Why to switch from cast iron to steel dryer cylinders?

By: De Iuliis C&A

Introduction

The drying phase in the paper machine is the most energy-consuming process of a paper mill. Therefore, it is essential to invest in the optimization of the drying section consumption, which constitute one of the principal direct cost of every paper mill. In the past, drying cylinders were generally built in cast iron because it was an easy to find low-cost material and above all easily machinable.

Currently, the demand for higher machine speeds and wider paper size imposed by the market, requires a proportional increase in the number of drying cylinders to maintain the same level of drying capacity of the machine.

The use of modern steels and modern manufacturing techniques, made cast iron cylinders disadvantageous and their replacement can bring great benefits in terms of machine management, especially regarding energy saving. In this short technical excursus, we will try to demonstrate the reasons.

The factors that most influence the heat exchange through the drying cylinder are:

· diameter, thickness and material of the cylinders;

· operating pressure and temperature;

· condensate drain system.

Given the limits on maximum operating pressure and on maximum condensate that can be extracted with current technologies, it is logical to invest to improve the efficiency of the drying by replacing the cast iron cylinders with steel ones.

In fact, the change from cast iron to steel brings 4 fundamental advantages:

- Greater thermal efficiency, since thinner thickness of the shell leads to a significant increase in heat exchange;
- Greater useful drying surface, due to the enlargement of the working width, consequent to the smaller size of the heads;
- Faster reaching of the working temperature, given by the increased heat exchange;
- Increase of safety standards, linked to the higher safety coefficients used for steel.

Heat exchange

A drying cylinder can theoretically be treated as a thin-wall pressure vessel (s << 2R). It is therefore possible to schematize the heat exchange between the steam and the sheet of paper with the simplified model schematized in figure 1 and based on the following hypotheses:

- the shell of the cylinder may be dealt as a flat plate (s << 2R);
- the global heat transfer shell-paper also includes the transfer of heat through the thin layer of air between the shell and the sheet of paper

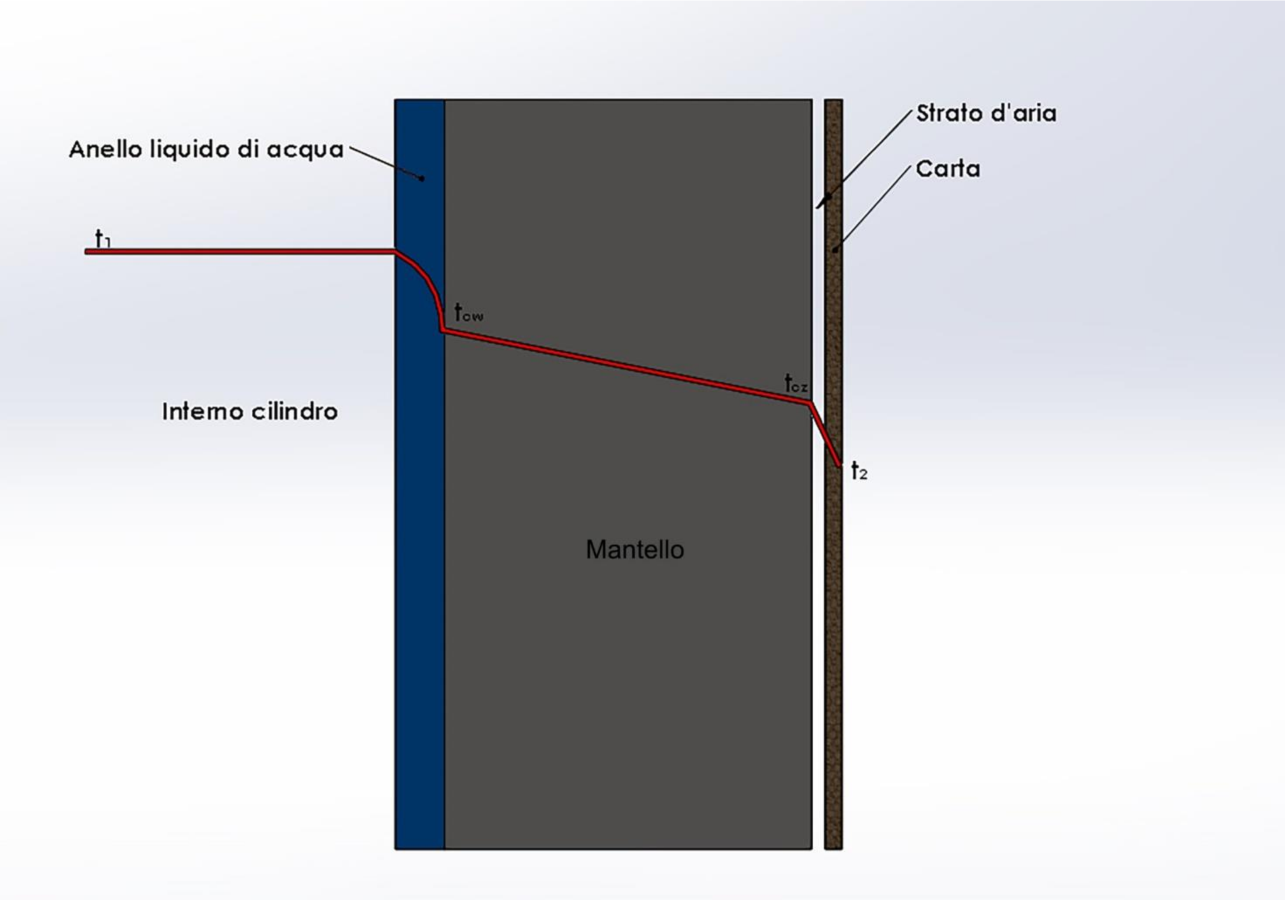

FIGURE 1: Qualitative trend of the temperature in the system.

Anello liquido acqua = Liquid water ring; Interno cilindro = cylinder internal; Carta= paper; Strato aria = air layer; Mantello = shell

Therefore, starting from the previous hypotheses, the equation that represents the thermal flow affecting the surface of the cylinder is given by:

$$q = \left(\frac{1}{\alpha_1} + \frac{s}{\lambda} + \frac{1}{\alpha_2}\right)(t_1 - t_2) \qquad (1)$$

Where:

q = thermal flow, W m-2;

t1 = steam temperature inside the cylinder, ° C;

t2 = external temperature of the sheet of paper, ° C;

a1 = steam thermal conductance - internal shell surface, W m-2 K-1;

s = wall thickness, m;

a2 = thermal conductance; outer surface of the shell - outer surface of the sheet of paper, W m-2 K-1;

λ = *thermal conductivity of the shell, W m-1 K-1.*

Assuming the value of the sum constant for both cast iron and steel cylinders and equal to 1,35 · 10-3 m2 K W-1, the only paramameter that we can modify in order to increase the heat flow is the thickness of the drying cylinder shell, which must be sized according to the standards (ASME / UNI), that define the minimum thicknesses to be used.

In the following discussion we have chosen to use the UNI EN 13445-3: 2019 standard, which allows us to arrive at the following formulation of the thermal flow transmitted by the steam to the sheet of paper.

$$q = \frac{1}{\frac{1}{\alpha_1} + \frac{s}{\lambda} + \frac{1}{\alpha_2}}(t_1 - t_2) = \frac{1}{\frac{1}{\alpha_1} + \frac{\frac{pDe}{2(f/i)z+p}}{\lambda} + \frac{1}{\alpha_2}}(t_1 - t_2) \qquad (2)$$

where:

p = steam pressure inside the cylinder, Pa;

De = outer diameter of the shell, m;

f = material yield stress, N / mm2;

i = safety factor, according to UNI EN 13445-3: 2019 adim.;

z = joint coefficient, according to UNI EN 13445-3: 2019, adim.;

From (2) it can be deduced that, for the same pressure and diameter of the cylinder, the heat exchange depends on λ and f, so, on the characteristics of the material used. The values of λ and f for steel P 275 NH and cast iron G25, used for the construction of drying cylinders, are shown in Table 1, from which it is evident that, even if they have similar thermal characteristics, the best mechanical characteristics play in favor of steel, that allows a thinner shell.

Table 1 - *values of λ and f for steel P 275 NH and cast iron G25*

material	**λ** [W m^{-1} K^{-1}]	**f** [N/mm^2]
steel P 275 NH	49	275
Cast iron G25	46	110

Working Width

The second factor to consider when choosing the drying cylinders to be used in the drying section of the paper machine is the maximum width. In fact, the paper market is pushing its trends towards wider paper size, so that paper mills, in order to be competitive, must expand their paper size. As we will see, the steel drying cylinders, with the same overall dimensions, can have a bigger useful width, thus allowing a precious recovery of centimeters of paper size and an increase in the thermal energy transferred to the sheet of paper, without necessarily modifying the external frames of the machine.

Figure 2 shows the construction drawing of two drying cylinders, one in steel and one in cast iron. It is evident that steel cylinder’s heads, thanks to the weldability of the material and the best mechanical characteristics, has smaller dimensions compared to cast iron ones.

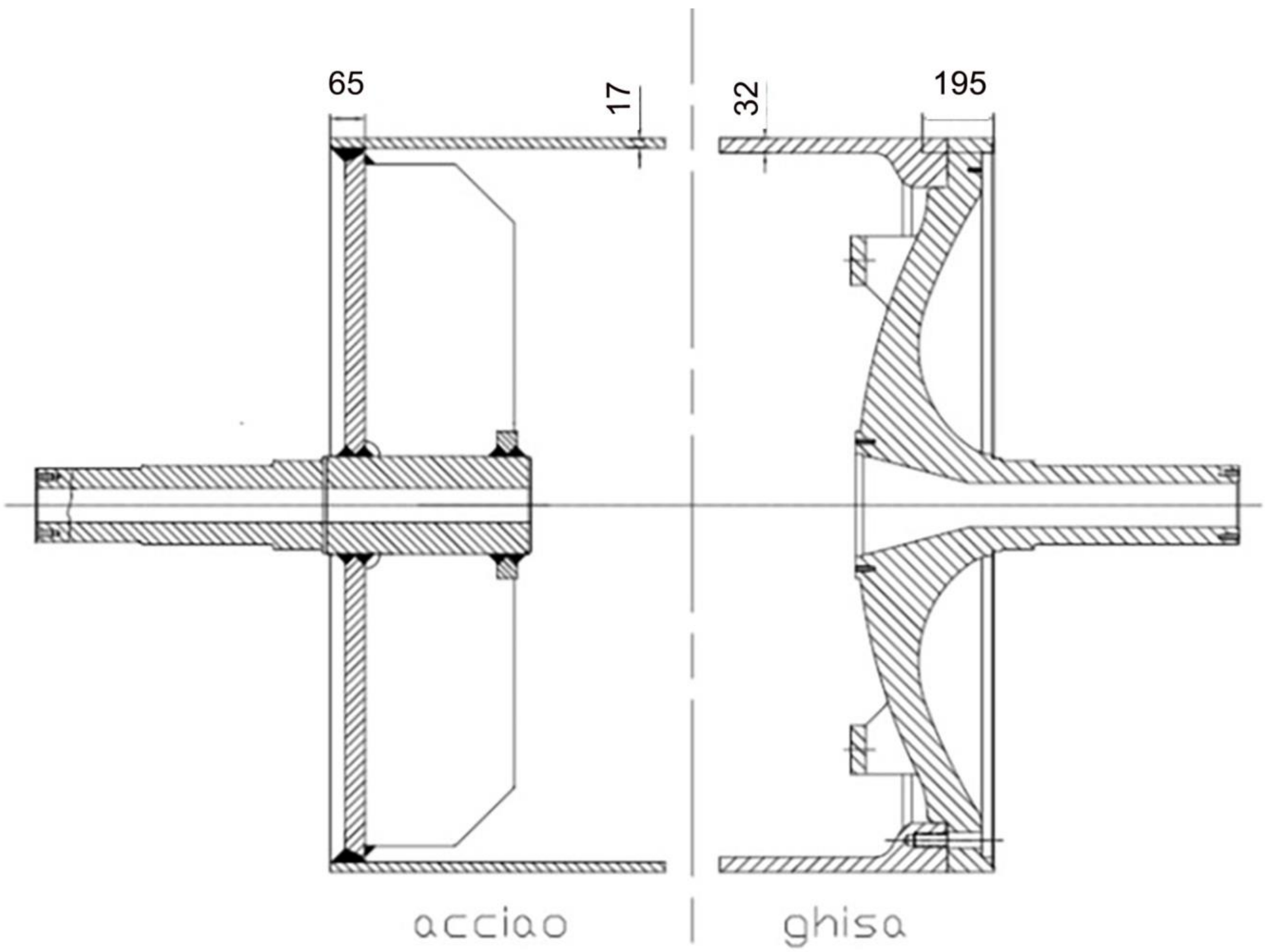

FIGURE 2: Construction drawing of steel (left) and cast iron (right) drying cylinders.

Furthermore, due to the different type of design and construction technique, steel cylinder's shell maintains a constant thickness up to the head, which determines the temperature trend shown in Figures 3 and 4, with a uniform heat distribution in the shell up to the ends of the cylinder.

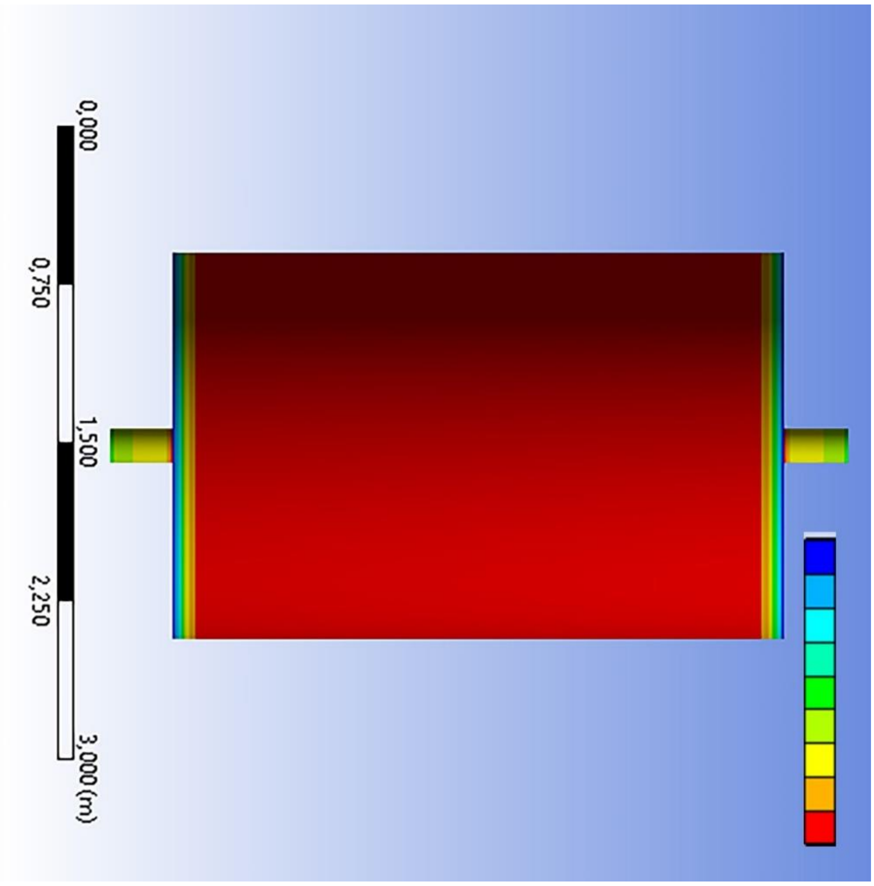

FIGURE 3: Trend of temperatures on the shell of the P275NH steel dryer cylinder.

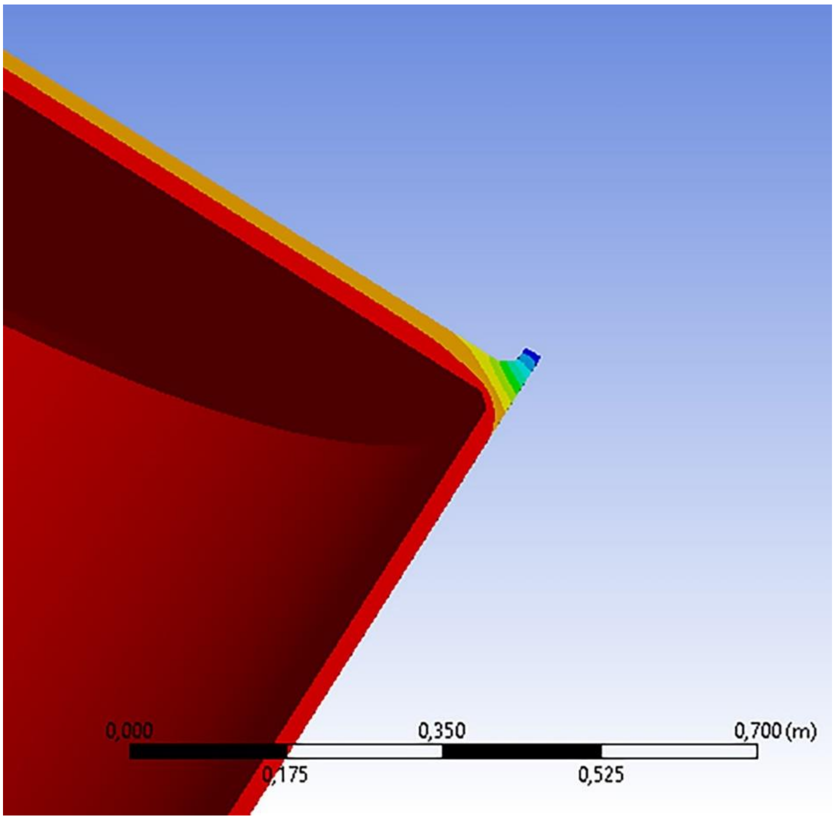

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FIGURE 4: Trend of temperatures in the thickness of the P275NH steel dryer cylinder.

Figures 5 and 6 show that the cast iron cylinder, as mentioned, has the head slightly more recessed and it has a variation in thickness on the extreme sides of the shell.

For that reason, the temperature trend is not uniform and doesn't allow to obtain a perfect drying process of the sheet.

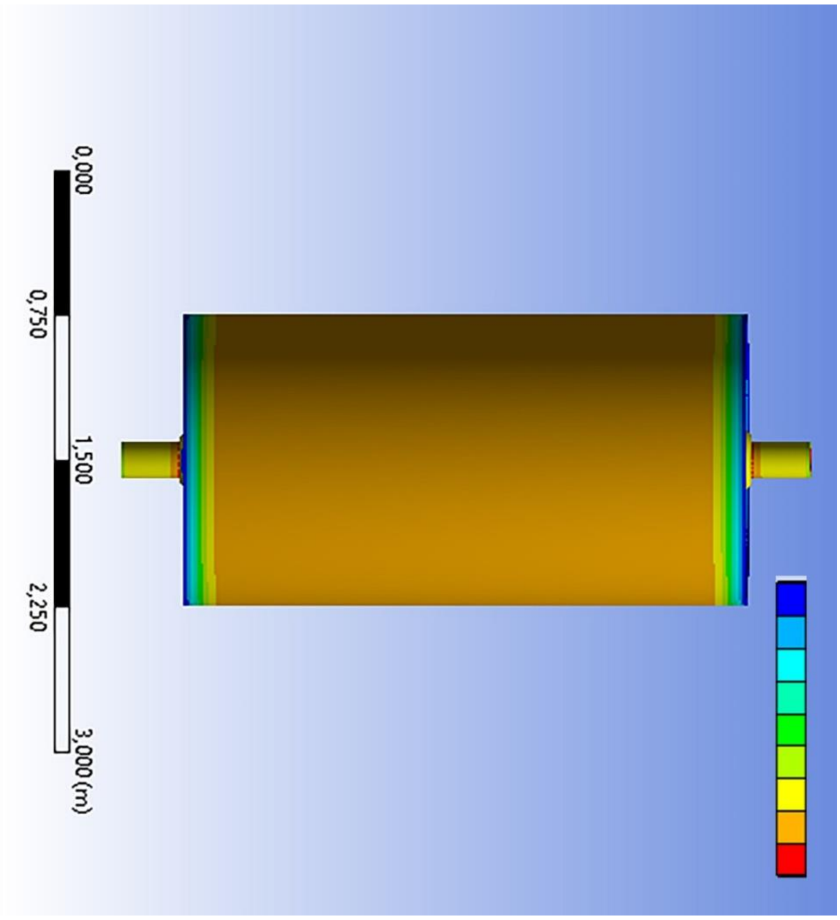


FIGURE 5: Trend of temperatures on the shell of the G25 cast iron dryer cylinder.

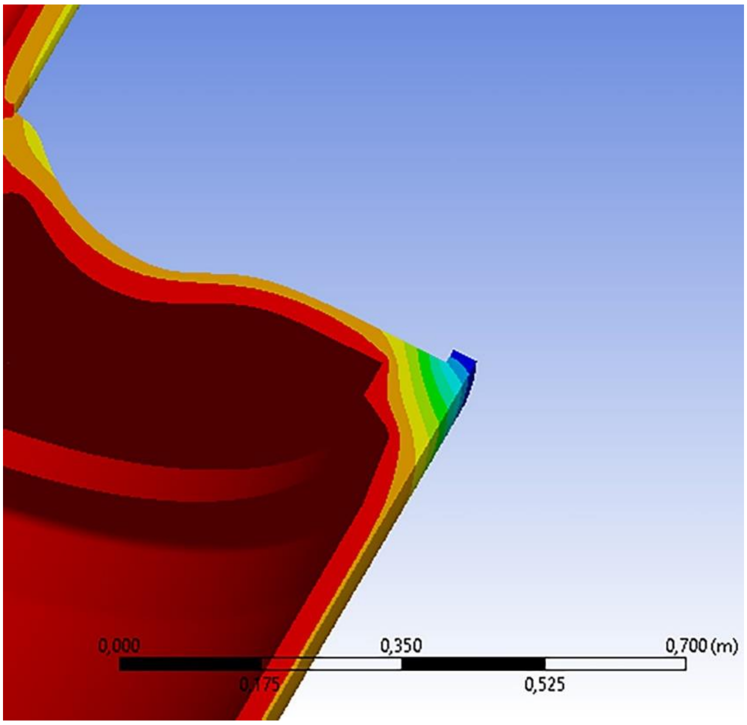


FIGURE 6: Trend of temperatures in the thickness of the G25 cast iron dryer cylinder.

Geometrically speaking, using a steel instead of a cast iron cylinder, bring generally to an increase of up to 130 mm of useful width per side, therefore 260 mm of width difference, simply because of the different construction design. As consequence steel cylinders are able to achieve a larger width, and to reduce heat loss through the walls of the cylinder, with a general increasing of efficiency.

Case study

Two possible models of dryer section are compared below, one with cast iron cylinders and one with steel cylinders, to understand the differences between the two materials. We start from the hypothesis of cylinders of the same diameter and the same operating pressure, therefore under the same working conditions, which are interchangeable with each other without modifications of the machine frames; the only variation will be due to the different thickness of the shell, linked to the different resistances of the two materials. The data relating to the two models are shown in Table 2.

material	Diameter [mm]	Shell thickness [mm]	Width [mm]	pressure [bar]
steel P 275 NH	1500	17	2400	3
Cast iron G25	1500	32	2400	3

Table 2 - *Data relating to the two models of dryers considered*

The useful drying area of the two cylinders are obtained with the equation:

$$A = 2\pi r * (L - b) \qquad (3)$$

where:

L = cylinder width, mm.

b = useful width reduction, mm.

From (3) therefore it results:

AP275NH=12,98 m2

AG25= 9,42 m2

Using the relationships (1) and (2), the transition to the steel cylinders in this case allows an increase in the useful drying area equal to 13%, with the important benefit of eliminating the problems of lateral humidity at the edges of the sheet. With reference to the heat exchange, considering the same values of the temperatures t1 and t2 of Figure 1, the change to steel cylinders guarantees an increase equal to 18%, due to the lower thickness of the shell, while maintaining a higher safety coefficient. Considering the contribution due to the different characteristics of the materials and the widening of the useful width, the use of the steel cylinders increase the heat exchange of 33%, an increase that is immediately translated into a saving of the quantity of steam needed by the dryer, and therefore in less drying cylinders necessary to obtain the same performance obtainable with the cast iron ones.

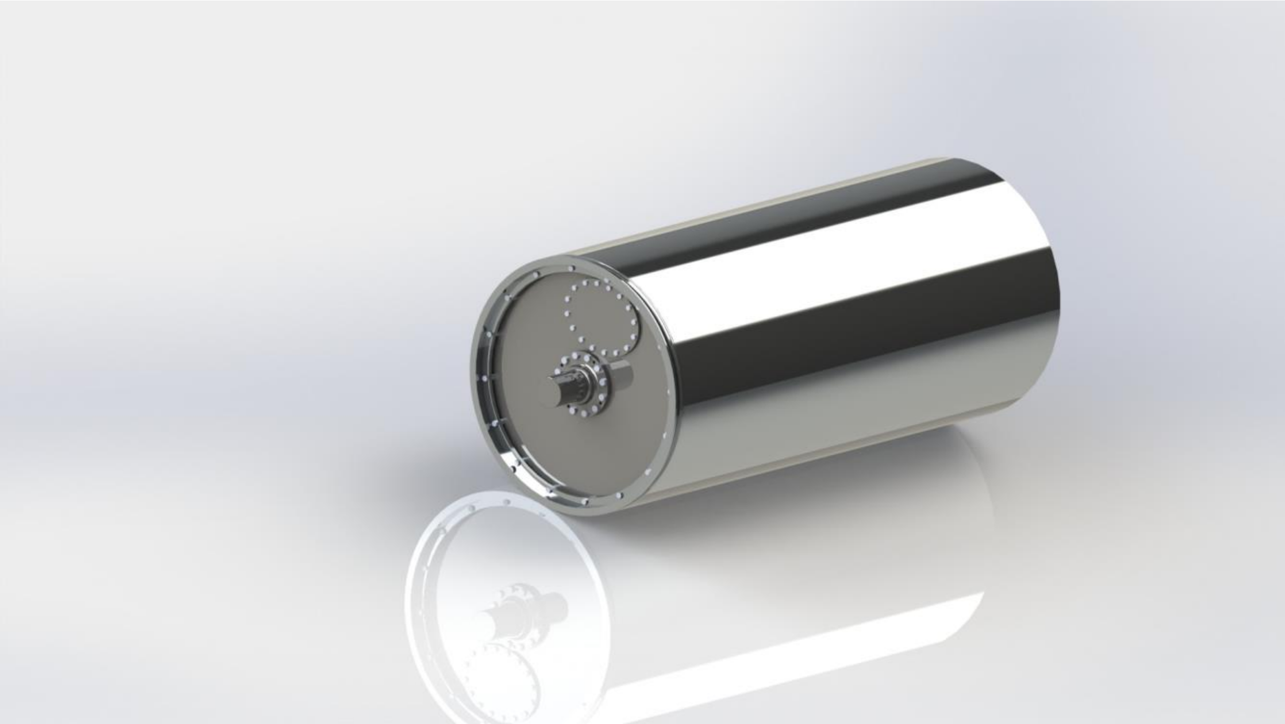
A second type of analysis concerns the more drastic situation in which a paper mill want to carry out a deeper upgrade of its own dryer section, varying not only the material of the drying cylinders, but also their diameter and their operating pressure. The data relating to the cylinders and the operating pressure values pre and post intervention are shown in Table 3.

Table 3 - *Data relating to the cylinders and the operating pressure values at the pre and post intervention dryers*

material	**Diameter [mm]**	**Shell thickness [mm]**	**Width [mm]**	**pressure [bar]**
steel P 275 NH	1830	20	2400	10
Cast iron G25	1500	32	2400	3

In the first analysis it is clear that the larger diameter and the larger useful width of the steel cylinders entail a much higher drying surface, which can be calculated with (3) and is equal to 38%. For that reason, the steel shell, while maintaining a high safety coefficient, will have a smaller thickness than the cast iron shell, and this will generate an increase in the steam-paper heat exchange equal to 14% in advantage of steel. Ultimately, the heat exchange obtainable with the steel cylinder is 57% greater than the one that occurs with the homologous cast iron cylinder. Obviously, the basic hypothesis is that the temperature difference between the inside of the hood and the steam introduced into the cylinder is the same for the two types of cylinder.

Conclusions



The transition from cast iron to steel cylinders appears to be a winning choice for all paper mills that want to modernize their drying section and improve their efficiency by reducing their management costs. Of course, the increase in efficiency from the point of view of heat exchange does not correspond to a proportional increase in the water extracted from the paper, which also depends on other physical factors not explained in this review. In any case, already from this first partial analysis, the advantages linked to the use of steel in drying process emerge, and that will certainly represent the future of all paper mills.

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