Investigations concerning the possibility to minimize the stacks aerodynamic resistance

I.B. Bedelean[1] & D. Sova[2]

Abstract

The task of this research was to elaborate and to test a solution for minimizing the aerodynamic resistance of the stacks. According to the theoretical approach this task might be achieved by attaching some aerodynamic profiles. The numerical results have shown that the proposed solution assures a minimization of the local resistance stacks. For the current variant, assuming that the volume of air delivered by the fans would remain constant and using numerical analysis, it has been established that 45 mm stickers generate the same pressure loss, like in the proposed variant. But, the air velocity was diminished by 33% because the stacks open area has increased. In what concern the drying capacity, it was found that both variants involved a decrease of the capacity between 20% - 25%. Two experimental tests were performed in a lab kiln in order to establish if the proposed solution generates enough advantages to compensate the drying capacity decrease. The material which was used was taken from green logs of spruce. For each run, 36 pieces - 50 x 150 mm^2 in the cross section and 1.45 m long – were dried to a target of the moisture content equal with 30%, because the air velocity has an important effect on the drying time only during the first period of drying. The stickers' thickness was 25 mm for both variants. The aerodynamic profiles were attached only in the proposed variant. For each run the drying time and the power energy consumption were established.

1. Introduction

In a drying kiln the air flow is constrained to overcome a series of local resistances: heat exchangers, fan cases, stacks, and those which are caused by the kiln geometry (the change of the flow direction of air). From all of these resistances the researchers have decided to intervene on those that are caused by the kiln geometry (Nijdam & Keey 2002), and very rare on those generated by the stacks. Since the kiln operators, during the kiln operation, cannot intervene on the local resistances, which are caused by the stacks, the development of the current possibilities is necessary and they refer to the minimizing of the stacks local resistance, with the purpose to reduce the absorbed electric energy.

The average velocity in the stack active channels v_m is related to the stack pressure drop Δp_{stack}, which is determined by use of the pressure-loss

[1] Teaching assistant, bedelean@unitbv.ro
[2] Associate Professor, sova.d@unitbv.ro
Transilvania University of Brasov, Romania

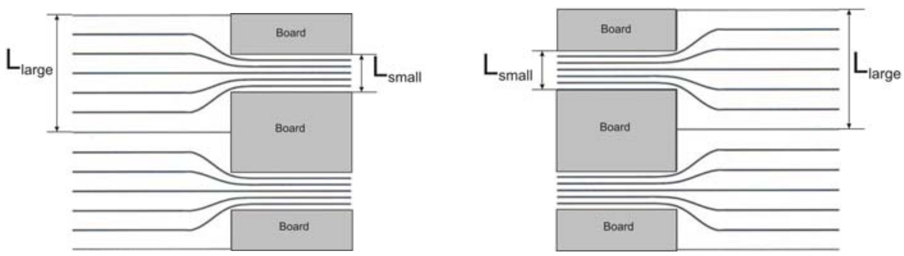
coefficient ζ (Equation1). This coefficient takes into account the pressure losses which appear at the inlet ζ_i and the outlet of air from the timber stack ζ_o, the losses that are stimulated by the channel length and its roughness ζ_f and the losses due to the gaps existing between the boards ζ_g (Equation 2) (Ledig et al. 2008).

$$\Delta p_{stack} = \xi \frac{\rho}{2} v_m^2 \qquad \text{Equation 1}$$

$$\zeta = \zeta_i + \zeta_f + \zeta_g + \zeta_o \qquad \text{Equation 2}$$

The aim of this paper was to reduce the pressure loss which occurs at the inlet and the outlet of the airflow from the timber stacks, because it is difficult to intervene on the losses which are stimulated by the length of the channels and their roughness, and on the gaps between the boards.
The pressure loss which takes place at the inlet and the outlet of the airflow from the timber stack is influenced by the leading edge of first board and the trailing edge of the last board. These lead to the stream separation and to the formation of recirculation zones, too (Figure 1). Since the plenum area is larger than the stack area, at the moment when the airflow enters or leaves the timber stack, the sudden contraction and enlargement of the flow area are encountered (Figure 2).

a – The leading edge of the first board b – The trailing edge of the last board
Figure 1: The stream lines contour of the current variant (Sun 2001)



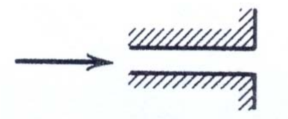
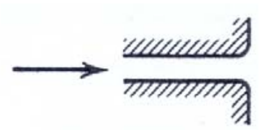
a - inlet b - outlet
Figure 2: The sudden contraction and enlargement of the flow area
(Smith *et al.* 2007)

The current variant for minimizing the aerodynamic stack resistance supposes the increase of the stickers thickness (Salin 2005, Riley 2000). The disadvantage of this solution refers to the diminishing of the drying capacity. In order to eliminate the disadvantage of the current solution, a documentation stage was carried out in the Fluid Mechanics field upon current types of inputs and outputs. The results have shown that the current type of input generates a pressure loss coefficient ζ_i equal to 0.5, and if the edges are rounded, the pressure loss coefficient ζ_i is equal to 0.04 (Table 1). The pressure loss coefficient for both types of outputs is equal to 1 (Table 2).

Table 1: The local resistance coefficient for various kinds of inlets (Fox *et al.* 1972)

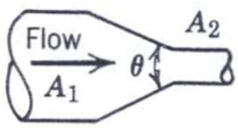
The kind of inlet	Figure	Local resistance coefficient
Square – edged inlet **(current variant)**		0.5
Rounded inlet (r/R = 0.25)		0.04

Table 2: The local resistance coefficient for various kinds of outlets (Fox et al. 1972)

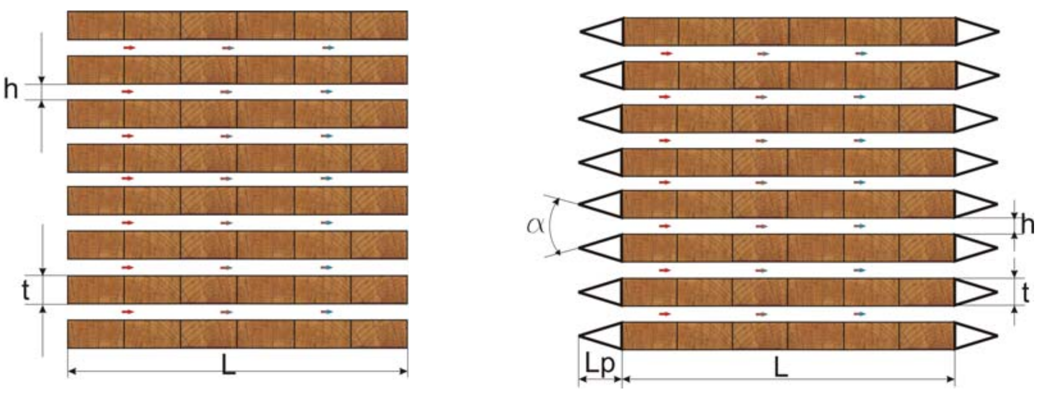
The kind of outlet	Figure	Local resistance coefficient
Square – edged outlet **(current variant)**		1
Rounded inlet		1

Therefore, if the variant which implies the rounding of the board edges, at both stack inlet and outlet, would be chosen, this would generate only the minimizing of the pressure losses which take place when the air enters the stack.
The deepening of the research has shown that the local resistance, due to the sudden contraction and enlargement, may be diminished by attaching a cone at the inlet and the outlet of the air flow from the stack channels. The advantage of this solution consists in fact that the proposed variant is able to ensure a gradual transition from the larger area of the plenum to the smaller area of the stack channels. This advantage will ensure the minimizing of the local resistance coefficient compared with the current variant (Table 3).

Table 3: The local resistance coefficient for gradual contraction (Fox *et al.* 1972)

Figure	Cone angle	Local resistance coefficient
	30	0.02
	45	0.04
	60	0.07

In order to create the cone effect at the inlet and the outlet of the air flow, in and from the stack channels, the solution of attaching some wood profiles in front and back of each board row was chosen (Figure 3).



a – current variant b – proposed variant

Figure 3: The evidence of how the cone effect is created at the stack channels

Since in a drying kiln the air flow is reversed, the profiles which will be attached will create successively the cone effect both at the stack inlet and outlet. Also, the attachment of some profiles in front and back of each timber row will lead to the elimination of the negative effects which are caused both by the flow detachment and the recirculation zones (Figure 4).

a – The leading edge of the first board b – The trailing edge of the last board

Figure 4: The stream lines contour of the proposed variant

2. Materials and methods

In the first stage of the research the proposed variant was compared with the current variant using the numerical analysis technique. It was assumed that the kiln fans generate a constant airflow for all studied variants. For the current variant there were studied different stickers thicknesses until the same pressure loss was obtained like that generated by the proposed variant. The air velocity in the front of fans was assumed that is equal to 3 m/s for all the analyzed numerical variants. Also, it was assumed that all the gaps around the stack were blocked. The pre-processing stage was performed by Gambit, and the processing and post-processing stages by Fluent. The input data used for the numerical analysis of the velocity field and the pressure loss, for each variant, are shown in Table 4.

Table 4: The input data for the numerical analysis study

Parameter	Value
Material thickness, t	50 mm
The sticker thickness, h, for the current variant	25, 30, 35, 40, 45 mm
The sticker thickness, h, for the proposed variant	25 mm
Cone angle, α	60^{0}
The stack width, L	1300 mm
The profile width, Lp	150 mm

Two experimental tests were performed in a lab kiln. The material which was used was taken from green logs of spruce (*Picea abies*). For each run, 36 pieces - 50 x 150 mm^2 in the cross section and 1.45 m long – were dried from the initial moisture content (57%) to a target of the moisture content equal to 30%. The stickers' thickness was 25 mm for both variants. The aerodynamic profiles were made of timber and attached only in the proposed variant. The pressure loss and the air velocity were determined by use of a data-logger made by Ahlborn, a differential pressure sensor (FD A602 – S1 K) and an air velocity sensor (FVA915S220). The static pressure probes were made from two syringe needles, aiming not to disturb the airflow stream. The measurement of the static pressure was performed in eight points. The drying schedule which was applied for both variants is shown in Table 5. For each run the drying time and the electric energy consumption were established.

3. Results and discussion

The numerical results were obtained from the computational domains which are presented in Figure 5. Following the graphical representations, which are shown in Figures 6 & 7, it can be observed that a pressure loss minimization was obtained when the boards were stacked with larger stickers than those

Table 5: The drying schedule of the process

The stage of the process	Average wood moisture content, %	Temperature, ^0C	Equilibrium moisture content, %	Fan power, %
Heating	-	50	18	70
Stage I	40	50	12	70
Stage II	28	60	10	70
Stage III	16	65	4.8	55
Stage IV	10	65	2.9	50
Conditioning	-	65	7	70
Cooling	-	30	-	70

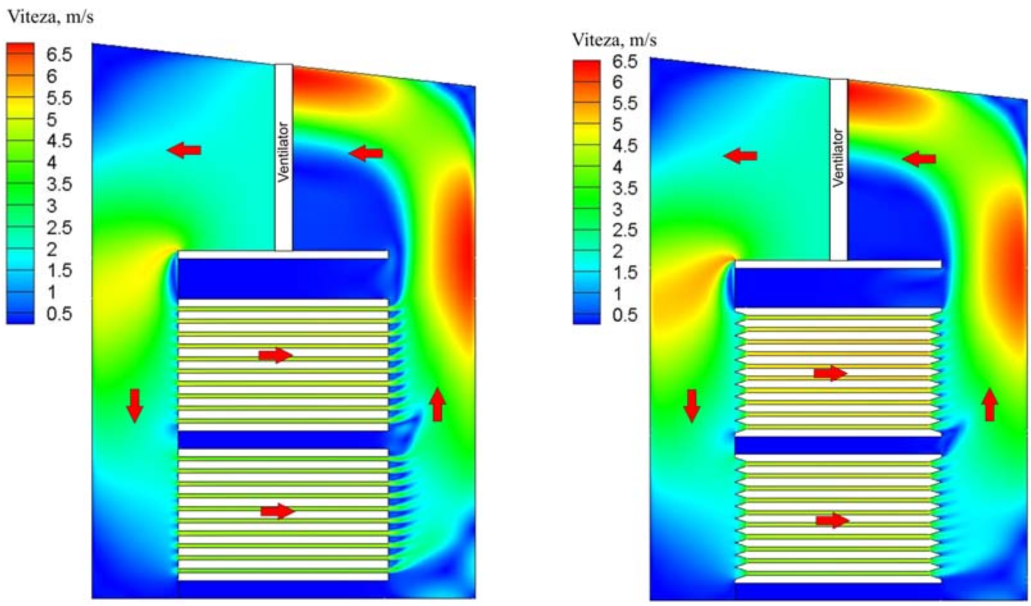


Figure 5: The variants which were compared numerically and experimentally
a - current variant, b – proposed variant

corresponding to the initial value (25 mm), but in this case the air velocity decreased. This disadvantage is due to the stack open area which increased once with the stickers thickness. Also, the numerical results have shown that the proposed variant generated a lower pressure loss, with 35%, than in the current variant. In addition, the air velocity was not affected since the open area remained the same. According to the numerical results, in order to obtain the same pressure loss for the current variant, it is necessary to assume that the timber boards are stacked with 45 mm thickness stickers, but the mean air velocity inside the stack is going to drop with 34%. The proposed variant keeps the same velocity, because, by attaching the profiles in front and back of each timber row, the stack open area doesn’t change. The main disadvantage of both variants is related to the fact that the kiln capacity is diminished with 20% for the current variant and with 25% for the proposed variant.

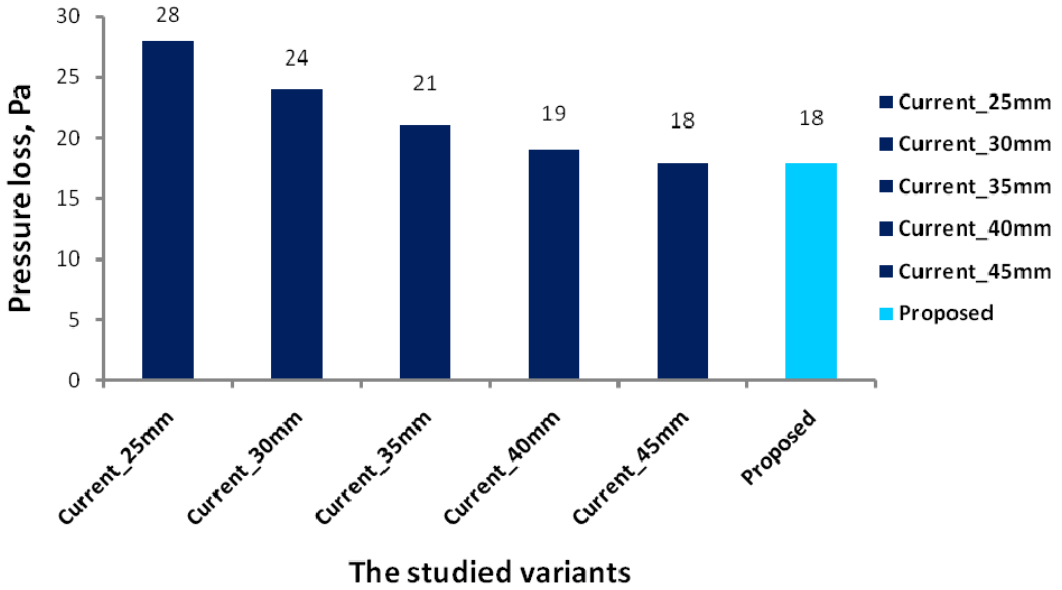


Figure 6: The numerical pressure loss for the studied variants

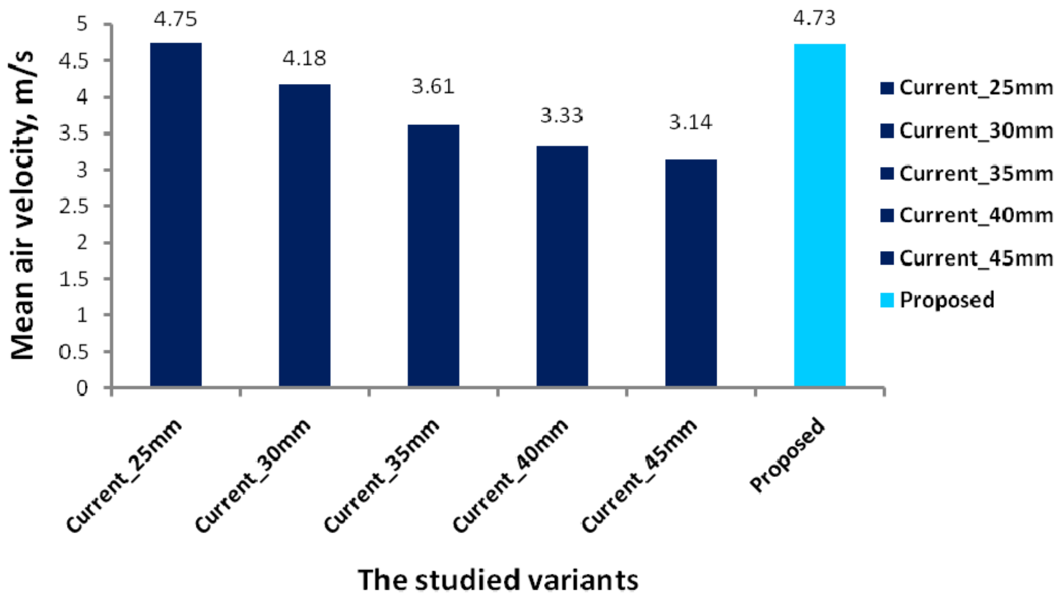


Figure 7: The numerical air velocity for the studied variants

The experimental results have shown that the proposed variant assured a diminishing with only 6 % of the pressure loss and an increase of the mean air velocity with 1.5 % in the stack. The increase of the mean air velocity is explained by the fact that the fan has generated a higher airflow than in the current variant, since the stack aerodynamic resistance decreased, while the open area remained the same. Also, the increase of the mean air velocity was proved by the diminishing of the drying time with 11 % (Figure 8). Because the drying kiln capacity was reduced by 25%, once the profiles were attached, the electric energy consumption for the drying of one cubic meter increased with 16% (Figure 9). Finally, it can be affirmed that the proposed variant doesn't generate enough energy benefits in order to balance the diminishing of the drying capacity.

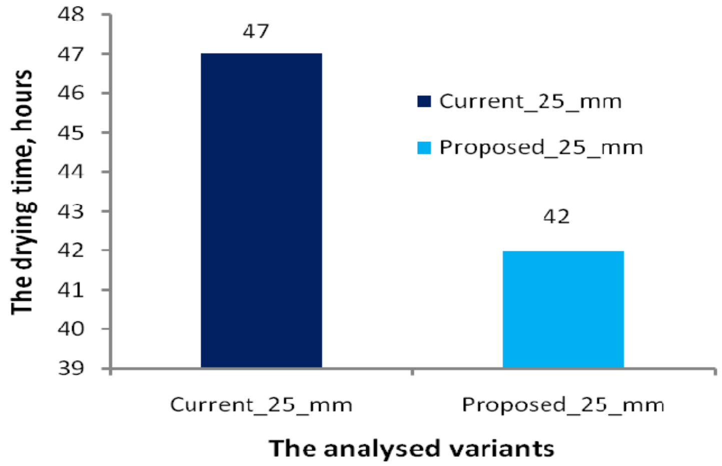


Figure 8: The drying time for all analysed variants

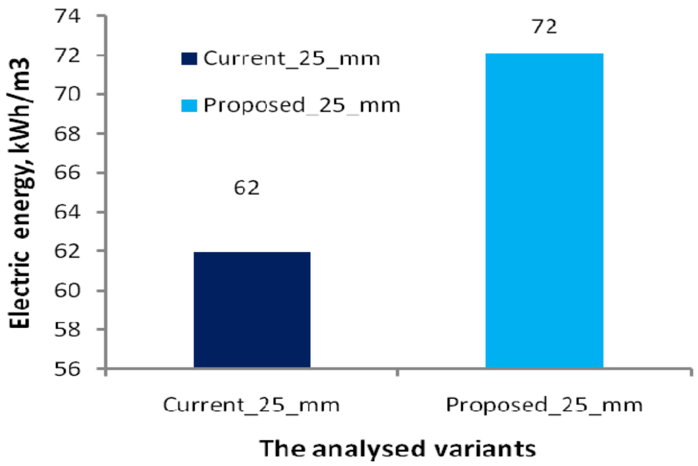


Figure 9: The electric energy consumption for both analysed variants

Conclusions

Within this study the possibility to minimize the pressure loss, caused by the timber stacks, was analysed. For this purpose, the authors have intervened upon the local resistances which are determined by the sudden contraction and enlargement of the flow area, the recirculation zones, and upon the flow detachment, which is caused by the edges of the timber boards. The proposed variant implies the attachment of some profiles in front and back of each row of timber. These profiles generate a gradual contraction or enlargement, when the air enters or leaves the stack. The proposed variant was compared numerically and experimentally with the current variant. The results have shown that through the proposed solution the pressure loss generated by the stack was diminished. Due to the fact that the drying kiln capacity was reduced by 25%, when the profiles were used, the proposed variant doesn’t generate enough energy benefits in order to balance this disadvantage.

References

Bedelean, I.B. (2009) – Contributions to the aerodynamic study of wood drying kilns. PhD thesis. Transilvania University of Brasov, Romania.

Fox, W. R., McDonald, A.T. (1973) - Introduction to Fluid Mechanics. Second Edition. John Wiley & Sons, New York, Toronto.

Ledig, S.F., Paarhuis, B., Riepen, M. (2008) - Airflow within kilns. In Fundamentals of wood drying. A.R.BO.LOR. Nancy, Chapter 13, 311 – 332.

Nijdam, J., Keey, R. (2002) ”An experimental study of airflow in lumber kilns”. Wood Science and Technology, Vol. 36, pp. 19 – 26.

Riley, S. (2000) ”Selection of kiln fillets”. Wood Proccesing Newsletter, No. 28, pp. 14 – 15.

Salin, J.G. (2005) “The influence of some factors on the timber drying process, analyzed by a global simulation model”. Maderas. Ciencia Tecnologia, Vol. 7 (3), pp. 195 – 204.

Smith, G.J.F., Du Plessis, J.P., Du Plessis (Sr), J.P. (2007) “Modelling of airflow through a stack in a timber-drying kiln “. Applied mathematical modelling, Vol. 31, pp. 270 – 282.

Sun, Z. F. (2001) “Numerical simulation of flow in an array of in – line blunt boards: mass transfer and flow patterns”. Chemical Engineering Science, Vol. 56, pp. 1883 – 1896.