Economics of coated paper production made from deinked pulp

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ABSTRACT: The fraction of deinked pulp for coated paper production is continually increasing, with some mills using 100% deinked pulp for the base paper. The brightness of the coated paper made from deinked pulp may be reached through a combination of more or less extensive deinking, compensated by appropriate coating, to optimize costs overall. The authors proposed general optimization methods combined with Kubelka-Munk multilayer calculations to find the most economical combination of deinking and coating process that would produce a coated paper made from DIP, at a given target brightness, while maintaining mechanical properties.

Application: The methods and software can help papermakers find the least expensive combination of deinking and coating process to produce coated paper with targeted optical properties.

Production of lightweight coated paper (LWC) from deinked pulp (DIP) is a growing trend in the industry [1], with some mills using 100% DIP for the base paper [2]. Pilot studies have shown that it is possible to coat a paper made with large fractions of DIP; however, this may cause coating defects, such as streaks and scratches [3], especially with the blade coating process. Coating color optimization combined with film press (for LWC only) or latest technologies such as soft tip blade or curtain coating may help solve such problems. Also, specks in the base paper may be difficult to cover by the coat layer. In most cases, however, optical specifications of the final product are achievable by a combination of deinking and coating. A lower-quality base paper (containing more inks) can be used to reach similar brightness after coating, provided additional coat weight is applied or coating color with higher scattering power is used. Optical properties can be achieved by deinking the base paper and then compensating by coating, but the question remains about the best combination of deinking and coating that will lead to optimization of overall production cost.

The optical characteristics of coated paper can be calculated using a multilayer Kubelka-Munk approach [4–6]. It has been shown that considering coated paper as a stack of distinct coating layers and paper layer leads to accurate predictions of brightness and opacity [7,8]. It is possible to take into account the impregnation of the base paper by the coating color through an additional mixing layer [9]. The multilayer Kubelka-Munk modeling requires identification of the optical characteristics of the coating layer itself; this can be determined from reflectance measurements of coated and uncoated paper, or coating layer deposited on a transparent film, and then using several numerical methods (e.g., [10,11]). The effect of variable composition of DIP (in terms of fiber type, filler, and inks) on optical properties can be accurately predicted thanks to the Kubelka-Munk mixing rules [12,13]. These methods have been successful in optimizing the formulation costs of coating colors for various coated paper and board grades [14,15].

The objective of this study was to find the most economical combination of deinking and coating processes to produce coated paper, with base paper formed from DIP. General optimization methods were developed to assess the effect of deinking and coating parameters on the optimum cost for coated paper production. The main target parameter for the cost optimization was the brightness of the coated paper. In addition, the evolution of mechanical properties of the coated paper as a function of deinking process yield and deposited coat weight was also modeled and used as an additional constraint.

METHODS

The production of DIP of different brightness was carried out on our deinking pilot plant (CTP; Grenoble, France). The furnish was a mixture of 30% old newsprint (ONP) and 70% old magazines (OMG). The deinking process used a drum pulper with alkaline chemistry and soap at 19% consistency for 20 min at 45°C; the chemistry was 0.35% sodium hydroxide, 0.6% soap (Serfax MT90 from Stephenson Group; Leeds, UK), 1.75% silicate, and 1% peroxide. The process also used fine screening (0.2 mm slots); two successive flotation steps (Verticell from Kadant; Westford, MA, USA) at 1.2% consistency, 45°C, constant froth flow, and 300% air ratio; thickening with a vacuum filter (15% outlet consistency); screw press (30% outlet consistency); and high-speed dispersing (30% consistency, 70°C, specific energy of 60 kWh/ton). Pulp was sampled at four locations throughout the deinking line, for further making of handsheets: flotation inlet ("pulp."), flotation 1 accept ("flot.1"), after flotation 2 accept ("flot.2"), and after dispersing ("disp."). The deinking process differed from common practice for LWC DIP. To limit the losses, there was no final washing. In addition, the dispersion step is usually per-

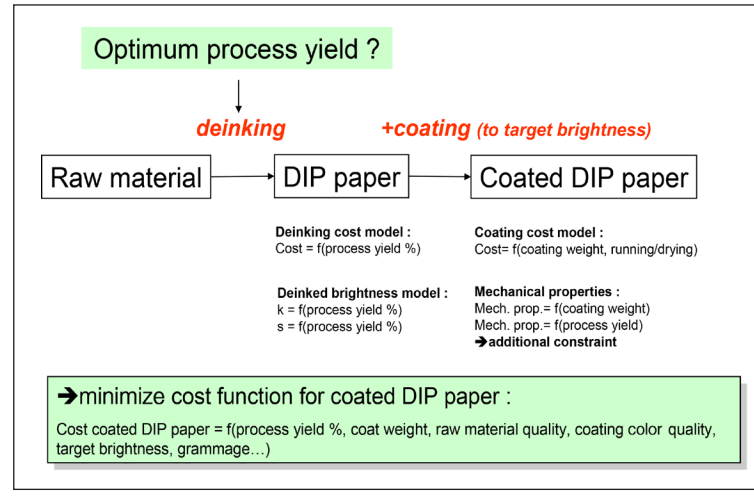
formed between the two flotations. However, the residual ink in the deinked pulp was increased (final effective residual ink concentration [ERIC] of 221 ppm compared with typical target values around 100 ppm). We wanted to see whether it was possible to recover the brightness with the coating layer, while preserving the deinking yield.

Handsheets (50 g/m²) were manufactured on the Formette Dynamique (Techpap; Grenoble, France) from pulp sampled along the pilot deinking line with alkenyl succinic anhydride as an internal sizing agent to achieve Cobb values of 18–20 g/m², together with cationic polyacrylamide retention polymer to maximize fines retention. They were coated on an Endupap bench-top laboratory coater (CTP; Grenoble, France) using grooved bars and infrared dryers at a speed of 8 m/min and coating color dry solids of 55%. The coating color formulation was 60 parts calcium carbonate (Covercarb 75 from Omya; Oftringen Switzerland), 40 parts clay (Capim NP from Imerys; Paris, France), 8 parts styrene-butadiene latex (EOC 9032 from EOC Polymers; Oudenaarde, Belgium), 3 parts starch (Stabilys A030 from Roquette Frères; Lestrem, France), 0.4 parts polyvinyl alcohol (Mowiol 4/98 from Kuraray; Tokyo, Japan), 0.8 parts calcium stearate (Olinor 2587 from Nopco; Drammen, Norway), and 0.2 parts optical brightening agent (Blankophor NC from Kemira; Helsinki, Finland). Handsheets were coated on one side only, with four increasing coat weights (from about 10 to 25 g/m²). The brightness (UV excluded) of the coated handsheets was measured (ISO 2470-2 "Paper, board and pulps – Measurement of diffuse blue reflectance factor – Part 1 : Indoor daylight conditions [ISO brightness]") with coating layer on the top side, as was their burst index (NF EN ISO 2758, 2004 "Paper—determination of bursting strength"). The reflectance of single handsheets was measured under conditions similar to those of the brightness measurement to calculate Kubelka-Munk coefficients k and s, which are relevant for brightness predictions. The ERIC was measured on both uncoated and coated DIP papers (ISO 22754 "Pulp and paper—Determination of the effective residual ink concentration [ERIC number] by infrared reflectance measurement"), with the coating layer on the top side.

Reflectance calculations assume that coated paper can be considered as a stack of distinct coat and base paper layer. The reflectance of a single layer was calculated with the classical exponential Kubelka-Munk equation (Eq. [1]):

$$R = \frac{1 - R_g\left(a - b\coth\left(bsW\right)\right)}{a + b\coth\left(bsW\right) - R_g} \qquad (1)$$

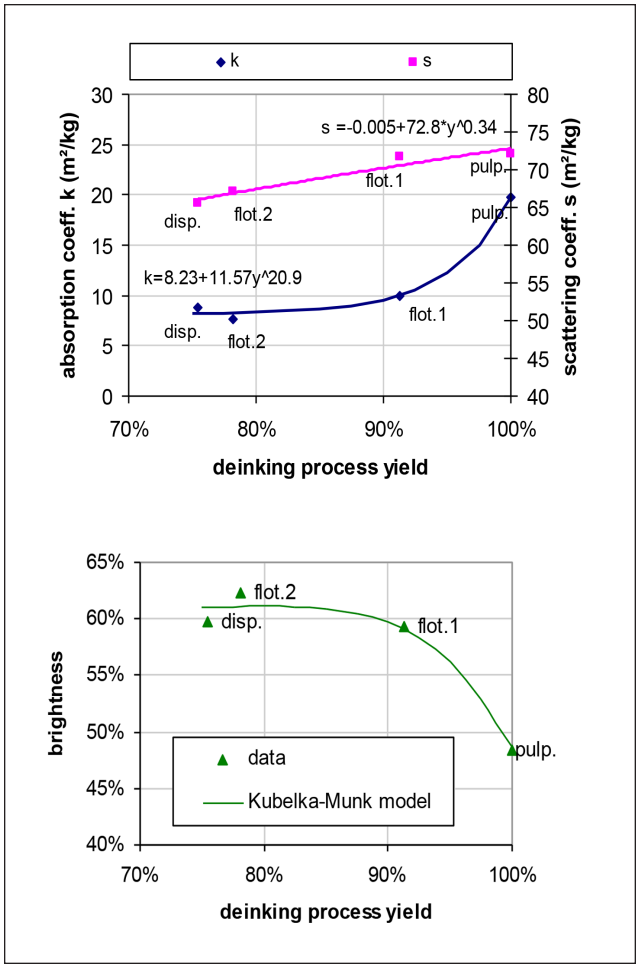
where $a = 1 + \frac{k}{s}$, $b = \sqrt{a^2 - 1}$, R_g is the background reflectance and W is the grammage. Reflectance of the multilayered structures was calculated by classical Kubelka-Munk theory [5]. The reflectance of a stack thick enough to be considered as fully opaque (R_{inf}) is calculated by iteratively considering an additional stack of coated paper layers on top of the previous stacks, until the R_{inf} value converges (with a tolerance of 1e-7, on fractional brightness value). This reflectance value is equivalent to the brightness, under appropriate lighting conditions.



1. General scheme of the cost optimization method.

The multilayer Kubelka-Munk modeling required the optical characteristics of the coating layer itself to be identified. This was determined from reflectance measurements of uncoated and coated paper with variable coat weight, using a dedicated fitting tool. Out of four available coated paper samples with variable coat weight, measured optical properties from three samples (together with the uncoated paper) were used to fit the *k* and *s* value of the coating layer, postulating a two-layer Kubelka-Munk model. The fourth coated paper sample was used for validation purposes.

The general cost optimization method consisted of finding the deinking process yield that led to the cheapest solution after coating to the target brightness (**Fig. 1**). The raw material was deinked to a certain yield, which determined the optical properties of the base paper (i.e., *k* and *s* Kubelka-Munk coefficients), and a certain cost was associated with that deinking operation. Then, the required coat weight to reach the target brightness was automatically calculated. This made use of the iterative Kubelka-Munk function that calculated the brightness of the corresponding multilayer coated paper, which was itself optimized to meet the target brightness, together with the target grammage, which was set as the grammage of the coated paper. This determined the cost associated with the coating operation. The overall cost function was constructed as the sum of deinking operation cost and coating operations cost and minimized by searching the optimum deinking yield. Also, the evolution of a mechanical property (i.e., burst index) of the coated paper was modeled as a function of deinking yield and deposited coat weight. An acceptable relative mechanical property degradation was defined



2. Evolution of k and s coefficients of the deinked pulp (DIP) vs. deinking yield (top) and corresponding evolution of brightness (bottom).

and set as an additional constraint to the cost minimization. In this study, only burst index was followed as an overall indicator of mechanical properties. It should be mentioned, however, that other sheet properties (such as surface smoothness) affect the coating process performance and coated paper quality.

The cost optimization software was developed in the MATLAB (MathWorks; Natick, MA, USA) environment, but can be distributed as a stand-alone application. All function minimizations were performed using the OPTIMIZE.M function developed by Rody Oldenhuis (minimization of [non]linear [in]equality constrained functions making use of a Nelder-Mead simplex search algorithm, available at http://www.mathworks.com/matlabcentral/fileexchange/24298-optimize). All parameters and model equations could be adjusted to a particular situation, through a user-friendly interface. Brightness and yield values were given as fractional values in all equations.

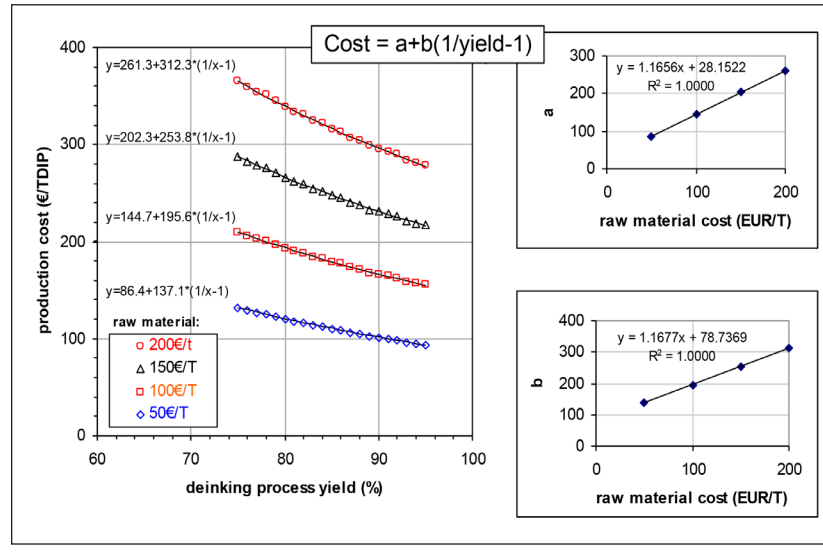
The deinkability model was identified on the basis of optical measurements on the handsheets sampled along the pilot deinking line (**Fig. 2**). The evolution of *k* and *s* coefficients was described by power-law models (Eqs. [2] and [3]):

$$k\ (m^2/kg) = 8.23 + 11.57 * yield\ ^{\wedge}\ 20.9 \quad (2)$$

$$s\ (m^2/kg) = -0.005 + 72.8 * yield\ ^{\wedge}\ 0.34 \quad (3)$$

The implicit assumption was that variation of reject flow at flotation would cause a continuous variation of pulp properties vs. yield similar to that approximated with the proposed regression curve. The "disp." data point included both the effect of thickening (fines losses on disc filter) and dispersion itself (ink fragmentation). Also, we fitted a power-law model for the *s* vs. yield curve (thereby allowing flexibility to describe the deinkability behavior of other raw materials); the response was very close to a linear regression in this particular case.

The proposed deinking cost model was built to take into account many aspects of the deinking process other than deinking yield and losses (for example, raw materials cost, chemicals cost, energy cost, and sludge handling cost). The methods are described in Fabry [16]. Briefly, the methodology was based on the determination of the production cost associated with each unit operation to produce 1 ton of deinked pulp. The yield of each unit operation determined the associated costs of chemicals and energy, and overall process yield determined the quantity of recovered papers to purchase and the quantity of sludge and rejects that were generated. Production cost data were generated from the Fabry [16] model for the studied process configuration. The effect of raw material on deinking cost, ranging from 50 EUR (€50)/ton to €200/ton, was studied. As shown in **Fig. 3**, a hyperbolic regression



3. Data used for cost vs. yield fittings (left) and fitted coefficients (right).

provided a satisfactory description of the generated production cost data vs. yield (Eq. [4]):

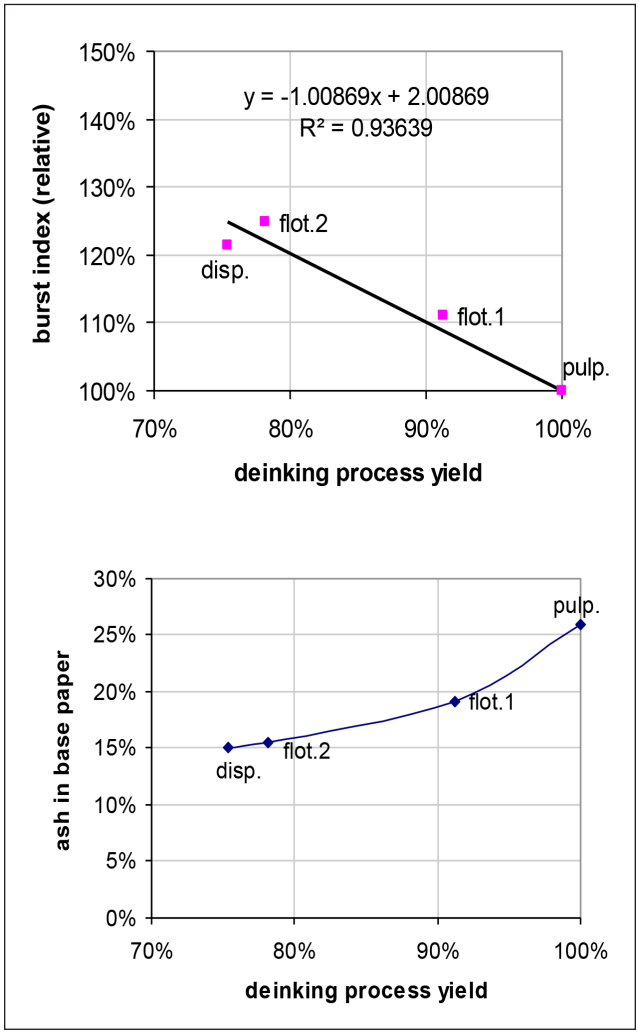
Deinking cost (€/ton) = a+b(1/yield-1)* (4)

where:
a = 1.1656*raw_material_cost (€/ton) + 28.152
b = 1.1677*raw_material_cost (€/ton) + 78.737

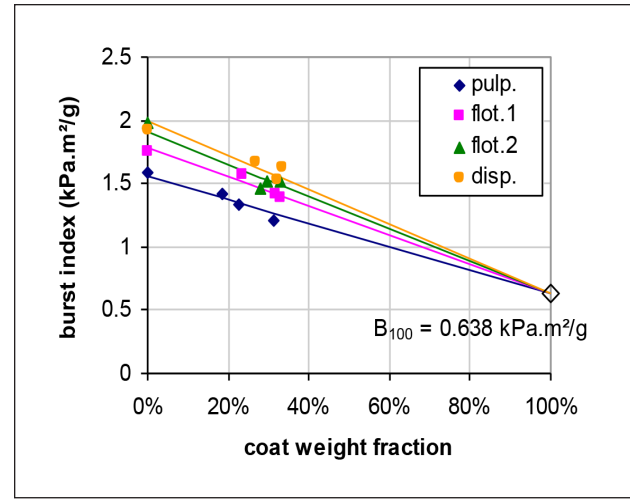
Multiplying by the base paper grammage allowed the cost, in €/m² of DIP base paper, to be calculated (Eq. [5]):

*DIP base paper cost (€/m²) = base paper grammage (g/m²)*1e-6*deinking cost (€/ton)* (5)

The coating cost model took into account the cost of the coating color, together with the cost associated with drying operations. These costs were set to be proportional to the dry deposited coat weight (Eq. [6]):



4. Evolution of burst index of DIP paper vs. deinking process yield (top) and relationship between ash content and deinking process yield (bottom).



5. Evolution of burst index of DIP coated paper vs. deposited coat weight fraction.

*Coating cost (€/m² of coated paper) = deposited_coat_weight(g/m²)*1e-6*(specific cost of coating color (€/dry ton of coating color) + specific drying cost (€/dry ton of coating color))* (6)

The evolution of the burst index of the DIP base paper was identified from the pilot deinking trial samples (**Fig. 4**). The relative contribution of deinking to burst index (*rBI_deinking*) was modeled as Eq. (7):

*rBI_deinking = (1+b) -b*yield* (7)

where *b* is the burst index increase factor provided by the deinking process (*b* = 1.00869).

The evolution of the burst index of the coated DIP paper was identified from measurements on the coated handsheets (**Fig. 5**). The simple proposed modeling was based on the observation that any coated paper sample would have similar mechanical properties with a very large deposited coat weight (and would feature the burst index of the coating layer itself). Thus, a set of regression lines was fitted through the data set while forcing all regressions to cross together at 100% coat weight fraction. The fitted value for the burst index of the coating layer was found to be BI_{100}= 0.638 kPa.m²/g. The relative contribution of coating to the burst index (*rBI_coating*) was therefore modeled as Eq. (8):

*rBI_coating = (BI_{100}/[BI_0*rBI_deinking] -1)*coat_weight_fraction + 1* (8)

where BI_0 is the burst index of the undeinked raw material (measured on the flotation inlet sample as BI_0 = 1.58 kPa.m²/g).

Finally, the relative evolution of the burst index (*rBI*) of the DIP coated paper vs. both deinking yield and deposited coat weight could be modeled by Eq. (9):

$$rBI = rBI_coated * rBI_deinking$$
$$= rBI_deinking - coat_weight_fraction * (rBI_deinking - BI_{100}/BI_0) \quad (9)$$

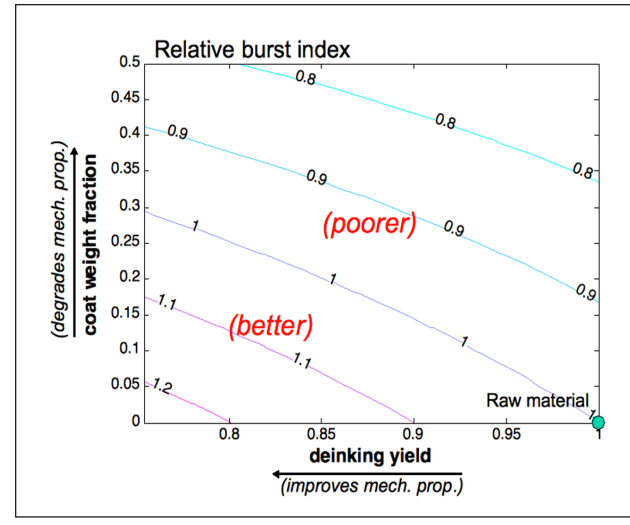
All default parameters used for the cost optimization scenario are summarized in **Table I**. Note that the default coating configuration was to coat the DIP base paper equally on each side, thus involving a three-layer structure. A series of handsheets was coated on both sides, and the effect on the burst index was not significantly different from a top-side coating at comparable total deposited coat weight. Also, brightness predictions with a three-layer Kubelka-Munk model were satisfactory for this coating configuration.

RESULTS AND DISCUSSION

As the raw material is processed through the recycling line, losses are generated that enable improvements of both optical and mechanical properties of the DIP. The brightness sharply increases after the first flotation stage, but further decreasing the yield does not offer major brightness gain (Fig. 2). This is explained by the strong reduction of the *k* value (corresponding to ink removal mainly) through the first flotation stage. In the second flotation stage, ink removal is less efficient but large losses are generated. The *s* value follows a more or less linear decrease with process yield, presumably explained by ash removal (data reveal that ash loss is somewhat correlated to process yield, as illustrated in Fig. 4). Brightness increases largely at the beginning thanks to efficient ink removal, then plateaus because the recycling process also rejects white filler materials that contribute to brightness. Slight decreases in brightness occur after dispersing, because of ink fragmentation. These data were used to model the evolution of DIP optical properties vs. deinking process yield.

Coated Paper Parameters • Target brightness: 0.65 • Grammage: 70 g/m² (including coating layer) • Mechanical properties constraint: Try to maintain burst index (BI) greater than or equal to that of the raw material (rBI ≥ 1)
Raw Material • BI_0: 1.58 kPa·m²/g • Raw material cost: 100 €/ton • *k* raw material: 19.8 m²/kg • *s* raw material: 72.02 m²/kg • Brightness: 0.48586
Deinking Parameters • Optical properties vs. deinking yield: Power law models • Minimum yield: 0.754
Coat Layer Properties • *k* coating: 2.9 m²/kg • *s* coating: 127 m²/kg • BI_{100}: 0.638 kPa·m²/g
Cost Model Parameters • Specific cost of coating color cost: 250 €/ton* • Specific drying cost: 20 €/ton* • Coating configuration: Divide coat weight equally on each side
*Values based on CTP experience for a typical LWC production.

I. Default parameters of the cost optimization scenario

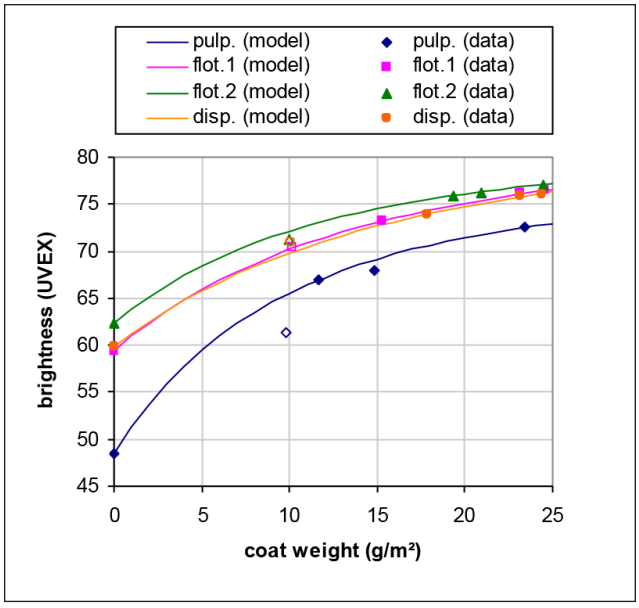


6. Illustration of the relative burst index (rBI) evolution model for the coated DIP paper, as a function of deinking process yield and deposited coat weight. (The limit to maintain burst index same as that of a base paper made of undeinked raw material corresponds to rBI=1).

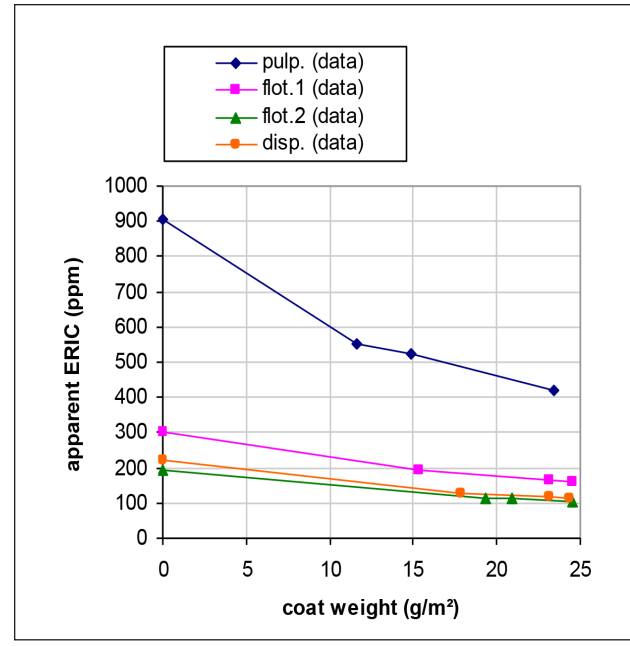
Although the recycling process improves the DIP mechanical properties because of ash removal, application of a coat layer decreases the mechanical properties because the coat layer is less resistant than the base paper (Fig. 5). These data were used to model the evolution of DIP mechanical properties vs. deinking process yield and deposited coat weight. The combined effect of deinking and coating processes on DIP relative burst index is illustrated in **Fig. 6**, according to the proposed models. Note that the bursting strength of the final DIP pulp for production of the base paper could also potentially be improved by refining, or by adding small amounts of starch or well-refined softwood pulp.

It should be mentioned that the yield values reported in this study were expected to be on the high side compared to industrial value. That is because a controlled raw material was processed; in an industrial process, additional losses would be generated to remove other contaminants, such as staples.

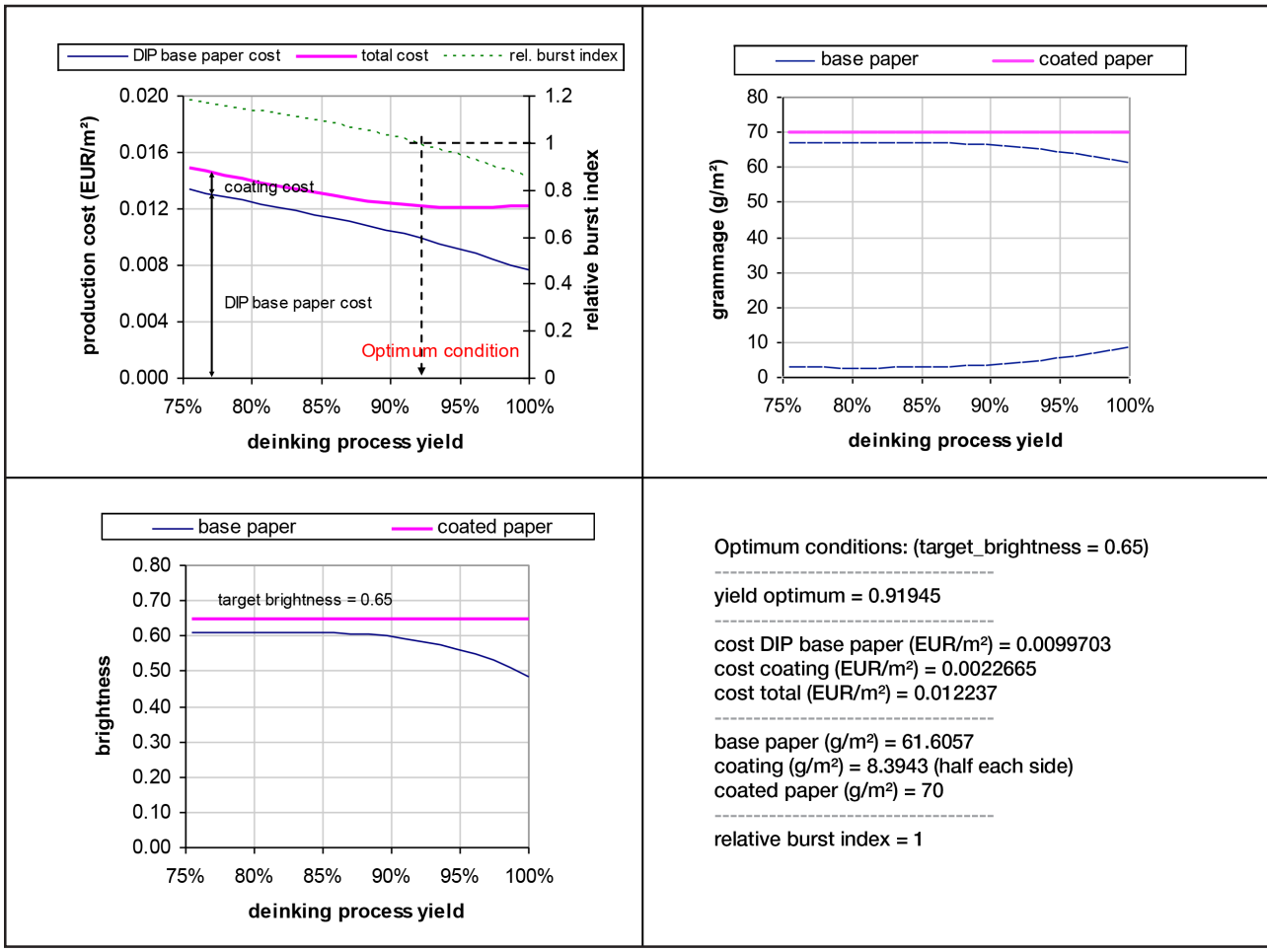
Brightness measurements of DIP coated handsheets revealed that the coating layer was very efficient at masking the residual ink in the base paper. For instance, depositing 10 g/m² allowed brightness of the final DIP base paper to increase by 11 points (from about 60% to 71%, as shown in **Fig. 7**). The ink-masking power of the coating layer was also illustrated by an apparent ERIC decrease (**Fig. 8**). In general, a deposited coat weight of 20–25 g/m² reduced the apparent ERIC by a factor of two. To identify the optical properties of the coating layer, a two-layer Kubelka-Munk model was fitted to the brightness data for coated paper samples series. The fitting was acceptable for all handsheet series (made from very



7. Fitting of a two-layer Kubelka-Munk model (with variable k *and* s *coefficients for the coating layer) to the brightness data set for all coated DIP paper samples (full symbols represent data used for the fitting and open symbols represent validation data).*



8. Evolution of apparent ERIC vs. deposited coat weight for the coated DIP base paper samples.



9. Evolution of DIP coated paper production cost and relative burst index (top left), layer structure (top right,) and brightness (bottom left) vs. deinking process yield. The cost optimization output is detailed in the bottom right panel.

	Undeinked + Coating	Deinked + Coating Minimum Cost	Deinked + Coating Low Cost Same Mechanical Properties
Brightness (coated paper)	65%	65%	65%
Deinking yield (optimum)	100.0%	95.6%	91.9%
DIP base paper cost (€/m²)	0.00766	0.00898	0.00997
Coating cost (€/m²)	0.00460	0.00313	0.00227
Total cost (€/m²)	0.01227	0.01211	0.01224
Base paper (g/m²)	53.0	58.4	61.6
Coating (g/m²)	17.0	11.6	8.4
Coated paper (g/m²)	70.0	70.0	70.0
Relative burst index	0.855	0.939	1.000

II. Possible scenarios of combined deinking and coating process to produce a 70 g/m² coated DIP paper with 65% target brightness (total coat weight is divided equally between each side).

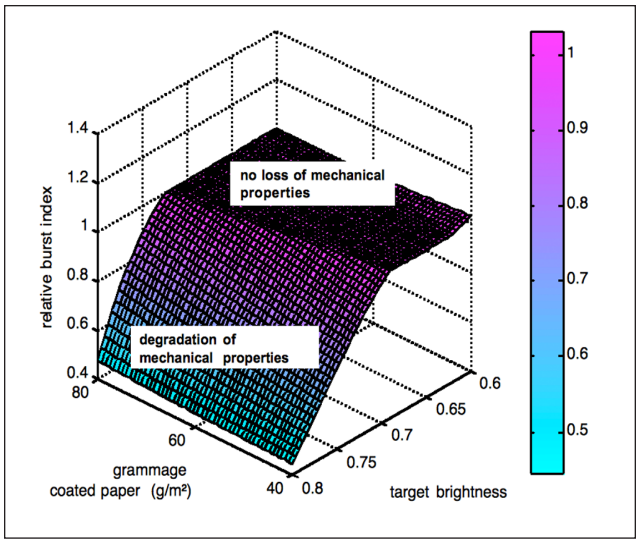
different pulp quality, as in Fig. 7; overall $R^2 = 0.9988$). The validation data confirmed the reasonable accuracy of prediction of the two-layer model (average absolute prediction error of 1.53 brightness points); however, one validation point was significantly lower than the prediction (for the pulp series). The identified coating layer Kubelka-Munk coefficients were $k_c = 2.9$ m²/kg and $s_c = 127$ m²/kg. Ramos et al. [11] found values of scattering coefficients for coating layers ranging from 80 m²/kg to 100 m²/kg for various coating colors containing precipitated calcium carbonate and kaolin.

Using these data, models, and methods, we then examined one case example for optimized production of a 70 g/m²-LWC coated paper at 65% brightness with base paper made from the studied wood-containing raw material (see Table I for all parameters). Before giving the final cost optimization result, we will discuss the evolution of coated DIP paper production cost vs. deinking process yield (**Fig. 9**). If base paper was produced from the undeinked raw material (brightness 48.6%), it could be possible to reach target brightness of 65% by applying a large coat weight (8.5 g/m²) on each side of a 53-g/m² base paper (**Table II**, left column). This situation was not optimized from a cost point of view. Also, a large coat weight fraction combined with high ash content in the base paper was detrimental to the mechanical properties of the coated paper, so that the burst index was reduced by 14.2%. It was thus desirable to deink the raw material before coating to improve both optical and mechanical properties of the base paper. This reduced the required coat weight and tended to minimize corresponding coating cost. However, generating large losses through the recycling process increased deinking cost so that a cost optimum was found for a deinking yield value of 95.6% (Table II, middle column). However, in this situation, the burst index of the coated paper was still slightly lower than that of the reference base paper made from the undeinked raw material. If we wanted to maintain mechanical properties of the coated DIP paper, the technico-economical optimum required a lower deposited coat weight and more extensive deinking. Finally, to produce a 70-g/m² coated paper at 65% brightness from our raw material in the least expensive way, we recommend deinking the raw material to 91.9% yield to produce a base paper with a grammage of 61.6 g/m² and apply 4.2 g/m² of coating to each side (Table II, right column). This scenario also made it possible to not degrade the mechanical properties of the coated DIP paper. This optimum yield value can help to decide the best deinking process configuration, or adjust flotation cells reject flows to limit the losses to bare necessities, for acceptable specifications after coating.

Brightness (coated paper)	60%	65%	70%
Deinking yield (optimum)	95.7%	91.9%	82.5%
DIP base paper cost (€/m²)	0.01002	0.00997	0.01006
Coating cost (€/m²)	0.00128	0.00227	0.00431
Total cost (€/m²)	0.01129	0.01224	0.01437
Base paper (g/m²)	65.3	61.6	54.0
Coating (g/m²)	4.7	8.4	16.0
Coated paper (g/m²)	70.0	70.0	70.0
Relative burst index	1	1	1

III. Optimized combination of deinking and coating process to produce a 70 g/m² coated DIP with given target brightness, while maintaining mechanical properties (total coat weight is divided equally between each side).

Similar cost optimization was performed for various target brightness levels of the coated DIP paper, while maintaining mechanical properties in each case (**Table III**). It appeared that producing coated DIP paper with higher brightness in the least expensive way required both more extensive deinking and a higher share of coat weight in the total grammage.



10. Evolution of relative burst index corresponding to the cost optimum combination of deinking process and coating process, as a function of grammage and target brightness of the DIP coated paper.

Of course, producing higher brightness coated DIP paper was more expensive, even after overall cost optimization.

One can then wonder whether it is possible to produce a 70-g/m² coated paper at much higher brightness. That can indeed be achieved, but one has to accept a degradation of mechanical properties because the required coat weight fraction is too large. Calculations showed that the maximum DIP coated paper brightness that could reached without degrading the mechanical properties was 72% (for a 70-g/m² coated paper). We investigated that maximum brightness vs. coated paper grammage limit, while maintaining mechanical properties. For that purpose, a series of cost-optimum calculations was performed for DIP coated paper grammage varying from 40 g/m² to 80 g/m² and target brightness varying from 60% to 80% on a 50x50 grid (**Fig. 10**). It appeared that the lower the grammage, the lower the maximum brightness that could be reached for coated paper, without impacting the burst index. For instance, under our conditions, it was not possible to produce coated paper with 70% brightness at a grammage lower than 50 g/m². This allowed specifications to be set for the coated paper to maintain mechanical properties, at given optical properties.

CONCLUSIONS

Methods to find optimum combinations of deinking and coating processes to produce coated paper made from DIP with given brightness at the lowest cost were developed, while maintaining mechanical properties (or accepting a given degradation). The modeling took into account raw material quality, deinkability behavior, deinking cost, coating color quality, coating cost, and impact on burst index of coated paper. The model predicted that it is possible to produce a 70- g/m² DIP coated paper at 65% brightness, while using standard 30% ONP/70% OMG raw material. The minimum production cost will be obtained by submitting the raw material to limited deinking (generating minimum combined flotation losses of 8.1%) and recovering the brightness by applying a coating layer on the DIP base paper (4.2 g/m² on each side, for a coating color formulation of 60 parts standard ground calcium carbonate and 40 parts fine Brazilian clay).

The method also made it possible to determine the lowest production, and therefore reduce their costs. The next step is to estimate the amount of coat required to cover the specks in the base paper. We found that this was more difficult to achieve, at least with a blade-type coating process.

ABOUT THE AUTHORS

There is a great potential to increase deinked pulp (DIP) usage in lightweight coated grades. Previous work on the CTP pilot coater showed that it was possible to use DIP-containing base paper, but an economical evaluation of the process was needed.

The most difficult aspect of this work was to build models to accurately describe deinking and coating process costs. Our hope was to use results from other projects at CTP to address these issues. Once reliable cost models had been built, together with deinkability models describing optical and mechanical properties of the DIP, it was easier to set up a global cost optimization procedure.

We were surprised to see how efficient the coating process was at masking residual ink in the base paper. Of course, it is not possible to reach very high brightness when coating a DIP base paper. However, it does not take much coat weight to largely improve brightness and reach the brightness target.

Deinking mills may use these results to find the maximum acceptable yield for DIP base paper pro-



Huber



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Carré

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acceptable grammage to reach the brightness and mechanical properties specifications, for a given grade. It was shown that producing a high-brightness DIP coated paper at low grammage will inevitably cause a degradation of burst index. The model showed that the crucial brightness (above which burst index has to be reduced) was 72% for a 70-g/m² coated paper, and only 70% for a 50-g/m² coated paper. These model predictions remain to be verified at mill scale.

The optimization method is very general and could be applied to other target functions, such as opacity (with appropriate *k* and *s* coefficient measurements). **TJ**

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