The effect of some parameters on brown stock washing: A study made with a pulp tester

Simple but extensive tests can be performed with the tester

BY H. HAKAMÄKI AND K. KOVASIN

SEVERAL PARAMETERS affect the capacity and washing efficiency of a brown stock washer. Understanding the relative effect of these parameters is important both for washer dimensioning and operation. With a pulp tester the effect of certain parameters can easily be tested on a small scale over a wide range of values.

Pulp tester

The equipment consists of the cylindrical tester chamber, volume about three litres, and a piston with which the pulp cake is formed. The piston has a rod, perforated plate and wire cloth. The tester has a recording arrangement for piston movement, a specially designed bottom valve with connections for a pressure gauge and a wash water pipe, and the equipment frame.

The height of the equipment is 1300 mm and the maximum width is 320 mm.

HAKAMÄKI KOVASIN

H. Hakamäki and K. Kovasin, Rauma-Repola Oy, Pori, Finland.

A schematic drawing of the tester is shown in Fig. 1.

The calculation of drum capacity as a function of drum speed is derived from pulp tester results. Drum washer operation can be seen in the schematic block diagram in Fig. 2. and the schematic flow sheet in Fig. 3. Using the notation given at the end of this paper, the equations for the simulation of washer capacity can be derived.

Fibre mat formation in an operational washer:

Fibre balance:

$$c_1 W_1 = c_2 W_2 \quad (1)$$

$$W_1 = W_2 + W_6 \quad (2)$$

The volume of the formed mat (W_2) is obtained from equations (1) and (2):

$$W_2 = \frac{c_1 W_6}{c_2 - c_1} \quad (3)$$

Fibre concentration at the end of mat formation stage (c_2) usually varies between 0.06 and 0.08 kg/L in drum washer for chemical pulp fibres.

Fibre mat formation in pulp tester:

In Fig. 4. schematic diagrams of the pulp tester operation are presented. Pulp slurry is poured into the tester chamber, the piston is set on the slurry surface level and mat formation is started by pushing the piston downwards. When the operational point (point x in Fig. 4.) is observed during the mat formation stage, we obtain:

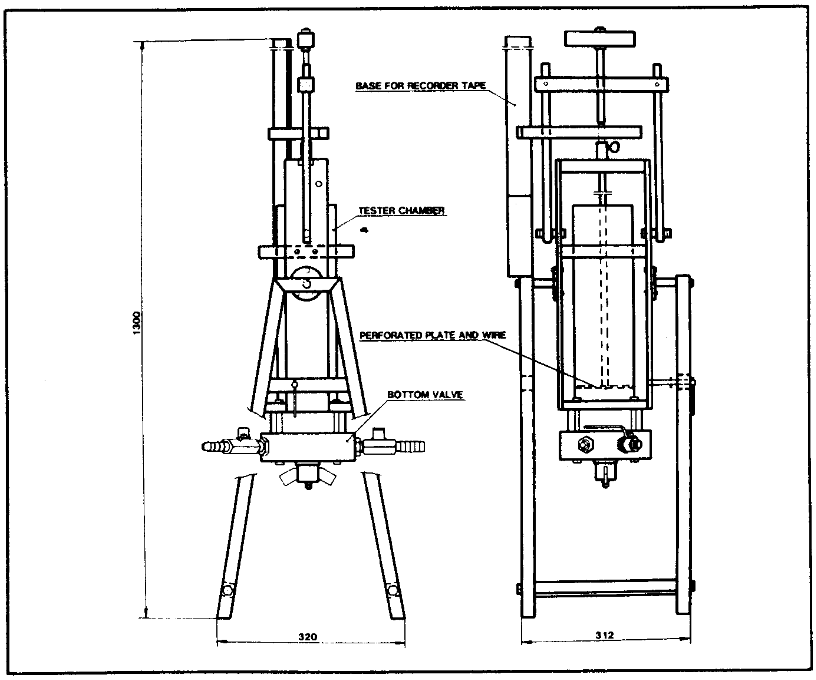

Fig. 1. Pulp tester equipment.

The volume of the formed fibre mat W_{2x} from equation (3):

$$W_{2x} = \frac{c_1 W_{6x}}{c_2 - c_1} \qquad (4)$$

where

$W_{6x} = A\ s_x$

Hence,

$$W_{2x} = \frac{c_1 A\ s_x}{c_2 - c_1} \qquad (5)$$

The fibre amount P_{2x} in the formed mat from equations (1) and (5):

$$P_{2x} = \frac{c_1 c_2 A\ s_x}{c_2 - c_1} \qquad (6)$$

Simulated washer drum speed and drum capacity (square metre load):

The time of one complete revolution of the washer drum:

$$t_{rx} = \frac{360\ t_x}{\alpha_1} \qquad (7)$$

Drum speed:

$$n_x = \frac{60}{t_{rx}} = \frac{60}{360\ t_x/\alpha_1} = \frac{\alpha_1}{6\ t_x} \qquad (8)$$

t_x is expressed in seconds

Pulp load for tester (g_{2x}) during mat formation:

$$g_{2x} = \frac{P_{2x}}{A\ t_x} \qquad (9)$$

Substituting P_{2x} from equation (6) for equation (9):

$$g_{2x} = \frac{c_1 c_2 s_x}{(c_2 - c_1)\ t_x} \qquad (10)$$

Simulated pulp load (G_{2x}) for a washer per total drum area:

$$G_{2x} = \frac{\alpha_1 g_{2x}}{360} \qquad (11)$$

g_{2x} from equation (10) is substituted into (11) and the final form for the simulated drum square metre load is obtained:

$$G_{2x} = \frac{\alpha_1 c_1 c_2 s_x}{(c_2 - c_1)\ t_x} \qquad (12)$$

Equations (8) and (12) can now be used for the determination of drum capacity as a function of drum speed using the results from the tester. Piston movement (s_x) is recorded as a function of movement time (t_x) and when the concentrations c_1 and c_2 as well as the fibre mat formation angle α_1 are known, square metre load can be calculated.

Pulp washing with tester

After the fibre mat has been formed as described, the piston is locked, the filtrate from mat formation is poured away and collected. The tester bottom valve is set in the washing position. Washing liquor corresponding to the desired dilution factor is led through the pulp mat by opening the wash liquor valve (Fig. 4.). Samples for washing efficiency calculations are taken.

In this paper, washing efficiency is presented using the modified Nordén's

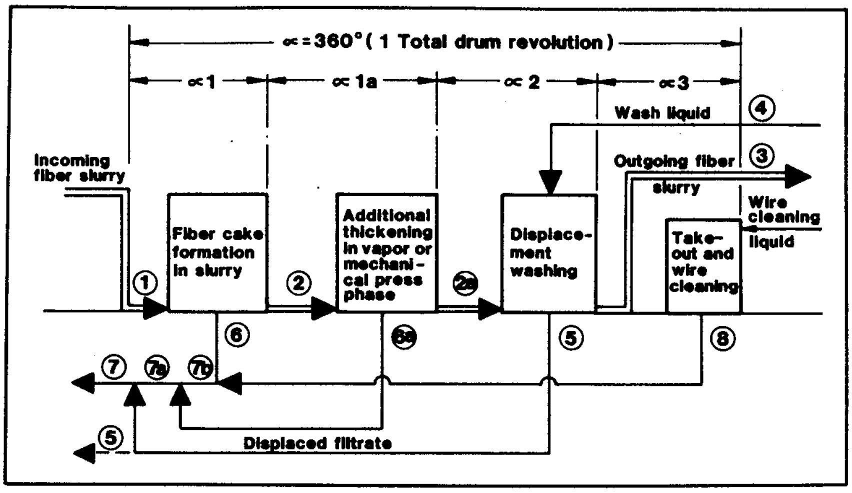

Fig. 2. Schematic block diagram of drum washer.

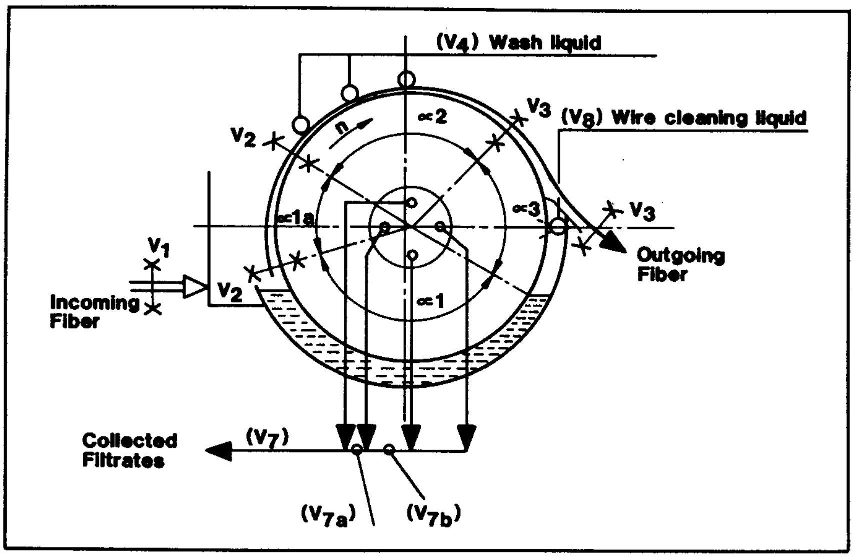

Fig. 3. Schematic flow sheet of drum washer.

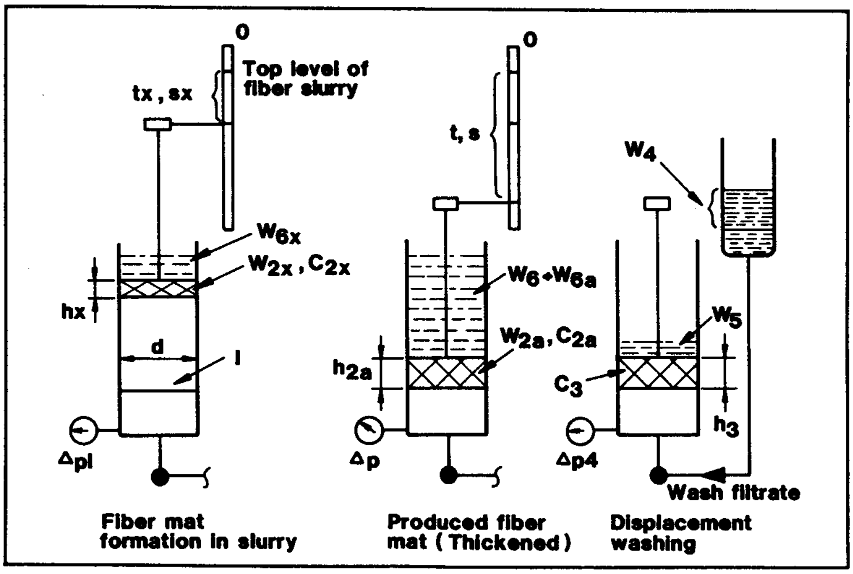

Fig. 4. Schematic diagrams of the pulp tester.

Efficiency Factor (E) /1/.

The efficiency is defined with equation (13):

$$E = \frac{\ln\left[\dfrac{dQ + dV\,K_7}{dQ + dV\,K_4}\right]}{\ln\left[1 + \dfrac{dV\,c_{st}}{(100 - c_{st})\,P}\right]} \qquad (13)$$

where

Q = washable material amount

dQ = washable material shortage

V = liquid flow amount

dV = liquid flow excess

K_7 = concentration of washable material (weight fraction) in the displaced filtrate

K_4 = concentration of washable material in the wash water

C_{st} = standard consistency where E is determined (12% here)

P = fibre amount

Washable material shortage, liquid flow excess and dilution factor can be defined by equations (13a) to (13c):

$$dQ = Q_3 - Q_4 = Q_1 - Q_7 \qquad (13a)$$

$$dV = V_4 - V_3 = V_7 - V_1 \qquad (13b)$$

$$DF = dV/P \text{ (dilution factor)} \qquad (13c)$$

In the above equations, subscript 1 refers to the incoming slurry, 3 to the outgoing slurry, 7 to the filtrate and 4 to the washing water.

Tester repeatability

The reproducibility of the tester was checked with two series of replication tests.

The first test series concerned the properties of the tester as a simulator for drum washer capacity. Twenty replication tests with as many identical pulp slurry samples were performed. Washer drum square metre loads as a function of drum speed were calculated from the results of the repeatability tests. Standard deviation of the square metre loads was calculated. Within the drum speed range 1.8 to 4.2 rpm, the relative standard deviation varied between 2.7 and 5.3%, the smallest relative deviation being at the lowest speed.

The second test series was for washing efficiency. Twenty identical pulp samples were thickened to equal consistency. Washing was performed using identical wash water amounts and washing efficiency was calculated according to equation (13). The relative standard deviation in the E-factor was 4.8%.

These repeatability tests show that the reproducibility of the tester is reasonably good for both filtration and washing.

Drum washer capacity

According to theoretical considerations for drum filtration, one can anticipate that the most important parameters for fibre mat formation on the drum are drum speed, effective filtration pressure, pulp slurry temperature, washer inlet consistency and pulp air content.

These variables were chosen to be tested and the ranges of the parameters were selected so that typical conditions on drum washers were covered. The range of inlet consistency was extended up to 4% because recent developments on drum washers indicate that higher than usual consistencies are possible. The air content range was chosen to cover normally observed air levels in pulp mills.

The parameter ranges:

- Washer drum speed 1 . . . 4 rpm
- Washer inlet consistency 1 . . . 4%
- Effective filtration pressure 0.5 . . . 1.5 m H_2O
- Pulp air content 0 . . . 5 vol-%
- Pulp temperature 30 . . . 90°C

The test series was performed using pulp samples from a Finnish kraft mill, from the brown stock washing line which consists of three one-stage Rauma-Repola pressure washers in series. Samples were taken from the infeed of the washers. The raw material of the pulp was pine (*Pinus silvestris*) and the Kappa number of the samples varied between 27 and 32.

From each test, the simulated washer drum capacity (square metre load) v drum speed was calculated. Regression analysis was performed in order to correlate square metre load to the parameters. Over 1100 data points were used and the best model turned out to be an exponential equation:

$$\frac{G_{2x}}{\mathrm{BDMT/m^2d}} = 1.34\left(\frac{n_x}{\mathrm{rpm}}\right)^{0.62}\left(\frac{c_i}{\%}\right)^{0.65}\left(\frac{t}{^\circ\mathrm{C}}\right)^{0.26}\left(1 + \frac{y_{air}}{\mathrm{vol\text{-}\%}}\right)^{0.24}\left(\frac{\Delta p}{\mathrm{m\ H_2O}}\right)^{0.30} \qquad (14)$$

The multiple correlation coefficient of the model was 0.948.

To illustrate the effect of individual variables, a number of graphs was prepared. Furthermore, it was found to be convenient to present washer capacity in relative units. The basis capacity = 1 is obtained at drum speed 1 rpm, pulp consistency 1%, temperature 60°C, effective filtration pressure 1.0 m H_2O and the air content 0%.

Drum speed and inlet consistency: Washer drum speed varies typically between 1

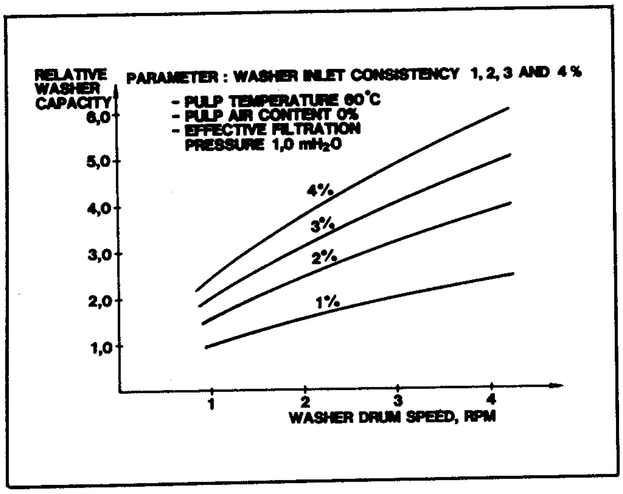

Fig. 5. Effect of drum speed on washer capacity.

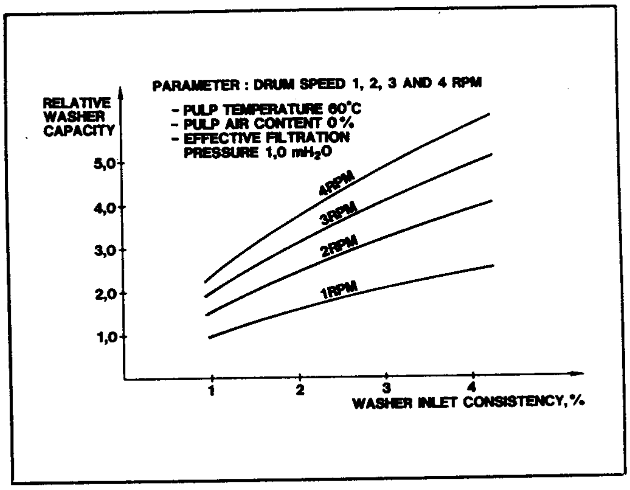

Fig. 6. Effect of washer inlet consistency on washer capacity.

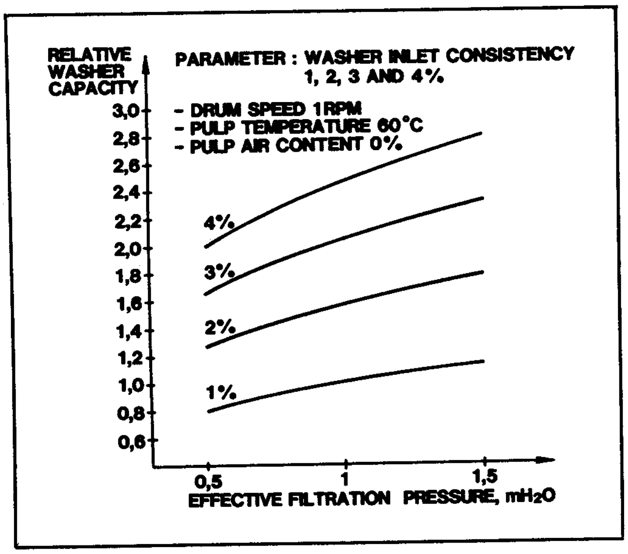

Fig. 7. Effect of filtration pressure on washer capacity.

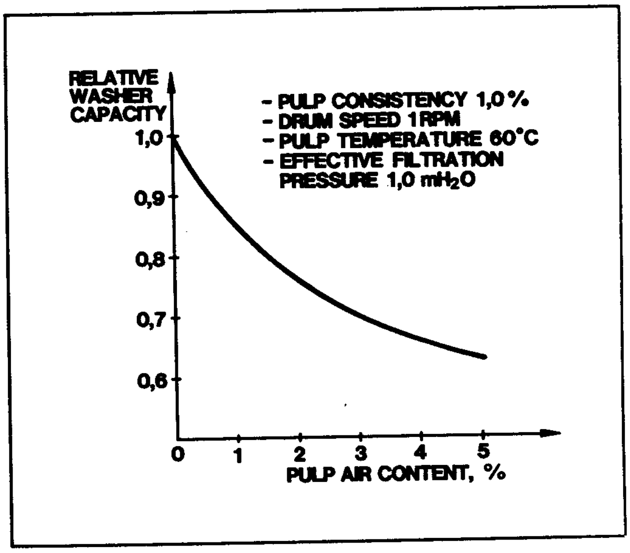

Fig. 8. Effect of pulp air content on washer capacity.

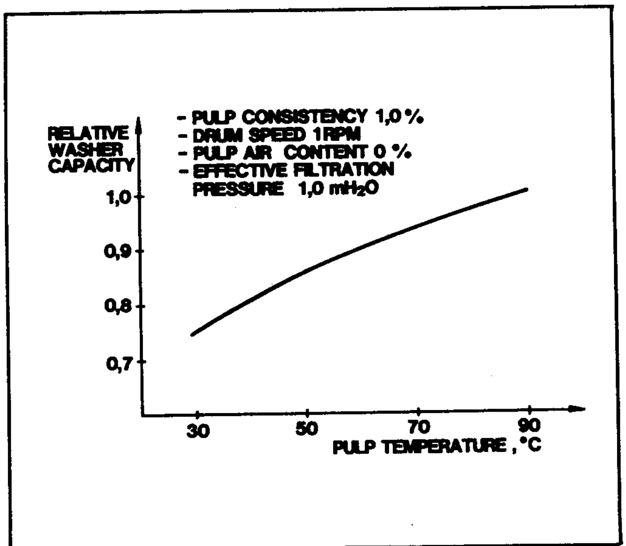

Fig. 9. Effect of pulp air temperature on washer capacity.

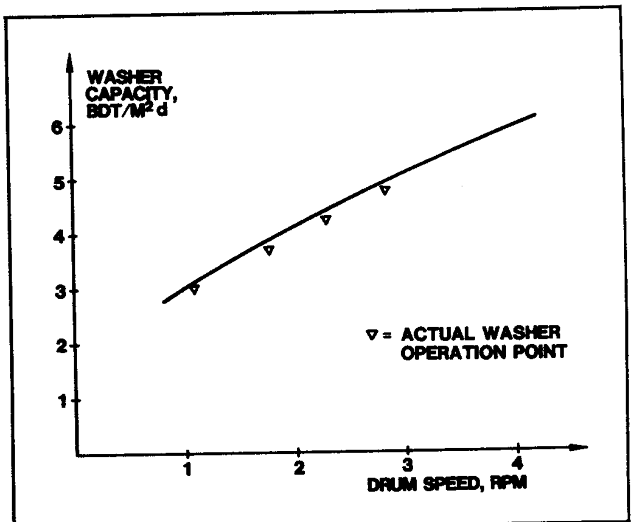

Fig. 10. A typical tester result curve and actual washer operation points.

and 4 rpm. The drum speed corresponding to tester results is obtained from equation (8). Figure 5 shows the relative washer capacity against drum speed. Washer inlet consistency has been used as a parameter. In Fig. 6, the relative drum capacity is presented v inlet consistency when the drum speed is used as parameter.

One can see from the graphs that if drum speed is increased from 1 rpm to 4 rpm, the capacity can be increased about 2.5 times while the other variables are kept constant. Correspondingly, a four times increase in the inlet consistency (say 1% to 4%) means about the same capacity increase.

Recently it has been found that higher inlet consistencies can be used in drum washers and the advantages of higher consistencies can clearly be realized from equation (14) and Fig. 5 and 6. During the tests, higher consistencies were accomplished by prethickening the samples taken from washer infeed (consistency 0.8 to 1.5%) to the desired consistency level after which the testing itself took place.

Effective filtration pressure: The range of effective filtration pressure was 0.5 to 1.5 m H_2O which is the typical range for pressure washers. During the tests, filtration pressure was monitored from the pressure gauge of the tester and the pressure was controlled by adjusting the pushing force exerted through the piston. Figure 7 shows the effect of filtration pressure.

Increasing filtration pressure increases drum capacity but relatively speaking the effect is not so remarkable as with drum speed and inlet consistency. From equation (14) one can calculate that if

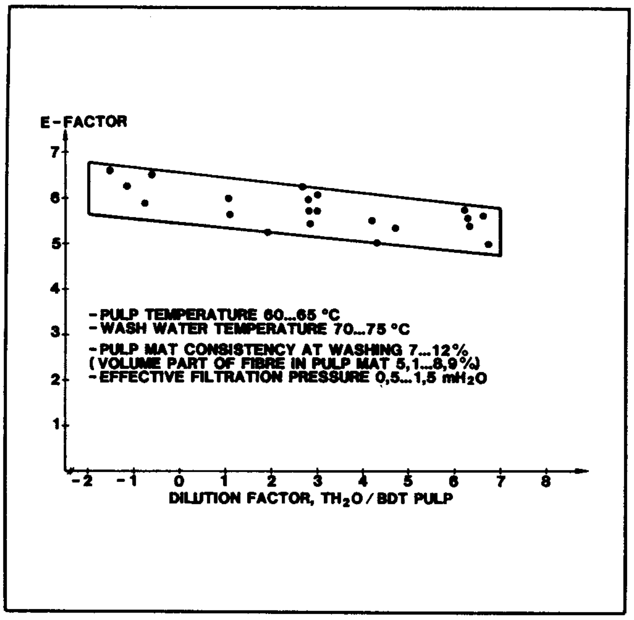

Fig. 11. Effect of dilution factor on washer E-factor.

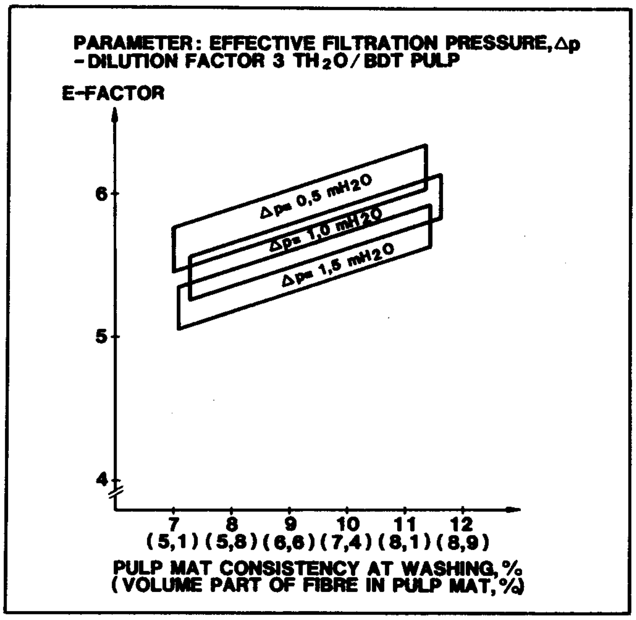

Fig. 12. Effect of pulp mat consistency on washer E-factor.

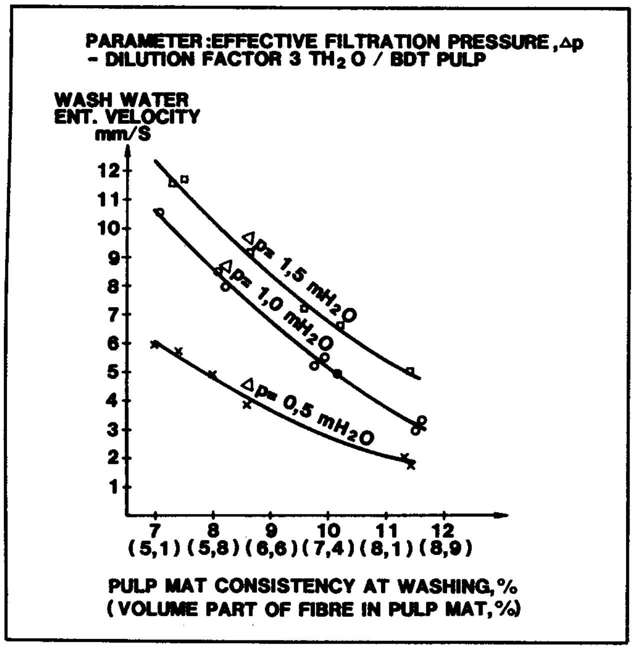

Fig. 13. Effect of pulp mat consistency on wash water entering velocity.

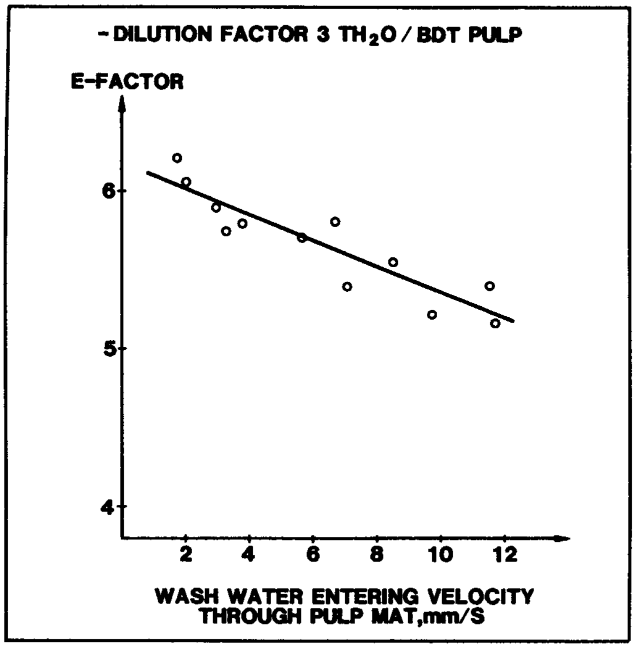

Fig. 14. Effect on wash water entering velocity through pulp mat on washer E-factor.

T247

filtration pressure is increased four times and other variables are kept constant, drum capacity can be increased 1.5 times.

Pulp air content: The range of pulp air content was varied between 0 and 5 vol-%. The upper limit used, 5 vol-%, is not uncommon in operating washing drums. Especially at the end of the washing line, the amount of air present reaches its highest value. During the tests, different air levels were achieved by mixing the slurry vigorously with a laboratory mixer.

The air content in the tester was determined by measuring the difference in the slurry surface levels between the air contained and the deaerated situation. Figure 8 shows how increasing the air content decreases washer capacity. Considering the effect of air, one can say that it is of primary importance to keep air levels low in order to guarantee satisfactory washer operation and capacity.

Pulp temperature: The effect of pulp temperature was studied between 30 and 90°C. In filtration, temperature has its influence mostly through filtrate viscosity and lower viscosities mean increased filtration capacity. Because higher temperatures mean also lower viscosities, higher capacities can be anticipated at higher temperatures. Figure 9 shows the effect of temperature from the tester results. In Fig. 9, the basis temperature for relative capacity is 90°C.

The tester v actual washing drums: It is important that the tester results and actual washing drum operation conform to each other. To check this, a washer drum was operated with four different speeds and respective actual capacities were determined. At the same time, a capacity test was performed with the tester using the washer infeed and the simulated capacity was calculated as the function of drum speed.

Figure 10 shows the results of the test as well as the actual drum capacity measurements. Good correlation is obtained. The tester seems to give slightly higher capacities which is natural because the mat formation can be performed in the tester in well-controlled conditions.

Washing efficiency

The variables that were chosen to be studied here were the dilution factor (defined by equation (13c)), the pulp mat consistency during washing, effective filtration pressure and wash water entering velocity through the pulp mat. Actually, wash water entering velocity is not an independent variable of the above variables but depends on mat consistency and filtration pressure. However, it is an illustrative parameter in practical washer considerations.

The ranges of the parameters in the tests:

- dilution factor − 2 . . . + 7 T H_2O/BDT pulp
- pulp mat consistency 7 . . . 12%
- effective filtration pressure 0,5 . . . 1,5 m H_2O
- wash water entering velocity 2 . . . 12 mm/s

The ranges of the above variables were deliberately exaggerated in relation to actual washing. Normally, the dilution factor varies between + 1 and + 5 T H_2O/BDT pulp, mat consistency during washing is typically between 10 and 12% and wash water entering velocity is normally of the order 3 . . . 6 mm/s. The reason for these wide ranges is to distinguish real trends in washing efficiency.

The pulp samples for the washing tests were taken from the infeed of the second washer in the above mentioned washing line. Wash water in the tests was pure. The efficiency factors were detemined for the washout of sodium. Dry solids washout was not considered.

Dilution factor: The test arrangement was such that wash water could be led in three stages through the same pulp mat. Displaced filtrates were collected to separate sample bottles thus allowing calculation of the E-factors for three separate dilution factors for each pulp sample.

Figure 11 shows the efficiency factor against the dilution factor. There is a slightly decreasing trend as a function of increasing dilution factor. In Fig. 11, along with the mat consistency also the fibre volume is given. It is a calculated quantity which is obtained from the mat consistency by assuming specific gravity for fibres to be 1.6 and for the liquid 1.15.

Pulp mat consistency and filtration pressure: The pulp samples were thickened to various consistencies between 7 and 12% while keeping mat thickness constant at 2 cm, and the washing was performed in the above mentioned way in three parts.

Figure 12 shows E-factor versus mat consistency (and fibre volume part). Effective filtration pressure is used as a parameter in the graph. The E-factors have been determined for a constant dilution factor 3 T H_2O/BDT pulp.

Figure 12 shows that on one hand, high mat consistencies mean higher efficiency factor and on the other hand, low filtration pressure increases washing efficiency.

Wash water entering velocity through pulp mat: As mentioned, wash water's entering velocity depends on filtration pressure and pulp mat consistency. The entering velocity was determined during each washing test by detecting the time elapsed for each wash water addition. The velocity is actually the superficial velocity above the pulp mat.

Figure 13 shows how wash water's entering velocity depends on filtration pressure and mat consistency. Earlier it was found that low pressure and high consistency bring about high efficiency factors. One can see from Fig. 13 that this very combination produces low water entering velocity. In Fig. 14, the efficiency factor is plotted against wash water entering velocity and indeed there is a clear correlation between velocity and the E-factor.

Because in operational washing plants there are strict requirements as to the dilution factor, the washer designer cannot usually choose the dilution factor arbitrarily, e.g., for E-factor adjusting. Therefore, wash water velocity seems to be among the few adjustable parameters for the increasing of E-factor. It is not, however, straight-forward only to decrease wash water velocity to obtain high washing efficiency because at the same time the drum capacity suffers if water velocity is decreased.

This is shown in Fig. 15 where washer capacity is correlated to wash water entering velocity. This kind of trade-off situation requires optimization to find the most economical wash water velocity.

Conclusions

This study shows clearly the versatility of the pulp tester apparatus. One can, in small scale and using simple arrangements, perform extensive tests to determine both filtration characteristics and washing efficiency.

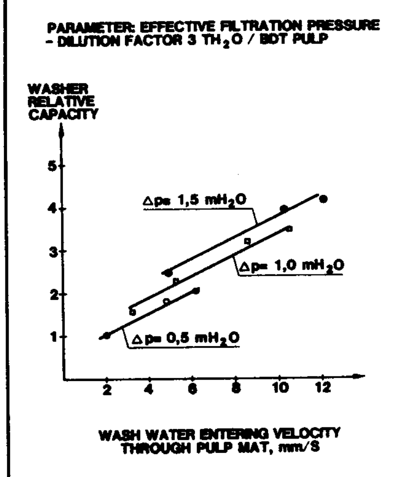

Fig. 15. Effect of wash water entering velocity through pulp mat on washer capacity.

These test results apply directly for the tested pine sulphate pulp only. Due to the specific conditions of the raw material and the pulping method itself, the pulp of each mill is more or less unique and has to be tested separately to draw final conclusions. The results of the present study can probably be used to obtain guidelines for the filtration and washing aspects for pine kraft pulp of rather low kappa numbers. But, for example, mechanical pulps have such drastically different filtration behavior one from the other that separate testing for them is essential.

When these filtration test results are summed-up, one can notice that each studied parameter is significant with respect to drum capacity. The effect of drum speed is traditionally known to be an effective means to manipulate drum capacity. This effect is clearly demonstrated here, but the effect of infeed pulp consistency can be seen to be of primary importance, too. For normal drum washers the practical upper limit for infeed slurry consistency is of the order 1.5 to 2.0%, but some newer drum washers are using clearly higher consistencies (e.g. Rauma-Repola Pro-Feed Pressure Washer).

Drum speed and infeed consistency can be said to be the most important parameters in relation to drum capacity. However, effective filtration pressure is also a significant factor which according to this study has quite an extensive enhancing effect on drum square metre loads.

Again there is a practical limit for filtration pressure because the equipment construction and operational cost aspects have to be taken into account. Temperature which also has an increasing effect on washer capacity, does not seem to play as important a role as the above mentioned parameters.

Pulp air content is a very important factor that has to be considered because increasing air content clearly decreases washer capacity. The designer of washer equipment should keep the effect of air in mind and for the user of washing equipment, monitoring air content is very important. In fact, the pulp tester can be used effectively for air monitoring. Representative samples from the washing line can be tested, first with air present and then de-aerated. If there is a significant difference in the simulated square metre loads, countermeasures have to be taken to solve the air problem.

An important result from the capacity simulation tests was the good correlation between actual washers and the tester. This makes the interpretation of the tester results more reliable when considering practical applications. Agreement can be expected to be equally good for other pulps and washing plants.

The washing efficiency tests showed that the dilution factor does not have very significant influence on washing efficiency. Actually, over the normally-used range of dilution factor (2 to 5 T H_2O/BDT pulp) the effect is nearly overshadowed by the experimental error. Wash water entering velocity which is manipulated through filtration pressure and mat consistency seems to have a notable effect on the washing factor.

Low velocity, achieved by using small pressure and high mat consistency, means high E-factor values. Wash water velocity cannot, however, be decreased too low without having a negative effect on washer capacity. In this kind of trade-off situation the balancing of capacity and washing efficiency requirements is needed which leads to optimization in wash water velocity. The back-up data for the optimization is easily obtained with the tester.

References

1. HAAPAMÄKI, P., Modified Nordén's Method for Pulp Washing Calculations, paper presented at CPPA Chemical Recovery Workshop, 27.3.1979, Montreal, Québec.

Nomenclature

A = pulp tester cylinder cross-sectional area, m^2
c_1 = washer infeed (tester sample) consistency, kg/m^3
c_2 = pulp mat consistency after mat formation, kg/m^3
C_{st} = standard consistency for washing efficiency, %
DF = dilution factor defined by Eq. (13c), T H_2O/BDT pulp
E = modified Nordén's Efficiency Factor, dimensionless
G_{2x} = simulated drum square metre load, BD kg/m^2s or BDT/m^2d
g_{2x} = pulp load in tester, kg/m^2s
K_4 = concentration of washable material in wash water, kg/kg water
K_7 = concentration of washable material in displaced filtrate, kg/kg
n_x = simulated drum speed, rpm
P = measured fibre amount in the tester, kg
P_{2x} = fibre amount in the formed mat (in the tester), kg
Δp = effective filtration pressure, m H_2O
Q = washable material amount, kg
Q_1 = washable material amount, in the incoming slurry, kg
Q_3 = washable material amount, in the outgoing slurry, kg
Q_4 = washable material amount, in wash water, kg
Q_7 = washable material amount, in the displaced filtrate, kg
s_x = movement of the tester piston, m
t_x = registered piston movement time in the tester, s
t_{rx} = drum revolution time with respect to tester results, s
V = liquid flow amount (in washing), kg
dV = liquid flow excess (in washing), kg
V_1 = liquid flow amount in the incoming slurry, kg
V_3 = liquid flow amount in the outgoing slurry, kg
V_4 = wash water amount, kg
V_7 = displaced filtrate amount, kg
y_{air} = air content in the infeed slurry, vol-%
W_1 = volume (in washer) of the infeed slurry, m^3
W_2 = volume of formed mat, m^3
W_6 = volume of the filtrate of thickening, m^3
W_{2x} = volume (in the tester) of the slurry sample, m^3
W_{6x} = volume (in the tester) of the filtrate of thickening, m^3
α_1 = angle of mat formation on the drum, °

Résumé: Nous avons fait appel à un appareil d'essai de la pâte pour étudier les effets de certains paramètres sur la capacité et l'efficacité de lavage de la pile laveuse sur la pâte écrue. Nous article s'intéresse à la fois aux principes de fonctionnement et à la reproductibilité de l'appareil d'essai, et aux résultats obtenus au cours de l'étude. Pour mener à bien nos expériences, nous nous sommes servis de la pâte provenant d'une pile laveuse de pâte écrue d'une usine de pâte kraft filandaise.

Abstract: A pulp tester has been used to study the effect of some parameters on brown stock drum washer capacity and washing efficiency. The principle and reproducibility of the tester as well as the results obtained in the study are presented. Pulp from the brown stock washing line of a Finnish kraft mill was used in the tests.

Reference: HAKAMÄKI, H. and KOVASIN, K. The effect of some parameters on brown stock washing: A study made with a pulp tester. *Pulp Paper Can* 86(9): T243-249 (Sept. 1985). Paper presented at the 1983 Pulp Washing Conference of the Technical Section, CPPA, at Mont Gabriel, Quebec, September 27 to 29, 1983. Not to be reproduced without permission. Manuscript received August 3, 1983. Approved by Review Panel, November 13, 1984.

Keywords: WASHING, PAPER STOCK, PULP TEST, TEST EQUIPMENT, WASHERS, EQUATIONS, EFFICIENCY, PROCESS VARIABLES, RELIABILITY, THICKENING.