

Dryer Pressure Rating

Gregory L. Wedel
President
Kadant Johnson Inc.

Gerald L. Timm
Vice President, Research & Development
Kadant Johnson Inc.

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EXECUTIVE SUMMARY

Paper is dried by direct contact with the hot surfaces of paper drying cylinders. These cylinders are heated with pressurized steam. Steam condenses inside the dryer cylinders as it transfers its heat to the dryer shell.

Since the steam is saturated inside the dryer, the steam temperature is directly related to the steam pressure. As the steam pressure is increased, the steam temperature also increases. This causes an increase in the dryer surface temperature and hence the drying rate of the paper. This phenomenon has been used for decades for controlling the drying rate of papermaking machines.

In order to contain the steam pressure in the dryers, the drying cylinders are designed and manufactured to meet pressure vessel codes, the most common of which is the ASME Boiler and Pressure Vessel Code. The thickness of the dryer shell is dictated by these codes. The required thickness depends on the dryer pressure rating and the shell material.

As the dryer pressure rating increases, the increase in steam temperature may not be sufficient to offset the increase in conductive resistance of the shell. In fact, it is possible for a dryer with a higher steam pressure rating that is operating at its rated pressure to have less drying capacity than a dryer with a lower steam pressure rating that is operating at its rated pressure. This technical paper explores this phenomenon.

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INTRODUCTION

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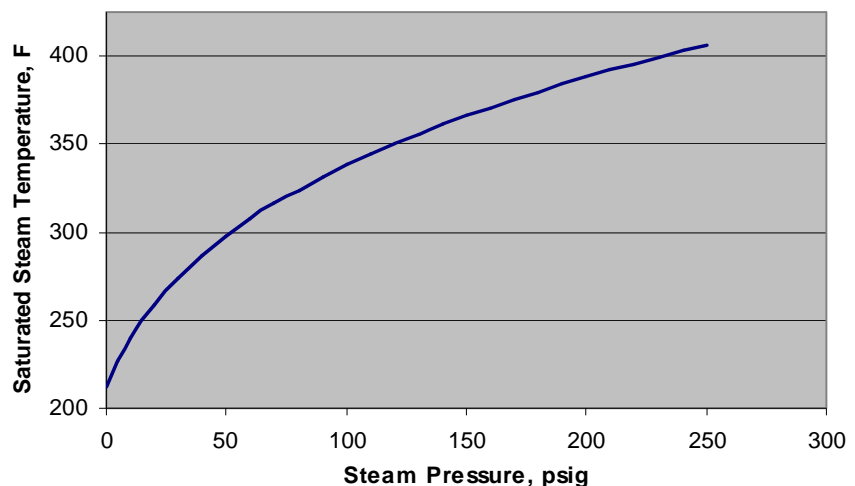
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As a first-order approximation, the shell thickness must be increased directly with the pressure rating of the dryer. A thicker dryer shell has a higher resistance to conductive heat transfer from the steam inside the dryer to the outside surface of the dryer. This increase in heat transfer resistance is partially offset by the corresponding increase in the operating steam temperature.

As the dryer pressure rating increases, however, the increase in steam temperature may not be sufficient to offset the increase in conductive resistance of the shell. In fact, it is possible for a dryer with a higher steam pressure rating that is operating at its rated pressure to have less drying capacity than a dryer with a lower steam pressure rating operating at its rated pressure.

Figure 1



ANALYSIS

Dryer Shell Thickness

For this review, we consider only the ASME Boiler and Pressure Vessel Code. For unfired pressure vessels, the dryer shell thickness is determined by the following equation.¹

$$t = P R / (s E + 0.4 P) \quad (1)$$

where: t = minimum required dryer shell thickness, inches
 P = internal design pressure rating, psi
 R = dryer shell outside radius, inches
 s = maximum allowable shell stress, psi
 E = joint efficiency (1.0)

In practice, paper dryer shells are machined to a thickness slightly larger (say 1/16") than the minimum required by the pressure vessel code in order to ensure that the dryer does not have to be de-rated because it is too thin. Further, many paper dryer manufacturers today will increase the thickness of the shell to account for the centrifugal forces on the shell resulting from operation at high rotational speeds. For simplicity, this effect is ignored in this review. This is a reasonable assumption for dryers operating at speeds less than 3000 fpm.

Dryer Shell Stress

The shell material determines the allowable stress. Most paper dryers are manufactured from gray cast iron (SA278). The class (grade) of cast iron is typically 30, 35, or 40. These classes correspond to shell tensile strengths of 30, 35, and 40 kpsi. For these cast iron grades, the ASME Boiler and Pressure Vessel Code limits the dryer pressure rating to 160 psig (the traditional upper limit of paper dryer pressure ratings). By appropriate heat treatment and dryer design, however, the Code does allow ratings up to 250 psi.²

Overall Heat Transfer

The dryer section drying capacity is related to the overall heat transfer coefficient between the steam and the paper. This coefficient consists of three thermal resistances: Condensate, shell, and sheet, as shown in the following equation:

$$U = 1 / [(1/h_c) + (1/h_d) + (1/h_s)] \quad (2)$$

where: U = overall heat transfer coefficient, Btu/hr-ft²-F
 h_c = condensate heat transfer coefficient, Btu/hr-ft²-F
 h_d = dryer shell heat transfer coefficient, Btu/hr-ft²-F
 h_t = sheet contact heat transfer coefficient, Btu/hr-ft²-F

The dryer shell heat transfer coefficient is the ratio of the shell thermal conductivity and the shell thickness, as shown below:

$$h_d = k / t \quad (3)$$

The thermal conductivity of the dryer shell depends on the grade of iron (class) and its average temperature. In general, the thermal conductivity decreases with increasing shell strength (class of iron) and with increasing steam pressure (dryer shell temperature).

Drying Capacity

The drying rate from paper dryer cylinders is directly related to the overall heat transfer coefficient and the difference between the steam temperature and the paper temperature, as shown below:

$$E_v = U (T_s - T_p) / h_{fg} \quad (4)$$

where: E_v = drying rate, lb/hr-ft²
 T_s = steam temperature, F
 T_p = paper temperature, F
 h_{fg} = latent heat of evaporation of water, Btu/lb

The steam temperature is dictated by the steam pressure (as outlined above). The sheet temperature is related to a number of operating parameters: Grade of paper, steam temperature, overall heat transfer coefficient, ventilation efficiency, and sheet dryness. The paper temperature can be measured on an operating machine using an infrared pyrometer or calculated from detailed drying models.

For this review, the Kadant Johnson Can-By-Can™ drying rate program is used to determine the sheet temperature. For simplicity, the grade of paper, sheet dryness, and ventilation are assumed to be constant so that the only parameters that affect the sheet temperature are the steam temperature and overall heat transfer coefficient.

ANALYTICAL RESULTS

Using the above analysis format, the shell thickness required by the ASME code was calculated for various code pressures for a 72" diameter dryer. For this study, the dryer shell is assumed to be Class 40. The minimum required thickness was increased by 1/16" to account for typical manufacturing targets. The sheet contact coefficient is assumed to be constant at 100 Btu/hr-ft²-F, the shell thermal conductivity is assumed to be constant at 27 Btu/hr-ft-F, and the condensate coefficient is assumed to be constant at 400 Btu/hr-ft²-F (typical of conventional dryer bars). Table 1 summarizes these results.

Table 1

MAWP psi	Shell inches	Steam F	Paper F	Shell hd Btu/hr/ft2/F	Overall U Btu/hr/ft2/F	Evaporation lb/hr/ft2
125	1.17	352.9	231	276	62.03	8.50
150	1.39	365.9	238	233	59.53	8.65
175	1.61	377.5	244	201	57.24	8.70
200	1.83	387.9	249	177	55.13	8.69
225	2.04	397.4	254	159	53.18	8.63
250	2.26	406.1	259	144	51.37	8.53

The results are shown graphically in the following four figures.

Figure 2 shows the design shell thickness as a function of the Maximum Allowable Working Pressure of the dryer (MAWP). The shell thickness increases nearly linearly with increasing MAWP.

Figure 3 shows the dryer shell coefficient. As indicated by Equation (3), the shell coefficient decreases as the shell thickness increases.

Figure 4 shows the overall heat transfer coefficient as a function of the MAWP. Although the overall coefficient decrease with increasing dryer pressure rating, this loss in heat transfer coefficient is partially offset by an increase in the corresponding steam temperature.

In Figure 5, the overall drying capacity, as indicated by Equation (4), is shown as a function of the dryer steam pressure rating. The data in this graph is based on having each of the dryer cylinders not only rated for the listed pressures, but are also operating at their rated pressures.

As illustrated in Figure 5, there is a clear point of maximum drying capacity. Using dryers with steam pressure rating above this maximum results in a loss in drying capacity, even when the dryers are operating at their maximum rated pressures.

In this example, increasing the dryer rating from 125 psi to 150 psi increases the drying capacity of the machine by 1.8%. Increasing the dryer rating from 150 psi to 175 psi increases the drying capacity by only an additional 0.6%.

Increasing the dryer rating from 175 psi to 200 psi does not provide any increase at all in drying capacity and a further increase in pressure rating causes a net loss in drying capacity.

Figure 2

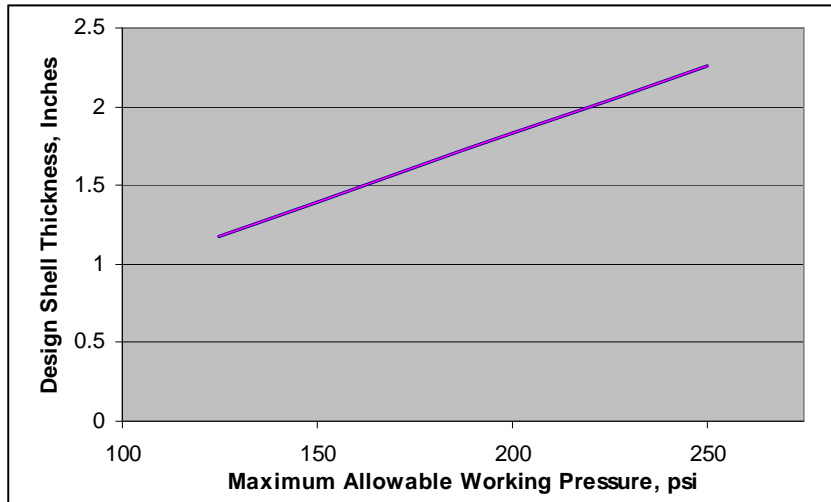


Figure 3

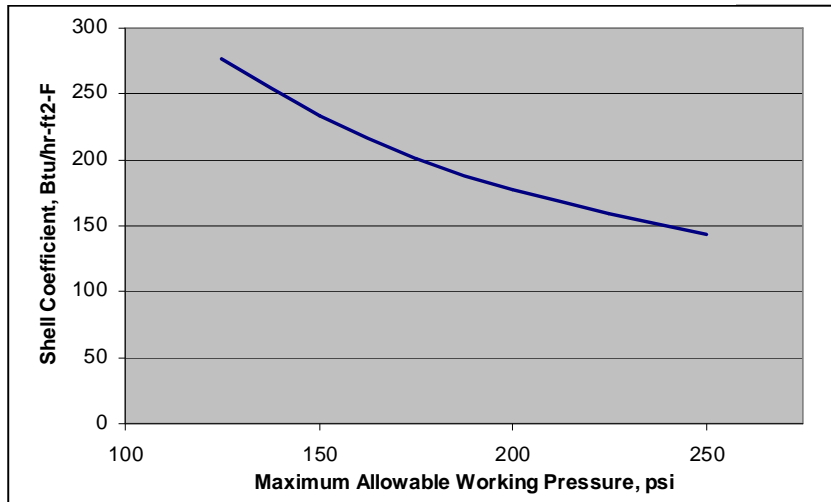


Figure 4

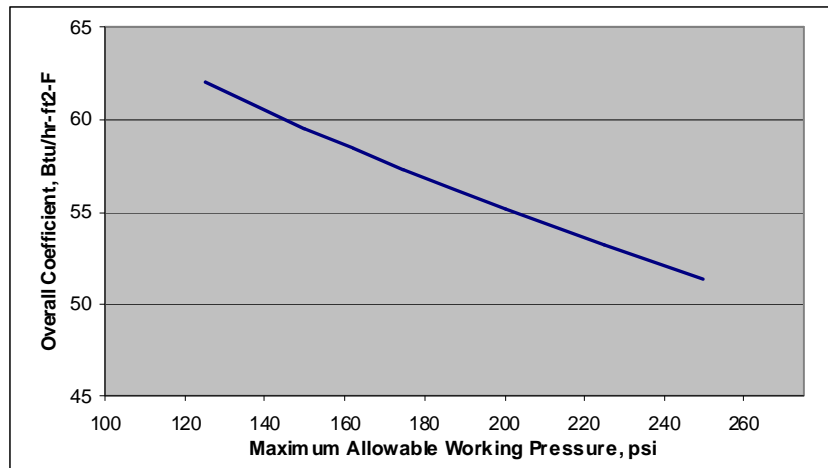
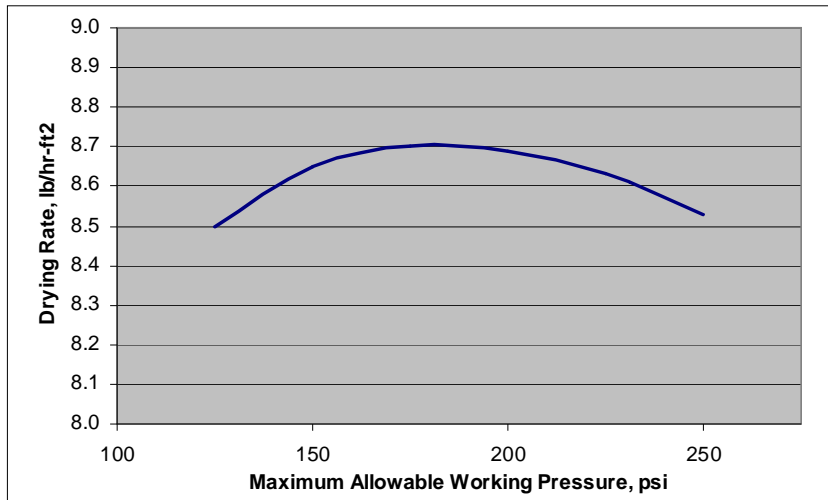


Figure 5



In addition to the impact of increased pressure rating on the drying capacity, there are also five other factors that should be considered:

- High-pressure dryers must operate at higher pressures to achieve the listed rates.
- Higher steam pressures must be available in order to operate at a higher MAWP.
- This could reduce the amount of power that can be generated by the turbo-generator.
- The capital cost of the thicker dryer shell will be higher.
- The thicker shells have higher thermal inertia, resulting in slower response times and increased overshoot and undershoot during sheet break recovery.

CONCLUSIONS

Using paper dryer cylinders with increased pressure rating can increase the drying capacity of the dryers, but only up to a point. Above this point, there is a loss in drying capacity. Before committing to using high-pressure dryers, the overall drying rate and penalty should be evaluated.

The example shown in this study was for a particular grade of paper, for dryers equipped with dryer bars, and for a dryer shell made from Class 40 gray cast iron. If any of these parameters are changed, a similar analysis should be conducted to determine the potential for increasing the overall drying capacity. If, for example, the shell is made from another material that is recognized by ASME for paper dryer applications, other than Class 40 gray cast iron, the dryer pressure rating that produces the maximum drying capacity may be higher or lower. Each such material option requires detailed evaluation.

The above analysis is based on fundamental heat transfer equations. The analysis assumes that the sheet can tolerate higher dryer surface temperatures without picking, sticking, or casehardening the sheet. For some applications, problems with picking can limit the dryer surface temperatures, particularly in the wet end dryers, making it difficult to benefit from dryers with high pressure ratings.

REFERENCES

1. ASME Boiler and Pressure Vessel Code, Section VIII Division 1, Rules for construction of pressure vessels, Appendix 1, Section 1-1 (a)(1), 2001.
2. ASME Boiler and Pressure Vessel Code, Section VIII Division 1, Part UCI-3(a)(1) and Part UCI-3(b), 2001.

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.

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