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Principles of the Through-Air Dewatering Theory for Selected Fibrous Materials (Press Section Felts)

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Abstract
The conditioning process of press felts is a very important operation to intensify the dewatering process of the paper web in the press section of a paper machine. A new method of conditioning press felts by means of airflow, which is more efficient in the dewatering and cleaning processes of felts, is presented. Calculation methods for the dewatering efficiency of press felts and the air demand of the airflow are based on Darcy's modified formula . A few methods for the determination of empirical coefficients have been suggested. The through-air dewatering of press section felts is especially advantageous for modern felts made entirely of synthetic fibres.

Key words: *fibrous materials, press felts, water filtrating, porous materials, elastic materials, paper machines.*

One of the main techniques of intensifying the dewatering process of the paper web in the press section of a papermaking machine is to optimise the parameters of the conditioning process for press felts. Economic benefits from the proper tuning of the dewatering and cleaning processes for press felts can be very significant. The optimised cleaning and dewatering of press felts just before the press nip can result in a 2% or higher increase in the post-nip web dryness - a very significant saving for the dewatering process, while at the same time the effective felt life can be increased by 90 to 100%.

Although felt suction slot-boxes [1, 2] are still the most widely used felt water separators for press felt dewatering and cleaning processes, the new through-air techniques for press felt conditioning are gaining more of a foothold in the papermaking industry, i.e. felt-through-drying rolls and felt-through-drying boxes [3 - 6]. ***Figure 1*** illustrates the overall principles for the through-air process for a press section.

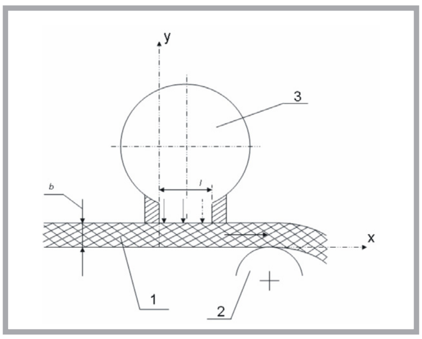

Figure 1. *Schematics of the through-air process for press felt conditioning: 1 – press felt, 2 – guide roller, 3 – felt-through-drying box , b - nominal thickness through a nozzle.*

A through-air dryer, schematically illustrated in ***Figure 1***, consists of a delivery pipe conveying compressed air, at 10 to 40 kPa pressure, to felt of nominal thickness b through a nozzle (made from ceramic components) of nominal width l. The resulting airflow removes water and contamination accumulated in the felt into an appropriate container located underneath the felt (not shown in ***Figure 1***). This alternative technology for felt conditioning has already been provided by Voith [5] in a slightly modified design version, where both the delivery pipe and nozzle are located inside a drum with an open honeycomb construction.

Experimental data for the felt-through-drying box obtained over the last few years clearly indicate the high effectiveness of this process for conditioning press section felts [3, 5, 7]. However, the main objective of this research was to develop a mathematical model describing a theory for the through-air conditioning of press section felts. Kawka [6] described methodology for studying the through-air dewatering process for paper products; arguably a similar approach can be applied to evaluate the through-air conditioning process for felts. Limited discussion of experimental results from an internal study [7] to determine a dynamic coefficient for water filtration through felt is provided in the latter part of this paper.

The proposed mathematical description of the through-air dewatering process for press section felts utilises the following assumptions:

a) the felt structure is based on a matrix of three components:
   - frame structure made of felt fibres
   - water
   - air

   with a varying amount of water and air in the felt pores.
b) water and fibre compressibility is not taken into consideration
c) Darcy's equations are used to describe water and air filtration through the felt
d) felt porosity varies over time
e) amount of air dissolved in the water is not taken into consideration
f) negligible impact of contamination

The following symbols are used to describe the parameters of the proposed system:

e – coefficient for the felt porosity
V_w, V_p – filtration velocity of the water and air through the felt
V_c – felt deformation velocity under applied air pressure
k_w, k_p – coefficients for water and air filtration through the felt
H – pressure drop
l – width of the felt-through-drying box exit slot
b – felt thickness.

Figure 1 provides the orientation of the x and y axes.

With the above assumptions it is possible to prove that the air and water filtration processes through press felt can be described by Laplace's formula [2, 6, 7]:

$$\frac{\partial^2 H}{\partial x^2} + \frac{\partial^2 H}{\partial y^2} = 0 \qquad (1)$$

The following boundary conditions are used to solve the above formula, which determines the pressure distribution of the water throughout the felt:

$$\left.\begin{aligned} H(x,0) &= 0 \\ H(x,b) &= H_0 \\ H(0,y) &= \frac{H_0 y^2}{b^2} \\ H(l,y) &= \frac{H_0 y^2}{b^2} \end{aligned}\right\} \qquad (2)$$

The above boundary conditions assume a parabolic character with regard to the change in the pressure of the water inside the felt when the water pressure changes from H_0 to *0*. By applying boundary conditions (2) to equation (1), the water pressure at any given point within the felt structure can be calculated from the following equation [7]:

The amount of water removed by the felt-through-drying box, with a slot width *l* and unit length "1", from the felt surface can be described as:

$$Q = -k_w \int_0^l (V_{wy})_{y=b} dx \qquad (4)$$

where:

$$V_{wy} = -k_w \frac{\partial H}{\partial y} + eV_c \qquad (5)$$

Equation (5) is a modified Darcy equation which provides the water velocity along the y axis and takes into account deformation of the felt during the dewatering process. Incorporating equations (3) and (5) into equation (4) provides us with a formula describing the amount of water removed from the felt by the felt-through-drying box:

$$|Q| = -k_w \frac{H_0 l}{b} + eV_c \cdot l \qquad (6)$$

The formula above contains the main design parameters of the felt-through-drying box:

- air pressure in the through-air chamber H_0,
- width of the felt-through-drying box slot *l* and parameters describing the felt being dewatered,
- coefficient for the water filtration through the felt k_w,
- felt thickness *b*,
- coefficient for the felt porosity *e*,
- felt deformation velocity V_c.

For the purposes of mathematical modelling, the above parameters are deemed to provide adequate characterisation of the felt.

Using a similar approach and assuming that any change in air pressure occurs only along the *y* axis (i.e. equation (1) can be described as $\frac{\partial^2 H}{\partial y^2} = 0$), the following equation – describing the airflow in the felt being dewatered by the through-air process – can be derived:

$$Q_{sr} = \frac{cS}{\eta} \frac{H_0 - H_1}{b} \qquad (7)$$

where:

c – coefficient of the felt air permeability,
S – airflow area under the felt-through-drying box (slot width by unit length),
η – coefficient of the air dynamic viscosity,
$(H_0 - H_1)$ – pressure drop through the felt,
b – felt thickness.

The felt air permeability coefficient can be calculated from the following [6]:

$$c = \frac{2G\eta b}{\gamma S(2 - P_b)P_b} \qquad (8)$$

where:

G – airflow through the felt,
P_b – drop in air pressure,
γ – specific weight of air.

Equation (6) can be used to determine the amount of water removed from the felt by the felt-through-drying box, with the specific filtration coefficient being determined experimentally. For the best results the specific filtration coefficient should be determined in a dynamic mode with a moving felt. However, in most cases a value for this parameter is obtained in a laboratory in a static mode [2 - pages 77 to 113].

In order to determine the relation between dynamic and static values of the filtration coefficient, an extensive study was conducted on the semi-work press located at the Institute of Papermaking & Printing, Technical University of Lodz [7]. This experimental press consists of two rolls, 0.6 m in diameter and 0.5 m long each: a soft rubber roll in the bottom position, with a rubber hardness of 20 PJ; and a hard stonit roll in the top position. The press was fitted with a hydraulic system to control the load in the nip area and with a felt tracking system with an air-through-dryer. The pressure of the through-air was set at 30 kPa.

The relationship between the dynamic and static filtration coefficient was determined using a synthetic needle entangled felt from Albany Co. with a basic weight of 1,100 g/sq.m. Selective results from the above study are illustrated in ***Figures 2, 3*** & ***4***. The dynamic coefficient of water filtration through the felt can be determined based on the monogram shown in ***Figure 3***.

The subsequent study of the water filtration process at a 90º angle to the felt surface shows a linear relationship between the filtration velocity and pressure gradient – this finding supports the approach taken in this study to use Darcy's formula to describe the through-air dewatering process for press section felts. This approach cannot be undertaken when there is a small pressure gradient (pressure drop) and low filtration velocity in the filtration process; in such cases the dewatering process is unable to overcome the resistance to the flow inside the felt structure.

Data from experimental evaluation of the through-air dewatering process shown in ***Figure 2*** indicates a strong linear relationship between the filtration coefficient, felt tension and dwell time in the through-air zone (***Figure 4***).

The exact value of the filtration coefficient obtained in laboratory conditions, k_{lab}, cannot be directly applied to calculate the amount of water removed from the felt in real-life situations, as provided by Equation (6).The controlled environment of a laboratory is very often unable to simulate all the dynamics of the real-life dewatering process, such as the moisture content of the felt and the dwell time of the felt under the felt-through-drying box exit slot. The correlation between the filtration coefficient calculated, k_o, and the laboratory obtained filtration coefficient, k_{lab}, can be derived either by the analytical method or can be based on experimental data.

In the present study, experimental data was used to correlate both filtration coefficients, $k_o = f(k_{lab})$, as this approach was shown to be of sufficient accuracy. Ex-

$$H(x,y) = \frac{8H_0}{\pi^3} \sum_{n=0}^{\infty} \frac{\cosh\frac{(2n+1)}{b} * \left(x - \frac{1}{2}\right)}{(2n+1)^3 * \sinh\frac{(2n+1)\pi l}{2b}} * \sin\frac{(2n+1)\pi y}{b} + \frac{H_0 y}{b} \qquad (3)$$

$$k_0 = \frac{k_{lab} - \left(-0.474 S_f H_0 - 5.0 S_f - 7.35 H_0 - 79.9\right) \cdot 10^6}{-4.54 \cdot 10^{-3} S_f H_0 + 3.64 \cdot 10^{-2} S_f + 0.115 H_0 - 0.996} \pm A \qquad (9)$$

Equation 3 and 9.

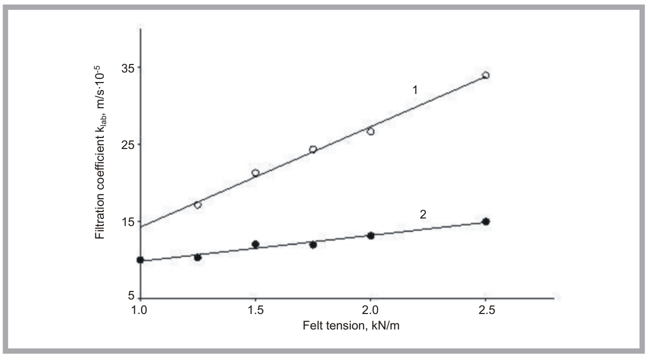

Figure 2. Effect of the felt tension on the filtration coefficient of various felts [6]: 1 – felt from Tamperen, 2 – felt from Albany.

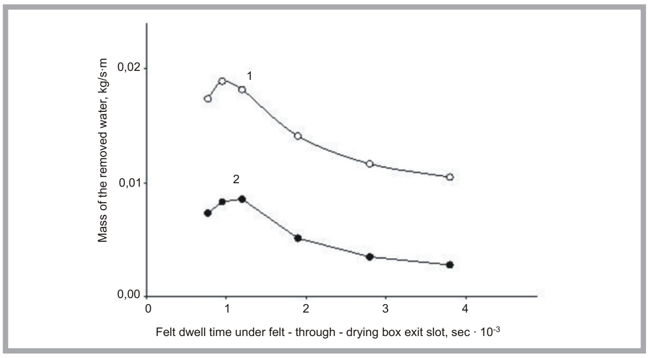

Figure 4. Effect of the felt dwell time under the felt-through-drying box on dewatering efficiency: 1 – felt with an initial dryness of 34%, 2 – felt with an initial dryness of 40%.

perimental evaluation also indicated that for a varying pressure and given initial dryness of the felt, there is a linear relationship between k_o and k_{lab}.

Based on the experimental data, the relation between k_o and k_{lab} was obtained using the least squares fitting presented in Equation (9) where:

S_f – dryness of the press felt before the felt-through-drying box in %,

H_o – filtration pressure in meters,

A – correction coefficient for the calculated filtration coefficient in m/s.

Correction coefficient A, which was shown to depend on the dwell time of the felt under the felt-through-drying box exit slot, can be determined from ***Figure 3***.

Experimental data, shown in ***Figure 4***, illustrate the relation between the amount of water removed from the felt and the dwell time the felt spends under the exit slot of the felt-through-drying box. The amount of water removed increases initially with an increase in the dwell time until it reaches a maximum value; after reaching the maximum, the dewatering efficiency drops significantly. The initial dryness of the felt has also been shown to have a significant effect on the maximum value of water removed from the felt, with a lower initial felt dryness resulting in a larger amount of water removed .

Conclusions

The mathematical model of the through-air dewatering and conditioning processes for press section felts has been shown to accurately predict the real-life process only when there is a dynamic coefficient of water filtration through the moving felt

The dynamic and static coefficients of water filtration through the felt was found to have a linear relationship at varying air pressure and initial felt dryness; however, there is a significant difference in their actual values. Although a laboratory determined static coefficient of water filtration through felt can be used for engineering calculation, it is necessary to correct it by considering the dynamic mode (***Figure 3***)

The mathematical model described was found to be especially useful for conditioning new felts of various designs that have not been over-compacted. Any contamination collected inside the felt can be easily removed by the airflow from the through-air process without any significant effect on the dewatering process.

Felt tensioning (***Figure 2***) and the dwell time in the through-air zone (***Figure 3***) were shown to significantly affect the felt dewatering process.

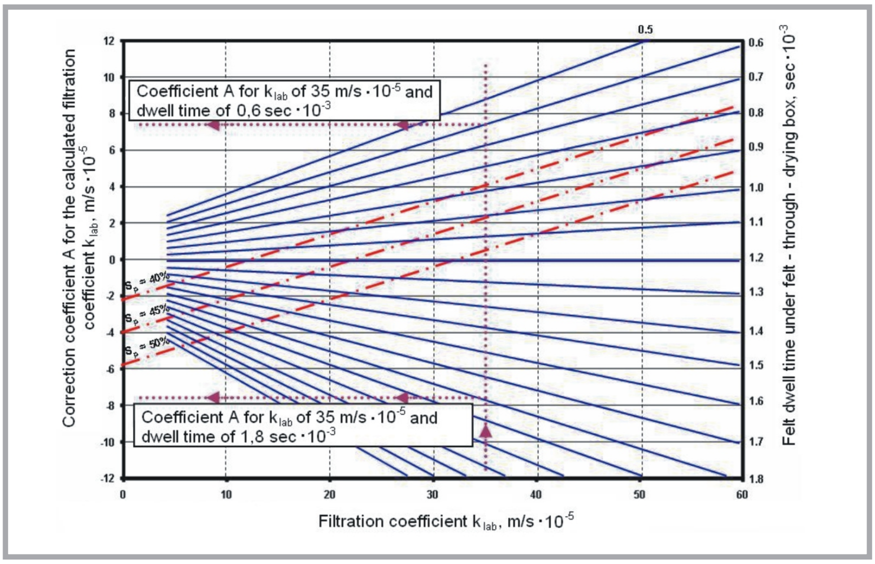

Figure 3. Correction coefficient A for the calculated filtration coefficient k_{lab}.

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