0.24 W/m°C, the density 2200 kg/m^3, and the specific heat 1050 J/kg°C. The contact coefficient was taken as 1000 W/m^2°C. The convective heat transfer coefficient from the Pt-100 to the surrounding air will depend on the surrounding air velocity; h_{conv} = 5 W/m^2°C corresponds to free convection and h_{conv} = 50 W/m^2°C corresponds to forced convection with an air velocity of 12 m/s. The Pt-100 element is shielded by the spring blade, reducing the convection to the surrounding air. In these calculations a value of 15 W/m^2°C was used for the convective heat transfer coefficient.

Calculations were performed with and without frictional heating at the interface between cylinder and Teflon band. The total weight of the meter and connecting rod is 0.55 kg, and the frictional coefficient for the Teflon was taken as 0.35 *(4)*. With a cylinder velocity of 10 m/s the generated frictional power at the interface can be calculated as 18.9 W. Normally, frictional power between two materials is divided in proportion to the heat conductivities; in this case 17.9 W was assumed to be generated in the steel surface and 1.0 W in the Teflon band surface. The frictional power is negligible as compared with the total heat transfer rate for a drying cylinder; however, the heat flux over the much smaller contact area is 7.9 kW/m^2. This is comparable with a heat flux of typically 25 kW/m^2 in a cylinder with condensing steam.

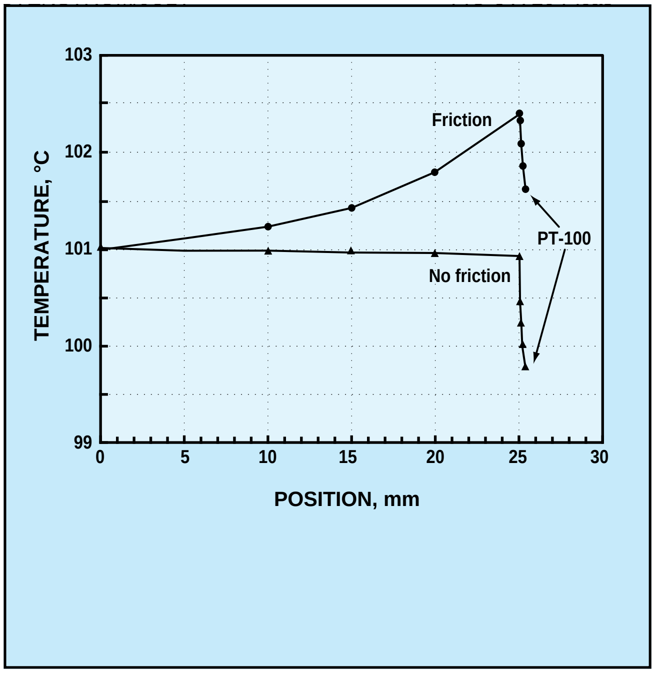
Calculations were performed for a rotating cylinder in contact with the Teflon band. No heat flux from condensing steam was included; thus, the cylinder was initially at 101°C throughout the whole thickness. The surrounding air temperature was taken as 70°C. The stationary temperatures in the cylinder and in the band are shown in Fig. 3.

Without frictional heat at the interface the measured temperature is 1.2°C below the correct cylinder surface temperature. Friction heats the interface 1.4°C above the initial surface temperature and the measured surface temperature is 0.6°C above the correct value. Most of the energy generated at the interfaces flows into the cast iron cylinder; 13.0 W (69%) flows radially, 4.8 W (25%) flows axially to neighboring cast iron material, and only 1.1 W (6%) is conducted through the Teflon band and to the surrounding air.

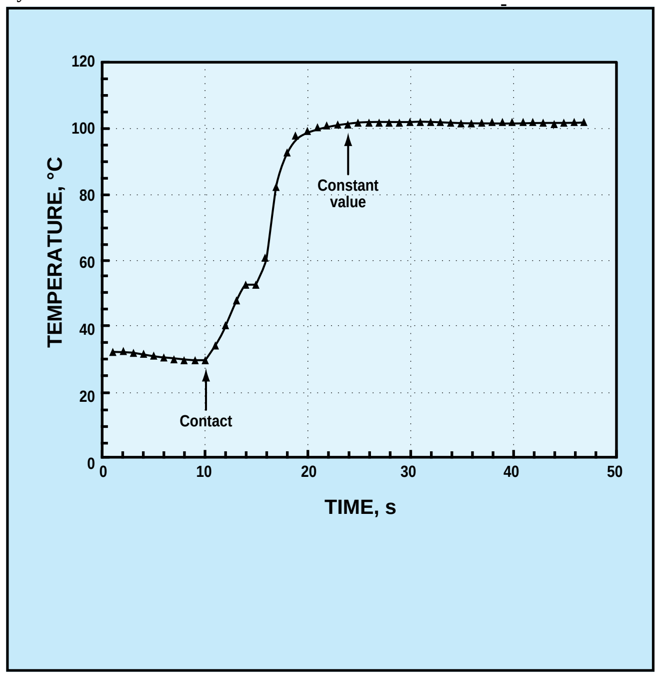
With friction at the interface a reasonable value of the contact coefficient (500–5000 W/m^2°C) has no influence on the measured temperature. This result was verified experimentally on a rotating 0.5-m cast iron wheel in a lathe at room temperature. The surface smoothness of the wheel was similar to the smoothness of drying cylinders. Two velocities were investigated: 503 m/min and 773 m/min. The temperature recorded with the instrument was between 0.4–0.9°C higher than the temperature recorded at zero velocity.

In the real cylinder the meter is exposed to a cylinder surface with a nearly constant temperature and heating of the Teflon

3. Temperatures with and without friction in a 25-mm cast iron cylinder in contact with a 0.36-mm Teflon band



4. Response time for the Teflon band design when measuring on a real cylinder



band will be lower than the value calculated and measured above.

As a summary, the error caused by frictional heating and convective losses can be considered to be less than 2°C with the design shown in Fig. 2.

Response time

The instrument has been used by Stenström *et al. (5)* on an industrial board machine with 83 drying cylinders. A typical response is shown for cylinder number 24 in Fig. 4. A rapid constant response is achieved within 15 s for the Teflon band design. This is much faster than the traditional mill instrument.

Conclusions

Cylinder surface temperatures in paper dryers as well as in calender stacks can be measured with a Teflon band design sliding in contact with the hot cylinder. Frictional heat at the interface causes a too high reading and convecting cooling of the band causes a too low reading. Adding these sources of error, the total accuracy of the meter can be estimated to be ±2°C. The response time of the instrument is less than 15 s. The meter is less sensitive to the surrounding air temperature than traditional mill equipment and it has a considerably shorter response time than for existing equipment.

One disadvantage is the wear of the Teflon band, and in our measurements the band ruptured and had to be winded forward after measuring roughly 30 dryers. This problem could be solved in an industrial meter by design modifications and changing to a more wear-resistant band material. TJ

Literature cited

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