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COOLING EFFICIENCY OF FLAT JET NOZZLES VERSUS FULL CONE NOZZLES ON WORKING ROLL

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Summary: *The cooling intensity of working rolls is very important in industrial applications. The durability of these rolls largely depends on proper cooling. In the case that the working rolls are not covered with a significant water layer, cooling is more effective with full cone nozzles than with flat jet nozzles. This paper is focused on the measurements of the cooling intensity of three different types of nozzles performed on an experimental roll, which enables the thermal boundary conditions which occur on a real working roll to be measured. Two flat jet nozzles with different spray angles and the same flow rate, and one full cone nozzle with half flow rate for equal pressure were tested. The measurements showed that it is possible to achieve the same cooling intensities with half the amount of water.*

1. Introduction

There are two main aspects which need to be taken into consideration in order to optimize the process of roll cooling. The first is the thermal deformation of rolls (Kotrbáček et al., 2009) and the second is the wearing out of rolls (Raudensky et al., 2002). These two aspects affect the durability of the surface layer and shape and tolerance of flat products. We can optimize the cooling of working rolls using different types of nozzles, their arrangement and coolant pressure. We can only find out from measurements and computations how good our design of cooling is. If we had to do these experiments under industrial conditions it would be very expensive and in some cases impossible.

Special apparatuses were built for experiments in the Heat Transfer and Fluid Flow Laboratory at the Brno University of Technology. If we test a new design of cooling or a new type of nozzle, we obtain data with temperatures from the test measurements. Then we use inverse problems of heat conduction to obtain boundary conditions (Pohanka et al., 2009). The boundary conditions are surface temperatures, heat transfer coefficient and heat flux. From this data we choose the optimal solution to the problem, which is then used in practice.

This paper describes the optimization of rolling mill cooling, which requires more homogenous cooling breadthwise. The others demands are water consumption reduction, higher temperature of rolled material at the end of rolling, and to extend the shelf life of a working roll.

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2. Experiment

For the optimization of rolling mill cooling we used a test roll and three types of nozzles – flat jet nozzles with spray angles of 60° and 120°, and a full cone nozzle with a spray angle of 90° and with half the flow rate of the flat jet nozzles.

In practice flat jet nozzles with a spray angle of 60° are often used. They are even used for a larger area than they are able to cool. The edges of working rolls are more strained. The flat jet nozzle with a spray angle of 120° can cool this area better. This type of nozzle allows itself to be easily turned the wrong way. A small turn of the nozzle results in worse cooling. In contrast, however, turning the full cone nozzle a different way does not result in worse cooling. From experience we assume that a full cone nozzle with a lower flow rate can obtain the same or even better cooling. Thus we can save water for cooling. That is why we are comparing this type of nozzle with the other two nozzles in this paper.

2.1. Flow rate measurements

The flow rate of nozzles was measured by the flow meter DN32 from ELA, spol. s r. o. company for prescribed water pressure.

2.2. Impact measurements

Next we measured the pressure distribution of water falling from the nozzles. Special apparatus was used. The pressure sensor is in a free stream. This sensor is moving in two directions. The pressure sensor moves under the spraying nozzle and it measures pressure from the falling water. The distance of the nozzle from the surface is 50 mm and the water pressure is 4 bar.

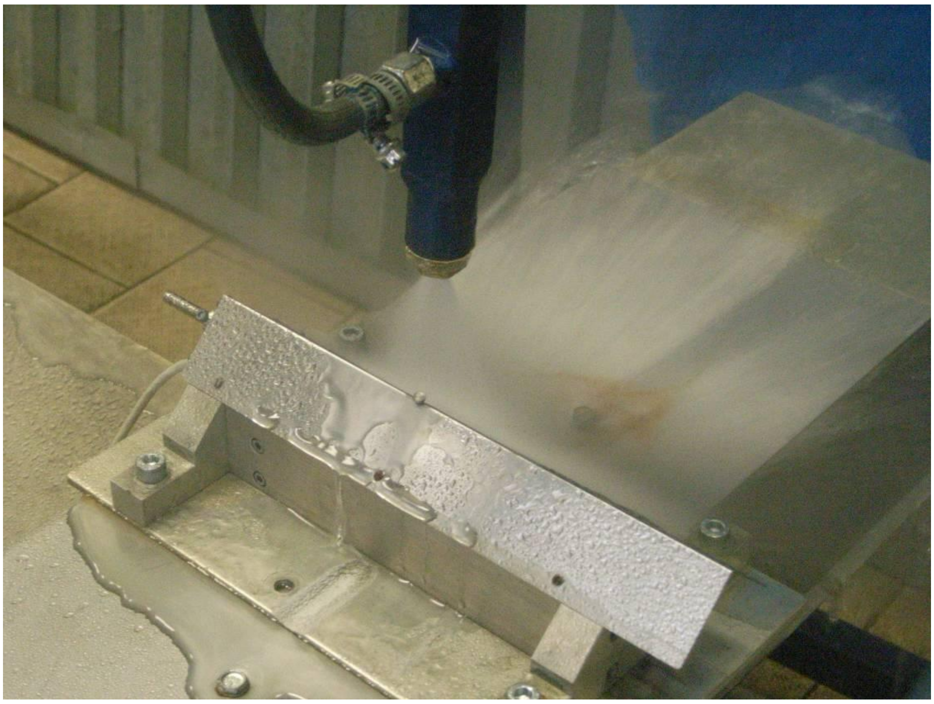

Figure 1 Experimental apparatus for the measurement of the distribution of pressure from falling water.

2.3. Cooling intensity measurements

The last set of measurements was made on the experimental roll (see Figure 2). In these measurements we monitored the effect of rotation speeds and distances of the nozzles from the roll to the cooling intensity in an axis of nozzles. Table 1 shows the list of measurements made on the roll.

Table 1 HTC measurements on the roll (FC – full cone nozzle, FJ – flat jet nozzle)

Experiment	Nozzle	Pressure	High	Speed
		bar	mm	m/s
v1	FC 90°	5	20	3
v2	FC 90°	4	20	3
v3	FC 90°	4	20	6
v4	FC 90°	4	50	3
v5	FC 90°	4	50	6
v6	FC 90°	4	70	1.5
v7	FC 90°	4	70	3
v8	FJ 120°	4	20	3
v9	FJ 120°	4	20	6
v10	FJ 120°	4	50	3
v11	FJ 120°	4	50	6
v12	FJ 120°	4	70	1.5
v13	FJ 120°	4	70	3
v14	FJ 60°	4	20	3
v15	FJ 60°	4	20	6
v16	FJ 60°	4	50	3
v17	FJ 60°	4	50	6
v18	FJ 60°	4	70	1.5
v19	FJ 60°	4	70	3

Figure 2 Experimental roll for HTC measurements on the surface of roll.

Sensors with thermocouples are fixed to the experimental roll. This part of the roll with sensors is heated to a temperature of 280 °C. The heating position is shown in Figure 2. When the heated part of the roll is at the prescribed temperature, the heater is taken off. When the roll speed is adjusted cooling water starts spraying. The data logger records the temperatures in the roll during cooling. Then boundary conditions are computed from the data using an inverse task (Pohanka & Horský, 2007). These boundary conditions are the heat transfer coefficient, heat flux and surface temperature.

3. Calculating of boundary conditions

Beck's sequential approach is used to solve the inverse heat conduction problem (Beck et al.,1985). This method uses sequential estimation of the time varying boundary conditions and future time steps. If the measured temperatures T_i^* are compared with the computed temperatures T_i at the current time m, the sum of squares error is then computed using f future time steps.

$$SSE = \sum_{i=m+1}^{m+f} (T_i^* - T_i)^2 \quad (1)$$

Temperatures T_i are computed from forward solver e.g. FDM, FEM, FVM. Surface heat flux q is obtained by a minimizing equation (1) using the linear minimization theory

$$q^m = \frac{\sum_{i=m+1}^{m+f} \left(T_i^* - T_i|_{q^m=0}\right)\zeta_i}{\sum_{i=m+1}^{m+f} (\zeta_i)^2} \quad (2)$$

where $T_i|_{q^m=0}$ are the temperatures in the thermocouple, which have been embedded in the sensor, and computed from the forward solver using all previously computed heat fluxes without q^m. ζ_i is the sensitivity of the sensor with thermocouple at time index i to the heat flux pulse at time m. These sensitivity coefficients physically represent the rise in temperature in the thermocouple embedded in the sensor for a unit heat flux at the surface. Sensitivity coefficient is defined as

$$\zeta_i = \frac{\partial T_i}{\partial q^m} \tag{3}$$

When surface temperatures T_0^m and surface heat fluxes q^m are known, the heat transfer coefficient can be computed

$$HTC^m = \frac{q^m}{T_\infty^m - (T_0^m + T_0^{m-1})/2} \tag{4}$$

T_∞^m is ambient temperature.

4. Results

4.1. Flow rate measurements

First we measured the flow rate of water for three types of nozzles with a pressure 4 bar. The results are summarized in Table 2.

Table 2 Flow rate of water for pressure 4 bar.

Nozzle	**Flow rate [l/s]**
flat jet 60°	0.24
flat jet 120°	0.24
full cone 90°	0.11

4.2. Impact measurements

Results of these measurements are shown in the following graphs: Figures 3-5. It is obvious that water distribution is not homogeneous. Flat jet nozzles have an intensive spray in the center area. The full cone nozzle sprays more water to the edges of the spray spot. The measurements confirmed the spray angles specified by producers. Figure 6 shows the amount of water pressure when surface passes under the nozzle. This amount of water reflects the cooling homogeneity across the water spray.

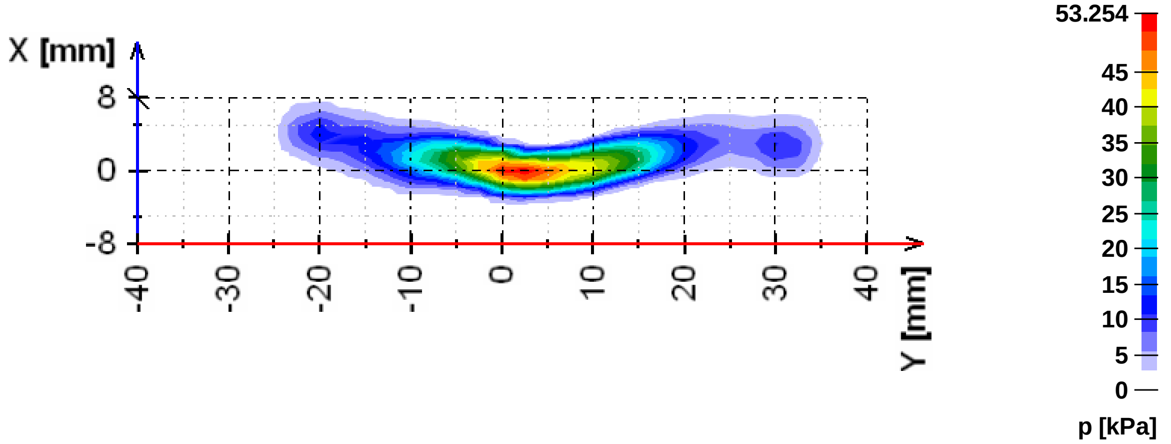

Figure 3 Distribution of water pressure for flat jet nozzle with spray angle 60°.

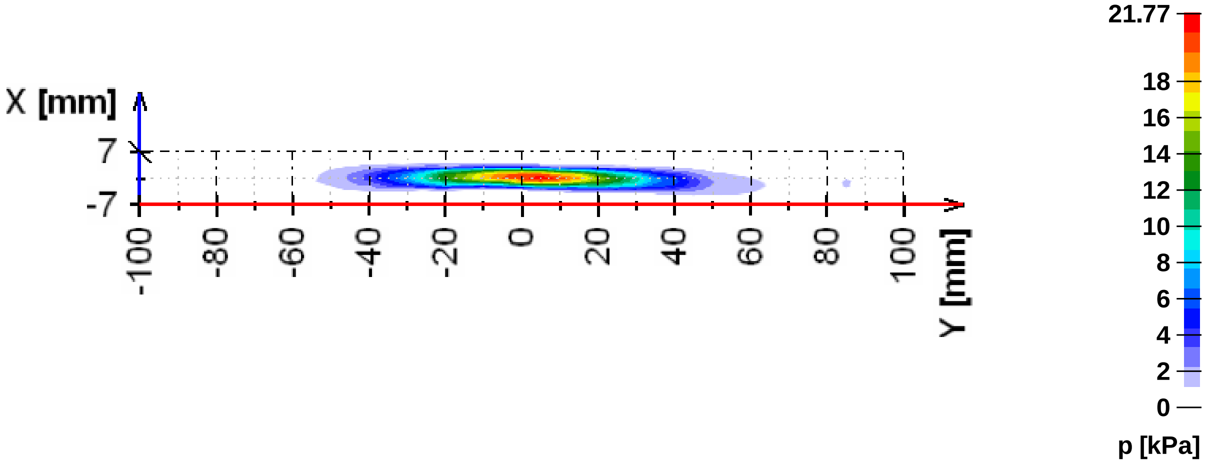

Figure 4 Distribution of water pressure for flat jet nozzle with spray angle 120° (632.807).

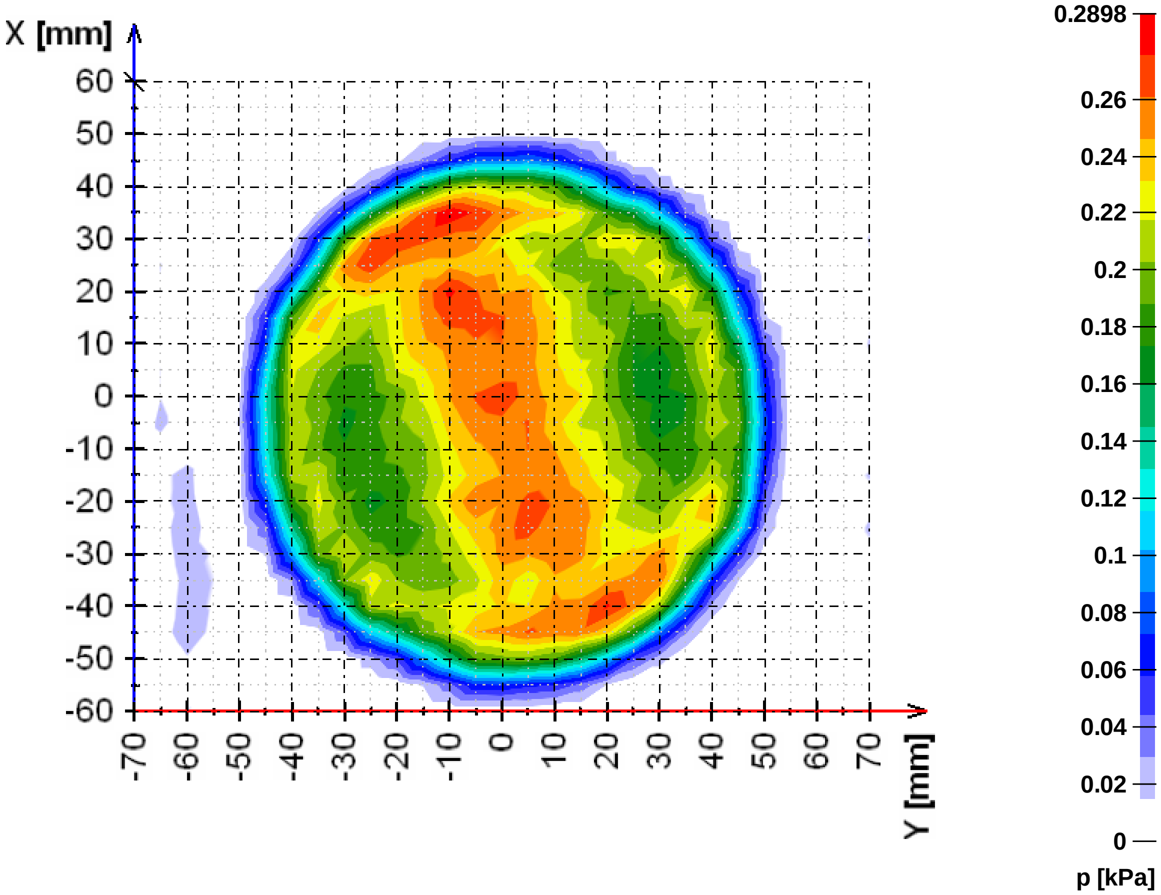

Figure 5 Distribution of water pressure for full cone nozzle with spray angle 90° (460.686).

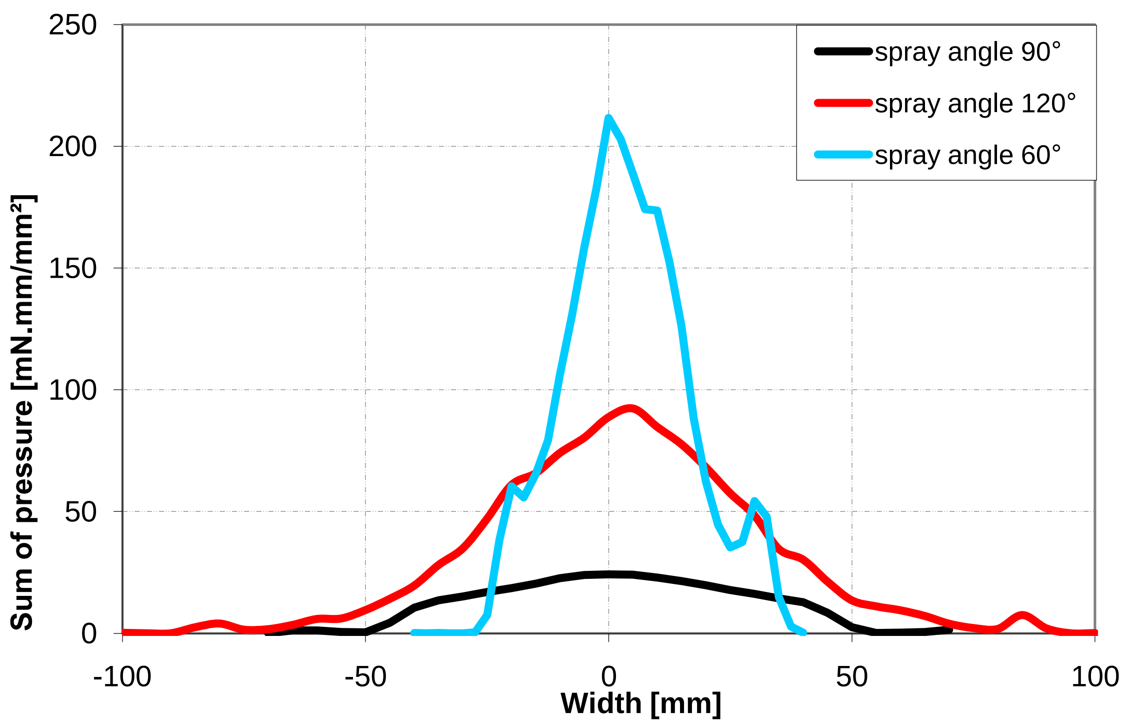

Figure 6 Summation of impact pressure in the direction of movement of the working roll.

4.3. Cooling intensity measurements

The calculated heat transfer coefficients are shown in the following Figures 7-9. The results are split into three parts according to the entrance surface temperature to the cooling section. In the first part the HTC is for a surface temperature over 140 °C, the second part is the transition zone and in the third part the HTC is for a surface temperature under 100 °C. Only the first part is of interest to us. The split temperatures are important because water fast evaporates from the surface with a temperature over 140°C, and the wetting of surface is for temperatures under 100°C. The graphs show the HTC distribution around the circumference of the roll. In Figure 10 the average values of the HTC are shown. These average values are obtained from every curve shown in Figures 7-9.

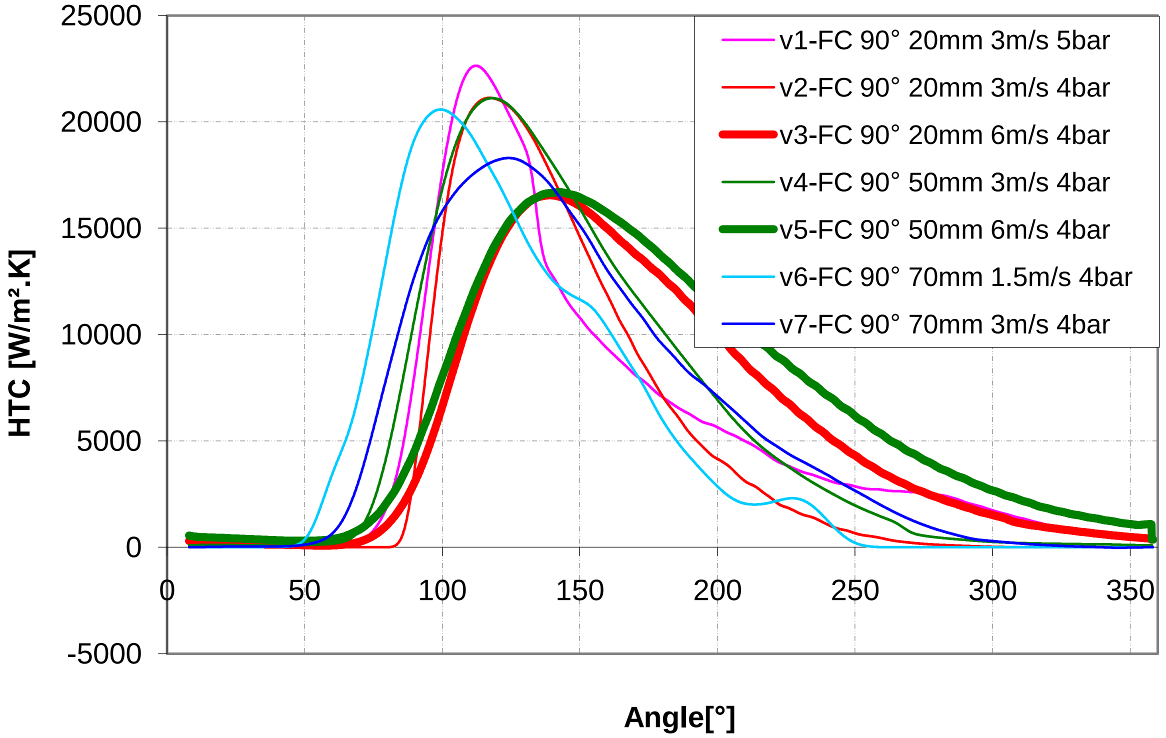

Figure 7 Distribution of HTC around the circumference of the roll, the experiments 1-7 in Table 1.

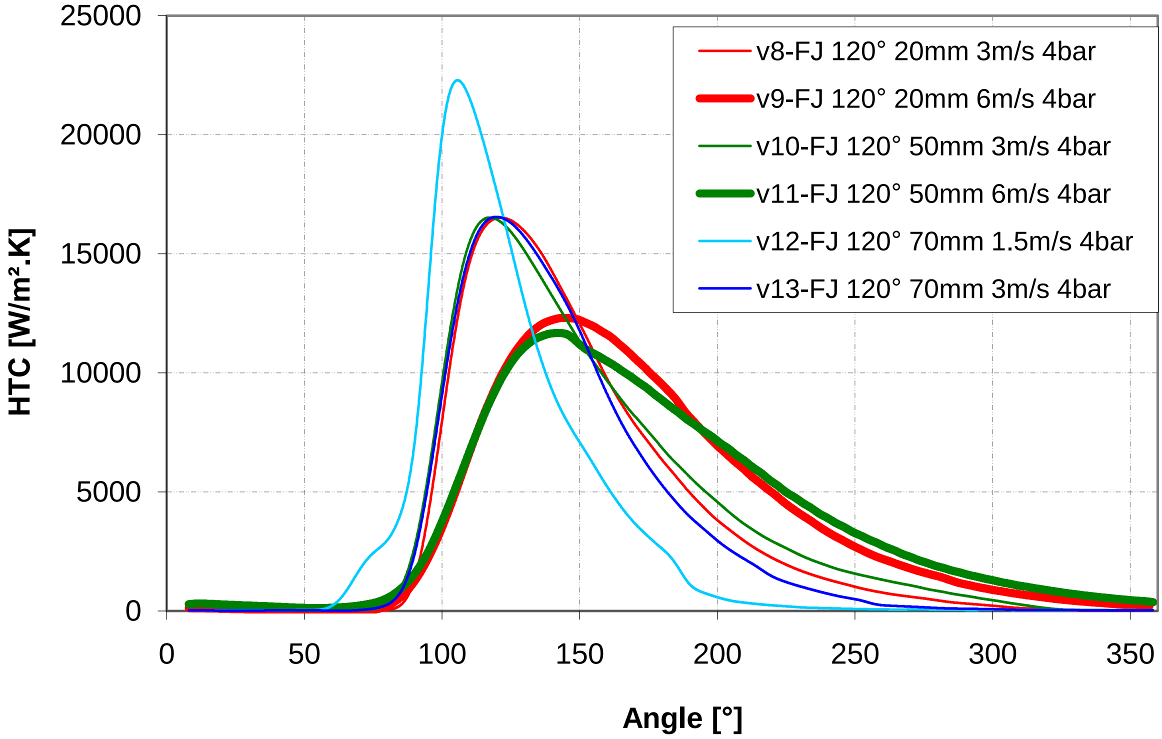

Figure 8 Distribution of HTC around the circumference of the roll, the experiments 8-13 in Table 1.

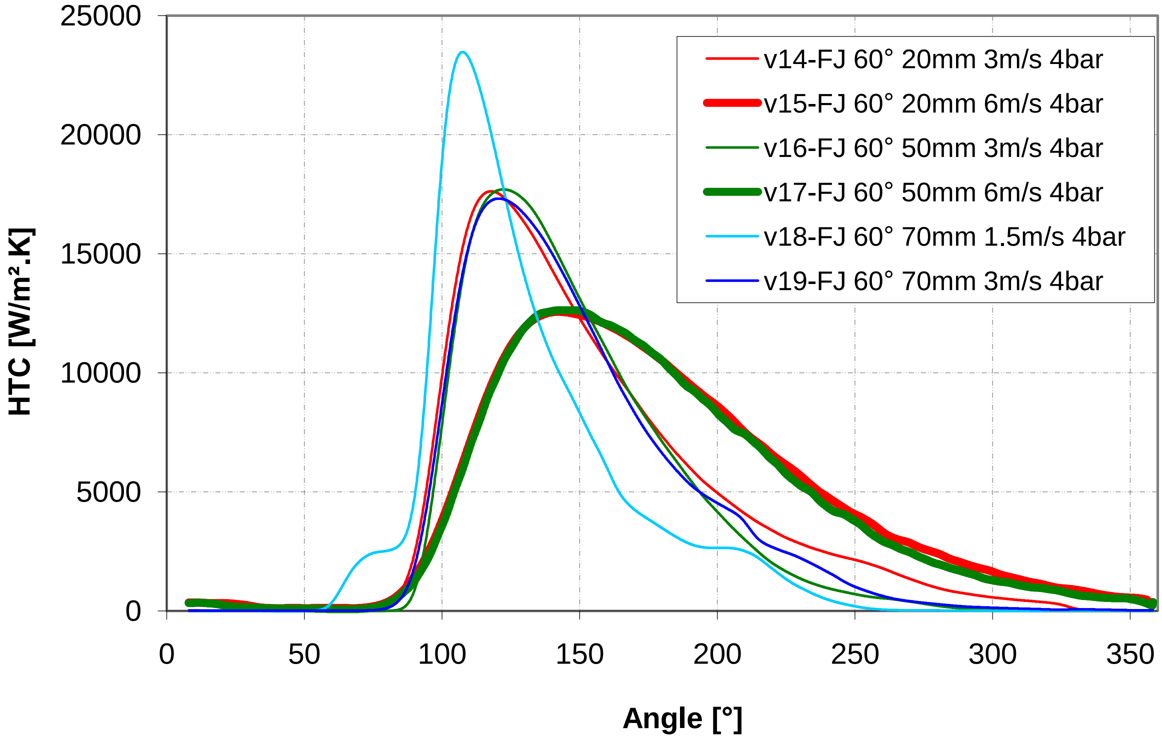

Figure 9 Distribution of HTC around the circumference of the roll, the experiments 14-19 in Table 1.

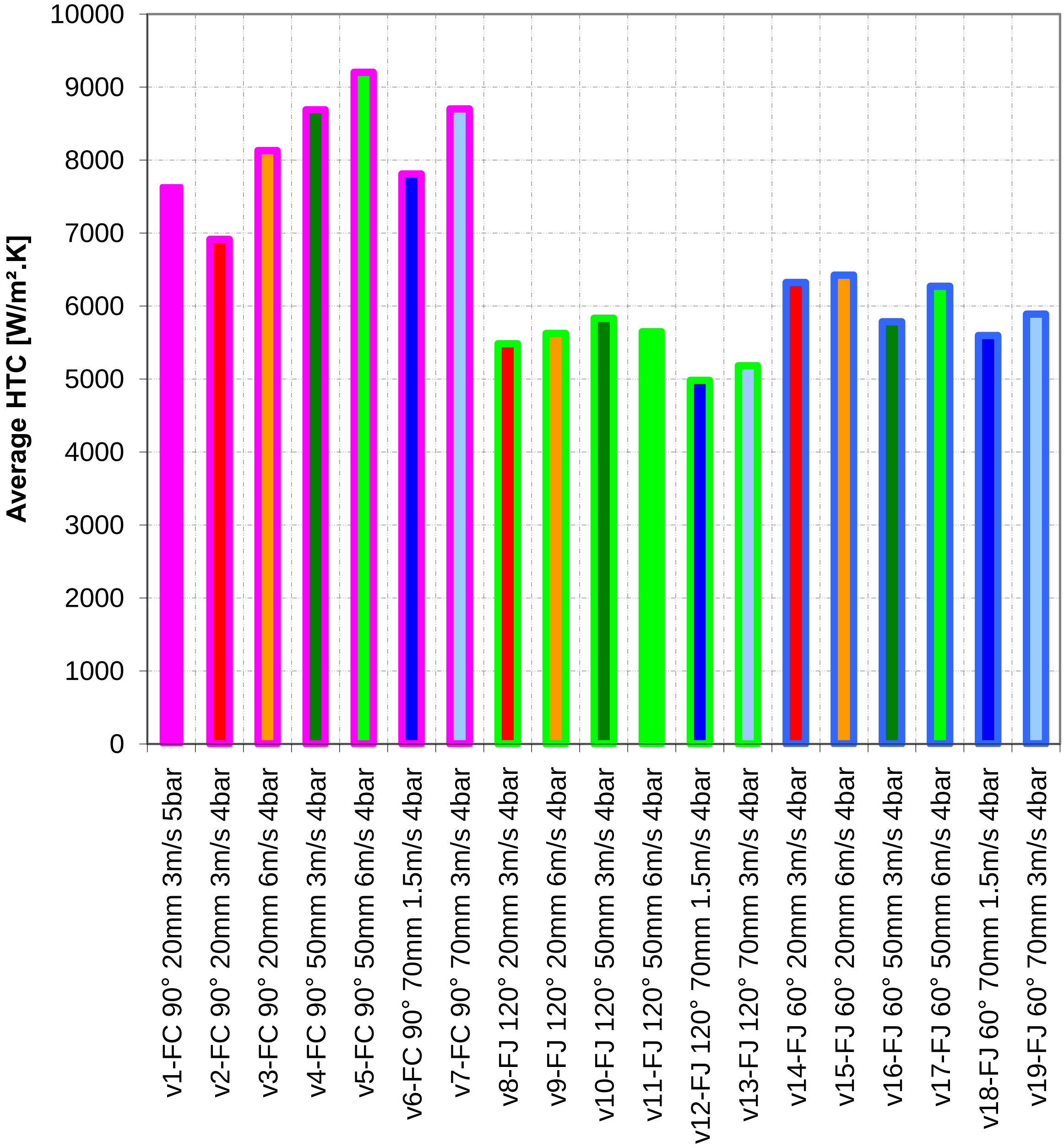

Figure 10 Average values of HTC for temperature over 140 °C.

5. Conclusion

In Figure 10 we can see that the average values of the HTC are higher for the full cone nozzle. Moreover, this nozzle has approximately half the flow rate of flat jet nozzles. This means that we save 54.17 % of water and a smaller amount of water gets to the rolled material. This should result in a higher temperature at the end of rolling.

If we calculate the variation coefficients of sums of pressure in Figure 6 we obtain the following numbers: 0.689899 for FJ 60°, 0.455192 for FC 90° and 0.961464 for FJ 120°. These variation coefficients show that the most homogenous cooling of rolls breadthwise is achieved with a full cone nozzle.

The flat jet nozzle with a spray angle of 120° can cool a wider area but only if it is correctly turned. If the full cone nozzle is used, the direction in which the nozzle is turned does not cause a problem. Because the full cone nozzle has the most homogenous cooling of roll breadthwise the shelf life of the working roll is extended. Using full cone nozzles with a spray angle of 90° is the most efficient way to cool working rolls.

6. References

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