Press dewatering: New life for an old concept

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ABSTRACT

An old press-dewatering concept is revisited with fresh interest. The original mathematical model has been refined, yielding an interesting relationship between dry fiber density and its capacity for "swell" water retention. However, the main result was a simple press-dewatering function in the form of a natural logarithm. Data from a field validation on a commercial paper machine show that the model provides an acceptable degree of reliability in predicting press performance. Finally, the practical use of the dewatering function is demonstrated.

Application:

A practical dewatering model for predicting pressing performance on a paper machine.

THERE ARE MANY CONCEPTS AND models to describe the dewatering process in the press sections of paper and board machines. However, almost all of these have some type of shortcoming, as was clearly demonstrated by El-Hosseiny *(1)*. One study that has not received much attention is Luey's work *(2)* on the pressing of recycled paperboard.

The current work attempts to revive Luey's concept by exposing it to more rigorous mathematical treatment. The results reveal a remarkably simple e-function that inspires credibility by its sheer elegance and, moreover, yields a new relationship between dry fiber density and its capacity for "swell" water retention. Finally, an easily understood press-dewatering constant is introduced, and a procedure for practical on-line use of the model is described.

LUEY'S CONCEPT

Luey's concept assumes the following conditions to be valid in the pressing process:

- The felts are sufficiently conditioned to accept all water that leaves the sheet without offering significant resistance.
- The water leaving the sheet flows perpendicular to the sheet surface, and the flow is laminar by nature.
- The effect of the pressure applied to the sheet decreases with increasing resistance of the fiber structure, and sheet dewatering comes to a halt when the pore volume approaches zero.

The concept therefore describes a purely "flow controlled" regime, wherein a critical solids content signals the end of water flow. That is why this concept is of particular interest in cases of pressing paper and board made of recycled fiber, with its high potential for free-water volume. Another important consequence of these assumptions is the continuous decrease of permeability during the compression cycle. Whereas almost all other press-dewatering models are based, in one way or another, on Darcy's law for flow through stationary porous beds of constant permeability, the origin of Luey's concept draws quite rightly upon Poisseuille's more fundamental law for water flow through pores:

$$v = \frac{D_p^2 \Delta P}{32\eta L_p} \qquad (1)$$

(Note: These and all other variables are defined in the Nomenclature section at the end of this article.) Luey develops Poisseuille's law with the drainage area ratio A (which represents the ratio of draining pore area to sheet surface area) and, further, with the change of free-water content:

$$U_i - U_o = \frac{1}{C_i} - \frac{1}{C_o} \qquad (2)$$

With G (ovendry solids per square meter of sheet surface), he thus finds that

$$G\Delta U = G\Delta\frac{1}{C} = v\,\rho_w A \Delta t \qquad (3)$$

which gives the weight of water per square meter of sheet surface. Accounting for the change of pore diameter (D_p), pore length (L_p), and drainage area ratio (A) with free-water content, this leads to Eq. 4:

$$\frac{dt}{dU}\,\frac{\Delta P}{32\eta}\,\frac{\rho_w}{G} = \frac{L_p}{D_p^2 A} \qquad (4)$$

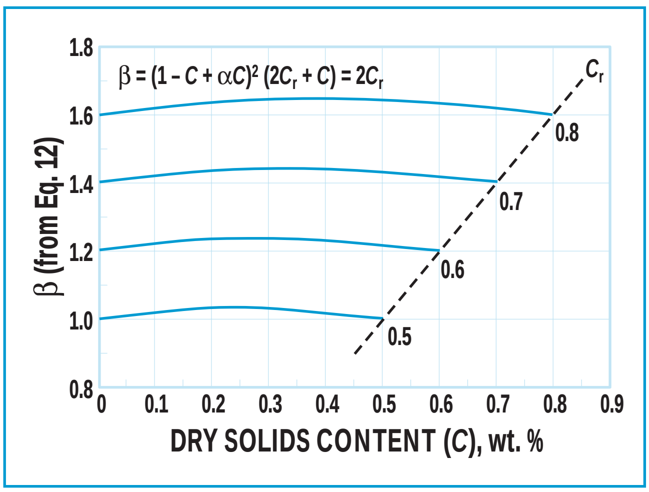
In Eqs. 1 and 4, ΔP represents the effective average hydraulic pressure difference spread out over the press nip and is assumed to be constant during the compression phase. All experts agree that, in theory, $\Delta P = P_{mech} - P_{struc}$, i.e., the difference between mechanical pressure exerted by the press and structural pressure exerted in reaction by the fiber web. However, some of them, in particular Gudehus *(3)* and Kataja *et al. (4, 5)*, have clearly demonstrated that in a flow-controlled regime, the value and change of structural pressure is so small that it can be ignored as long as the resulting dryness is well away from the critical dryness of the fiber material.

	Critical dry-solids content (C_r), wt.%			
	0.50	0.60	0.70	0.80
Water/solids density ratio (α)	0.633	0.694	0.738	0.771
Solids density (ρ_s), kg/m^3	1577	1438	1353	1295

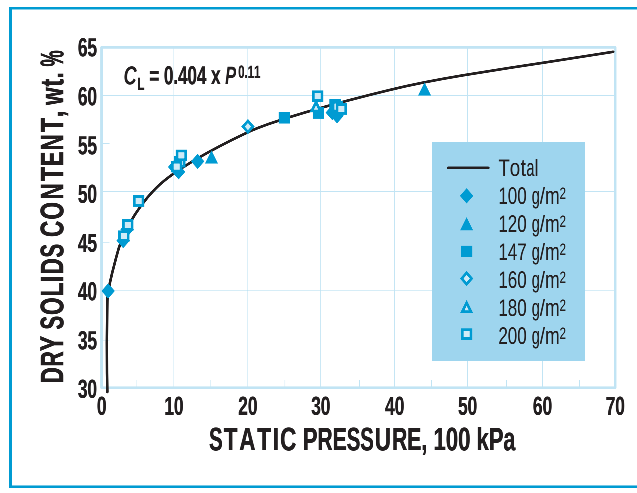
I. Calculated values for α and ρ_s as functions of C_r

G, g/m^2	112	148.4	185
C_i	0.2402	0.225	0.2114
C_{o1}	0.4755	0.451	0.4265
C_{o2}	0.4938	0.4741	0.4518
S_2/S_1	1.082	1.104	1.115

IV. Pressing results before and after a 20°C increase in sheet temperature



1. β as a function of C at four levels of C_r; maximum deviation of β is 3% when $C_r(1-\alpha) = 1 - \sqrt{2/3}$



2. Dry-solids content as a function of static pressure for corrugating medium at basis weights of 100–200 g/m²

If Eq. 4 is integrated over the pressing time, the result is Eq. 5.

$$\frac{Pt}{32\eta}\,\frac{\rho_w}{G} = \int_{1/C_i}^{1/C_o} \frac{L_p}{D_p^2 A}\, d\frac{1}{C} \qquad (5)$$

MATHEMATICAL TREATMENT

At this point, instead of following Luey's laborious calculus method for solving D_p^2A/L_p, we will try to solve the integral making use of the relations for pore diameter, pore length, and the pore drainage area ratio—all three relations introduced by Luey—expressed in terms of dry-solids content (C) and critical dry-solids content (C_r).

$$D_p^2 = K(C_r/C)^3 \qquad (6)$$

and

$$L_p = L\left(1 + \frac{C}{2C_r}\right) \qquad (7)$$

where

$$L = \frac{G}{\rho_w}(U + \alpha)$$

where

$$\alpha = \rho_w/\rho_s$$

and

$$U = \frac{1}{C} - 1$$

The drainage area ratio A equals the porosity, with the understanding that pore lengths (L_p) and pore diameter (D_p) have a random size distribution throughout the paper web.

$$A = \frac{U/\rho_w - U_r/\rho_w}{U/\rho_w + 1/\rho_s} = \frac{U - U_r}{U + \alpha} \qquad (8)$$

Equations 6–8 combined with the integral in Eq. 5 yields (with $P{\cdot}t = F/S$) Eq. 9,

$$\frac{K}{32}\left(\frac{\rho_w}{G}\right)^2 \frac{F}{\eta S} = \int \frac{(U+\alpha)\left(1 + \frac{C}{2C_r}\right)}{\left(\frac{C_r}{C}\right)^3 \frac{U - U_r}{U + \alpha}}\, d\frac{1}{C} \qquad (9)$$

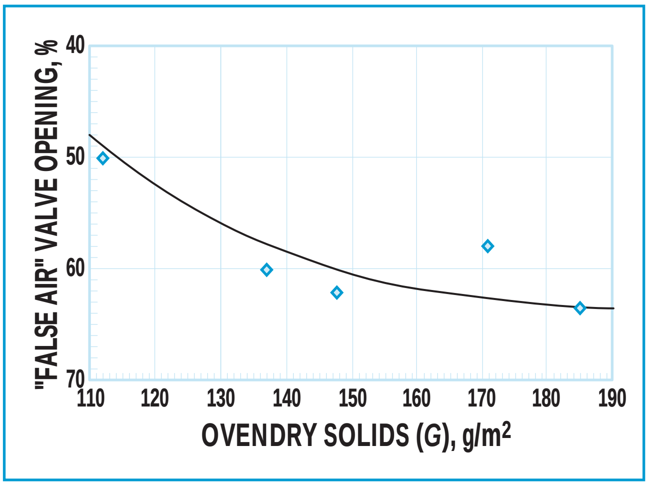
which develops into Eq. 10,

$$\frac{K}{32}\left(\frac{C_r\rho_w}{G}\right)^2 \frac{F}{\eta S} = \int \frac{(1 - C + \alpha C)^2\,(2C_r + C)}{2C_r\left(\frac{1}{C}\right)\left(\frac{C_r}{C} - 1\right)}\, d\frac{1}{C} \qquad (10)$$

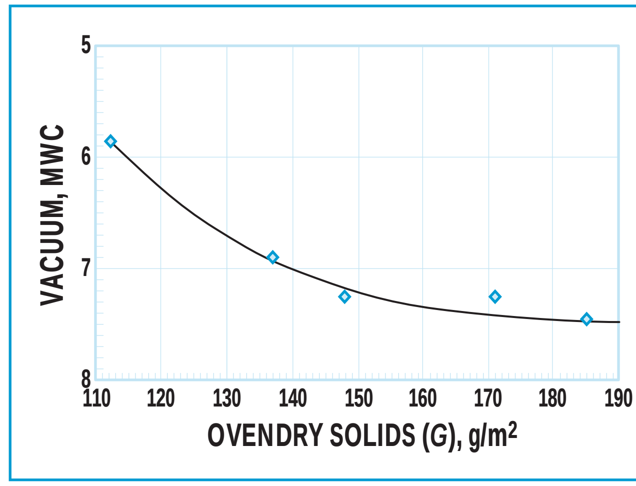
which, finally, for $(1 - C + \alpha C)^2\,(2C_r + C) = 2C_r$ and integrated between $1/C_i$ and $1/C_o$ yields Eq. 11.

$$\frac{K}{32}\left(\frac{C_r\rho_w}{G}\right)^2 \frac{F}{\eta S} = \ln\left(\frac{C_r - C_i}{C_r - C_o}\right) \qquad (11)$$

Naturally, this last development requires justification. To test the as-



3. "False air" valve opening to maintain constant vacuum level in the wire suction boxes over the range of dry-solids contents during the field study



4. Vacuum levels in the wire suction roll over the range of dry-solids contents during the field study (MWC = meter water column

sumption that $(1 - C + \alpha C)^2 (2C_r + C) = 2C_r$, let

$$\beta = (1 - C + \alpha C)^2 (2C_r + C) \qquad (12)$$

For $C = 0$, $\beta = 2C_r$
For $C = C_r$, $\beta = 2C_r$ provided that
$C_r(1 - \alpha) = 1 - \sqrt{2/3}$

From this intriguing relationship, it is possible to calculate values of α as a function of C_r (critical dry-solids content). And since $\alpha = \rho_w/\rho_s$ and $\rho_w = 998$ kg/m^3, we can also calculate values of ρ_s (solids density) as a function of C_r. As seen in **Table I**, at low C_r, the calculated values of ρ_s show remarkable agreement with the dry fiber density of cellulose, which has a high potential for "swell" water (i.e., low C_r). In contrast, at the other end of the scale, the ρ_s values are similar to the dry fiber densities of groundwood, with their low potential for "swell" water expressed in high C_r values. Finally, plotting all possible values of β for $0 < C < C_r$ in Eq. 12, one finds a maximum possible deviation of only +3% over $\beta = 2C_r$, as seen in **Fig. 1**.

All this is too good to be discounted as good luck or as purely accidental. For the time being, we accept its validity and use it to develop a simple and elegant e-function that is useful in testing press section performance and rewet phenomena. However, further investigation into the validity of $C_r(1 - \alpha) = 1 - \sqrt{2/3}$ is desirable.

PRACTICAL USE OF PRESSING EQUATION

Before the pressing equation can be applied to predict the performance of an individual press or a whole press section on a paper or board machine, further analysis of pressing variables is required.

Critical dryness (C_r)

In Luey's concept, the definition of the critical dryness is clear: Strictly speaking, C_r represents the dryness of the fiber mass, where there is no free water, and the remaining water is that held by the fibers through sorption alone.

The value of C_r is clearly demonstrated by drying a wet sheet in air. The critical dryness appears when the constant drying rate—more or less suddenly—changes into a falling drying rate. The value of C_r usually ranges within 0.70–0.80, depending on fiber quality, beating degree, and percent filler. Therefore, the dry solids at the press exit, C_o, approaches C_r only at infinite pressure during infinite time. Of course, no press section can achieve such a result. Time usually is limited to milliseconds, and maximum pressure is limited by construction specifications and economics. Therefore, every press or press section has its own limit of applied pressure and, consequently, its own limit of achievable dryness, which we will call C_L.

Dryness limit (C_L)

In Luey's concept, a minimum possible porosity depending on

$$U_L + 1 = 1/C_L \qquad (13)$$

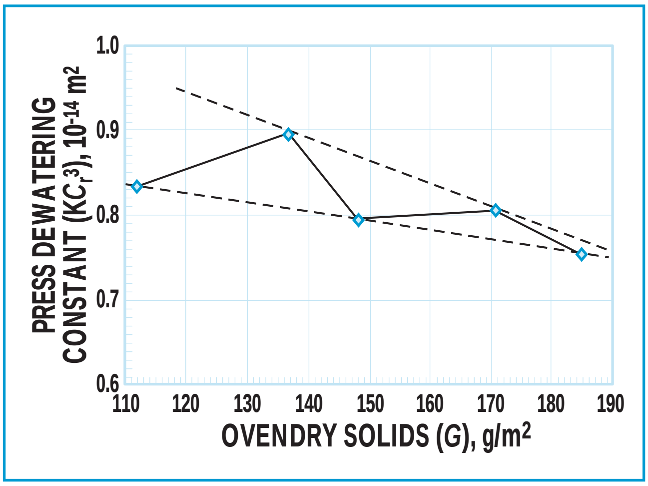
must therefore be introduced for the press under investigation, so that the drainage area ratio equals Eq. 14:

$$A = \frac{(U - U_L)}{(U + \alpha)} \qquad (14)$$

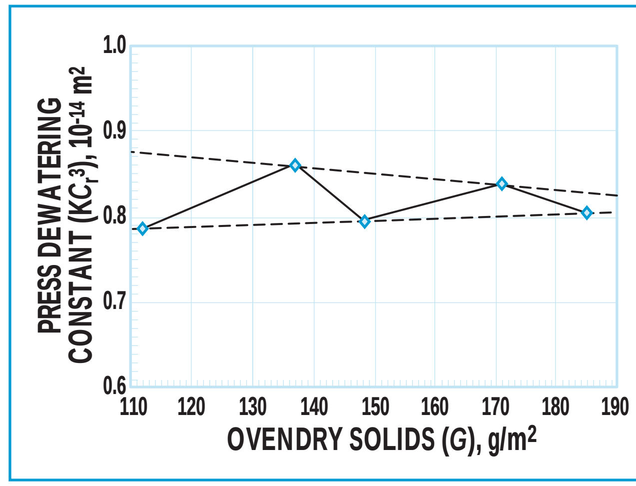
When this function for A (see also Eq. 8) is incorporated in the earlier found integral (Eq. 9), we obtain Eq. 15.

$$\frac{KC_r^3}{32C_L}\left(\frac{\rho_w}{G}\right)^2 \frac{F}{\eta s} = \ln\left(\frac{C_L - C_i}{C_L - C_o}\right) \qquad (15)$$

wherein $KC_r^3(\rho_w/G)^2$ represents a dimensionless press-dewatering constant specific to a sheet of given fiber quality and weight subjected to a change of press impulse exerted by a press characterized by C_L and to a change in the dynamic viscosity of water because of temperature variation.



5. *Calculated press-dewatering constant (**KC_r^3**) based on **C_o** values measured with NIR sensor over the range of dry-solids contents during the field study (based on calculated **R** = 19.33 g/m²)*



6. *Calculated press-dewatering constant (**KC_r^3**) based on **C_o** values measured in the laboratory over the range of dry-solids contents during the field study (based on calculated **R** = 13.60 g/m²)*

The press dryness limit C_L can only be defined as the nip dryness obtained at maximum possible line force divided by nip width applied over infinite time. The value of C_L for a given furnish is best defined by pressing samples under a static press. The relation between C_L and static pressure follows a power function in the form of $C_L = aP^b$. Static press tests were carried out in our mill on a furnish of 50/50 old newsprint and old magazines. **Figure 2** shows that C_L for this furnish was $0.404 \times P^{0.11}$, where P is the static pressure in units of 100 kPa.

*Proportionality constant (**K**)*

K represents the proportionality constant in Luey's equation for the change of pore diameter with freewater content:

$$D_p^2 = K\left(\frac{C_r}{C}\right)^3 \qquad (16)$$

This shows that $D_p = K^{0.5}$ when $C = C_r$. It also means that D_p never equals zero, and it explains the fact that hydraulic pressing action alone can never achieve $C_o = C_r$ in a flow-controlled regime. Therefore, it justifies the introduction of C_L for a particular press and also the exclusive use of C_r as a fiber-quality constant within the dimensionless press-dewatering constant. C_r is therefore the absolute but never achievable, pressing limit, while C_L varies with different press configurations.

The pressing quality of a given fiber mix is thus completely described by the constant KC_r^3, while C_L describes the press. Values for KC_r^3 can only be determined by cross testing over a wide range of machine conditions after rewetting has been ascertained.

*Rewetting (**R**)*

The derived dewatering equation (Eq. 15) does not account for possible rewetting of the sheet in the expansion part of the nip nor for rewetting after the nip. Rewetting phenomena have not been investigated sufficiently to make accurate predictions. However, experts like Wahlström *(6–8)* and others *(9–13)* agree that rewetting in the expanding part of the nip is independent of basis weight, machine speed, and nip width, and is controlled only by conditions at the paper–felt interface. Wahlström differentiates between various forms of rewetting, of which nip-expansion rewetting is the most important, which may amount to values of up to 35 g/m².

In Eq. 15, C_o should be replaced, strictly speaking, by C_n, the maximum dryness in the nip, and C_o should be used for the measured dryness after the press, so that rewetting amounts to

$$\frac{1}{C_o} - \frac{1}{C_n} = \frac{R}{G} \qquad (17)$$

Values for R can only be determined by cross testing over a wide range of machine conditions in conjunction with KC_r^3.

*On-line validation of **R** and **KC_r^3***

With the previously derived dewatering equation (Eq. 15), it is not necessary to find separate values for K and C_r, nor is it necessary to find an absolutely true value for the combination KC_r^3. All we need to do is find values for KC_r^3 and the rewetting R that, when combined with the dewatering equation, yields a reliable prediction of C_o.

Validation of KC_r^3 and R can therefore best be carried out on the machine. We conducted tests on a machine producing corrugating medium. The tests were run at various speeds and basis weights within the machine's normal production range of 120–200 g/m².

The paper machine has a maximum speed of 405 m/min, has no size press installed, and is equipped with three single-felted conventional presses, with the third press capable of producing a maximum line force of 105 kN/m. With its nip width of 0.0424 m, the maximum possible pressure thus amounts to 105/0.0424 = 2476 kPa. Based on the static pressing test (Fig. 2), this yields $C_L = 0.575$ ($C_L = 0.404 \times 24.76^{0.11}$).

The total operational line force of the three presses, together with the line force generated by vacuum in the bottom roll of the third press, was 214 kN/m. This was kept constant during the testing period of about 8 hours. Temperature was constant at 40°C, resulting in a water density (ρ_w) of 992.25 kg/m^3 and a dynamic viscosity of water (η) equal to 653×10^{-6} Pa·s.

Continuous monitoring of C_o was achieved by a NIR (near infrared) sensor calibrated for moisture contents as high as 60%. The sensor—located after the third press and before the drying section—was mounted on a supporting mobile structure and connected to an ordinary PC running specially designed software.

Vacuum level in the wire suction boxes was kept constant, but vacuum in the wire suction roll changed with sheet weight and fiber quality. The machine crew exercised great efforts to maintain constant dryness at the drum reel while keeping the quality of the furnish on the wire as constant as possible. Despite these efforts, the dewatering quality of the furnish on the wire showed clear signs of a steady decline. The forward creep of the dry line exceeded what would have been expected by the increase in basis weight.

Values for C_i and C_o were further checked by the mill laboratory from grab samples during each test. However, the quality of the results are suspect because of the great difficulties in obtaining the samples. Only the C_i-value of 0.225 (taken during the run at 160 g/m^2) was considered reliable. Thus this weight served as a baseline reference from which the C_i values for the other basis weights were calculated.

The calculation procedure was based on the following assumptions:

	BASIS WEIGHT, g/m^2 120	147	160	180	200
Wire Section [a]					
Ovendry solids (G), g/m^2	112.0	137.0	148.4	171.1	185.4
Machine speed (S), m/min	395	325	294	258	222
Suction boxes					
Net pressure (ΔP), kPa	25	25	25	25	25
Line force (F), kN/m	70	70	70	70	70
Suction roll					
Net pressure (ΔP), kPa	58.5	69.0	72.5	73.5	74.5
Line force (F), kN/m	23.4	27.6	29.0	29.4	29.8
Total line force (F), kN/m	93.4	97.6	99.0	99.4	99.8
Total press impulse (P_I), Pa·s	14,187	18,018	20,204	23,116	26,973
Press Section [b]					
Total line force (F), kN/m	214	214	214	214	214
Total press impulse (P_I), Pa·s	32,506	39,508	43,673	49,767	57,838
$\ln_{press}/\ln_{wire}$ [c]	1.095801	1.048646	1.033816	1.029656	1.025529
C_i (solids at wire exit), wt.%					
NIR sensor	0.240223	0.234523	**0.225**	0.216096	0.211449
Lab check	0.236898	0.232520	**0.225**	0.218629	0.215576
C_n (solids at press nip), wt.%					
NIR sensor	0.518011	0.501662	0.479148	0.458036	0.446348
Lab check	0.511389	0.497396	0.479148	0.463998	0.456272
C_o [d] (solids at press exit), wt.%					
NIR sensor	**0.4755**	**0.4685**	**0.4510**	**0.4355**	**0.4265**
Lab check	**0.4815**	**0.4740**	**0.4590**	**0.4475**	**0.4415**
R (rewetting), g/m^2					
NIR sensor	…	…	19.33	…	…
Lab check	…	…	13.60	…	…
KC_r^3 (press-dewatering constant), 10^{-14} m^2					
NIR sensor	0.8338	0.8900	0.7970	0.8049	0.7534
Lab check	0.7867	0.8607	0.7970	0.8373	0.8023

[a] $C_L = 0.275$, $C_w = 0.100$
[b] $C_L = 0.575$; bold-faced data represent measured values
[c] See Eq. 18
[d] C_o values are averages of two tests per basis weight. Lab checks on C_o were actually erratic and are here tuned to their tendency to be ca. 1% higher than the NIR-sensor-measured C_o, rising from +0.6% at 120 g/m^2 to +1.5% at 200 g/m^2.

II. Results of field tests

- Rewetting is equal for all five of the tested basis weights.
- The dewatering equation can be used to calculate dewatering on the wire section downstream of the dry line.
- KC_r^3 values steadily decreased over the 8-h testing period.
- The KC_r^3 value of a sheet, the dry-solids weight, temperature, and web-speed do not change during passage from wire to press.

These assumptions allow us to solve for the value of C_n for the reference test by using the ratio

$$\frac{\ln(\text{press})}{\ln(\text{wire})} = \frac{C_{Lw} F_p}{C_{Lp} F_w} \qquad (18)$$

and to solve for R by using Eq. 17

$$\frac{R}{G} = \frac{1}{C_o} - \frac{1}{C_n}$$

Having thus established all relevant reference values, the calculation proceeds using the same formula in

Ovendry solids (G), g/m²	112	148.4	185.4
Rewetting (R), g/m²	19.33	19.33	19.33
Temperature (T), °C	40	40	40
Dry-solids content, wt.% *			
Press section entry (C_i)	0.2402	0.225	0.2114
Press section exit (C_o)	0.4755	0.451	0.4265
Press limit (C_L)	0.575	0.575	0.575
Drum reel (C_d)	0.93	0.93	0.93

* As measured by NIR

III. Paper-machine data

obtaining C_n and C_i for the other tested basis weights. KC_r^3 for each tested basis weight follows then from the dewatering equations for the wire section

$$KC_r^3 = \left(\frac{G}{\rho_w}\right)^2 \frac{32\eta}{P_I} C_L \ln\left(\frac{C_L - C_w}{C_L - C_i}\right) \quad (19)$$

and the press section

$$KC_r^3 = \left(\frac{G}{\rho_w}\right)^2 \frac{32\eta}{P_I} C_L \ln\left(\frac{C_L - C_i}{C_L - C_n}\right) \quad (20)$$

Table II shows all relevant data for the wire and press sections as well as measured ovendry weights, machine speeds, dry-solids contents (C_i, C_n, C_o), and calculated values for R and KC_r^3. The C_L value for the wire section and the C_w value for the dry line on the wire were assumed to be 0.275 and 0.10, respectively, based on experience.

A constant vacuum level was maintained on the wire suction boxes and controlled by letting atmospheric air pass into the vacuum pump via a “false air” valve. **Figure 3** shows the extent of “false air” introduced over the range of ovendry solids. The vacuum level of the wire suction roll was allowed to increase with increasing basis weight. **Figure 4** shows these vacuum levels over the range of tested basis weights.

Figures 5 and 6 show the KC_r^3 values calculated from the C_o values measured by the in-line sensor and from C_o values measured on grab samples in the laboratory, respectively.

Influence of temperature on C_o

It is generally accepted that press performance improves by approximately 1% dryness for every 10°C rise of sheet temperature. Until now, there was no way to check the validity of this assumption. However, the dewatering model presented here lends itself well to this purpose, as illustrated by the following example.

We select some of the results from the field study as a starting point. The selected data are presented in **Table III**. Suppose a temperature rise of 20°C. The following water densities and dynamic viscosities are valid:

At $T_1 = 40$°C:

$\rho_{w_1} = 992.25$ kg/m³; $\eta_1 = 653\times10^{-6}$ Pa·s

At $T_2 = 60$°C:

$\rho_{w_2} = 983.23$ kg/m³; $\eta_2 = 466\times10^{-6}$ Pa·s

It is assumed that C_i remains constant, since its influence in this case is rather small. It is further assumed that the rewetting as well as drying capacity remain constant, so that the evaporation function, $(C_d - C_o)/C_o$, is (a) proportional to the press-dewatering function corrected for water density and dynamic viscosity and (b) inversely proportional to the machine speed S. Given these assumptions, the following Eqs. 21 and 22 are valid.

$$\frac{1}{C_{o_1}} - \frac{1}{C_{n_1}} = \frac{1}{C_{o_2}} - \frac{1}{C_{n_2}} = \frac{R}{G} \quad (21)$$

$$\frac{C_{o_1}}{C_d - C_{o_1}} \frac{\eta_1}{\eta_2} \left(\frac{\rho_{w_2}}{\rho_{w_1}}\right)^2 \ln\left(\frac{C_L - C_i}{C_L - C_{n_1}}\right) = \frac{C_{o_2}}{C_d - C_{o_2}} \ln\left(\frac{C_L - C_i}{C_L - C_{n_2}}\right) \quad (22)$$

From the given data, the left side term is known and, by iteration, C_{o_2} is solved from the right-side term. This procedure yields the results presented in **Table IV**. The calculated values at the higher temperature show good agreement with experience. This is another convincing indication of the model’s usefulness.

FINAL COMMENTS

- Lab tested C_o values are highly suspect because of the difficulty in obtaining samples at the running press.
- Despite only one reliable lab-tested C_i value, the graph of calculated KC_r^3 values from sensor-measured C_o values (Fig. 5) clearly shows the predicted falling trend.
- KC_r^3 values as well as R values need not be absolutely true. However, used in combination with the dewatering model, they will yield an acceptable prediction of the dewatering performance of the press.
- Reliable prediction of C_o with this model at any variable of weight, speed, line force, and temperature requires the following simple procedure:

1. Determine C_L (press) with the static pressing test.
2. Use experience values for both $C_{L,wire}$, the wire section dryness limit, and C_w, the dryness on the wire at the dry line.
3. Find KC_r^3 and R by means of an accurate reference test on the running machine.
4. Calculate C_o for any variable of

KEYWORDS

Water removal, presses, logarithms, mathematical models, press sections, on line measurement, water retention, moisture content, waste papers, reclaimed fibers.

weight, speed, line force, and temperature.

- The method is sensitive to the accuracy of C_w, C_i, and C_L.
- The dewatering model presented in this report does not pretend to be perfect and may not be universally applicable. However, its practical use is greatly enhanced by the introduction of C_L, the pressing limit of the press, and by the identification of C_r as a fiber-quality constant that—in combination with K in KC_r^3—describes completely the dewatering capacity of a fibrous material in a flow-controlled pressing regime. Such a regime is nearly always the case with the pressing of corrugating medium, liner, and solid board made of 100% reclaimed fiber.
- The model can be applied successfully to the dewatering process of the wire downstream of the dry line. However, the wire dryness limit $C_{L,wire}$ must be obtained by a method compatible with the applicable mechanism of dewatering on the wire. TJ

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NOMENCLATURE

A = drainage area ratio (draining pore area to sheet surface area)
C = dry-solids content, wt.%
C_d = dry-solids content at the drum reel, wt.%
C_i = dry-solids content at the wire exit, wt.%
C_L = dry-solids content pressing limit (i.e., achievable dryness for a given press), wt.%
C_n = dry-solids content at the press nip, wt.%
C_o = dry-solids content at the press exit, wt.%
C_r = critical dry-solids content (i.e., sheet with no free water), wt.%
C_w = dry-solids content at the dry line on wire, wt.%
D_p = pore diameter, m
F = line force, N/m
G = ovendry solids, g/m^2
K = proportionality constant, m^2
KC_r^3 = press-dewatering constant, m^2
L = sheet thickness, m
L_p = pore length, m
P = pressure, Pa
ΔP = net effective average hydraulic pressure throughout the press nip ($P_{mech} - P_{struc}$), Pa
P_{mech} = mechanical pressure exerted by the press, Pa
P_{struc} = structural pressure exerted by the fiber web, Pa
P_I = press impulse, Pa·s
R = rewetting, g/m^2
S = machine speed, m/s
t = time, s
T = temperature, °C
U = water/solids weight ratio
ΔU = change in free-water content ($U_i - U_o$)
U_i = water/solids weight ratio at the wire exit
U_L = water/solids weight ratio pressing limit (i.e., lowest achievable water content for a given press)
U_o = water/solids weight ratio at the press exit
U_r = critical free-water content
v = flow velocity, m/s
α = water/solids density ratio (ρ_w/ρ_s)
η = dynamic viscosity of water, Pa·s
ρ_s = solids density, kg/m^3
ρ_w = water density, kg/m^3

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