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AN EXPANDED MATHEMATICAL MODEL DESCRIBING THE CONVEYING OF PASTY MATERIAL IN DECANTER CENTRIFUGES

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ABSTRACT

When applying solid-bowl centrifuging procedures to slurries with very fine particle size distribution, the conveying of the settled solids inside the bowl can cause specific problems. The sludge can flow back down the cone, counter-current to the movement of the scroll conveyor, first through the clearance between the top of the conveyor blades and the inner surface of the bowl and secondly along the helical canal formed by the conveyor blades and the cone.

A mathematical model is developed describing the conveyance or the backflow of the sludge by variation of the machine geometry, the operating conditions, and the rheological behaviour of the pasty material. Using this model, data achieved by test runs with pilot machines can be applied to an industrial scale decanter, i.e. to set guidelines for the geometric properties and the operating conditions.

I. INTRODUCTION

When processing suspensions with very fine particle size distributions (x_{50} < 10 μm) in centrifugal decanters, problems arising from the limited separation efficiency are accompanied by special problems concerning the discharge of the solids.

Whereas granular solids which are easy to filter and dewater can generally be transported without difficulty by the screw from the cylindrical section through the conical section of the bowl from where they are discharged (Fig. 1), backflow occurs with fine-grained sludges which impairs the clarifying efficiency of the decanter.

This backflow also leads to higher torque as well as increased wear on the screw (or worm). There are two paths by which the paste can achieve backflow. The

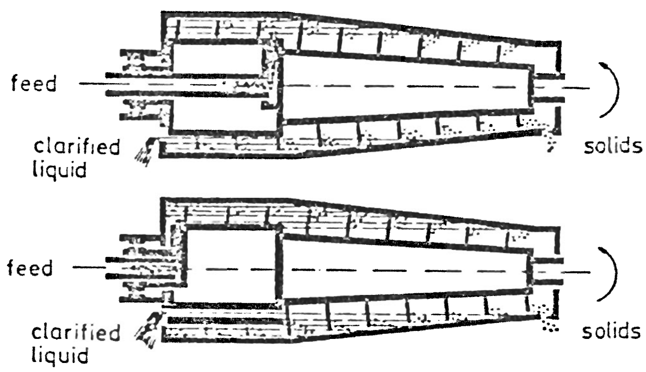


Fig. 1. Functioning principles of a centrifugal decanter
a) counter-current principle
b) co-current principle

sediment can either travel back down the conical section by flowing in the clearance between the blades of the screw and bowl (or drum), or it can spiral back on the screw thus achieving helical backflow |1|.

Each of these effects (actually, it is usually a combination of both effects) means that the forward conveying motion of the screw is opposed by a backflow which leads to a situation where the height of the solid layer accumulating in the cylinder rises significantly despite the continuous conveyance of the solid up the conical section.

Although the conveyance process of granular dewatered solids has been examined, but, as of yet, remains largely unpublished, there exists today no method by which to predict the "conveyance properties" of sludges through using the different rheological properties, different geometries or operating parameters.

One must be content with an empirical approach, whereby few specific conclusions for different instances of applications regarding machine and product can be drawn. Thus, it can happen, for example, that the functioning of a decanter which is geometrically enlarged, can come to a total halt, although the centrifuge functioned perfectly on a scale model.

II. MATHEMATICAL EVALUATION OF THE CONVEYANCE PROCESS OF THE PASTY MATERIAL IN A DECANTER

In the following, a mathematical model will be introduced through which it is possible to quantitatively evaluate the conveyance process, or, more precisely, the backflow in the decanter with respect to the geometry of the machines, operating parameters and the rheological properties of the sediment to give reliable conclusions in respect to the "scale up".

A. Mass Balance of the Solid

The total mass balance of the solid material in a decanter is as follows:

$$\dot{m}_{feed} = \dot{m}_{DS} + \dot{m}_{DC} \qquad (1)$$

where DS = discharge of solid from the cone
DC = discharge of solid in centrate

The mass balance of parts for a single continuous thread screw is:

$$\dot{m}_{screw,o} - \dot{m}_{spiral,o} - \dot{m}_{gap,o} =$$

$$= \dot{m}_{screw,1} - \dot{m}_{spiral,1} - \dot{m}_{gap,1}$$

$$\vdots \qquad (2)$$

$$= \dot{m}_{screw,n} - \dot{m}_{spiral,n} - \dot{m}_{gap,n}$$

Assuming that at the point of discharge from the cone $\dot{m}_{spiral,o}$ and $\dot{m}_{gap,o}$ are equal to zero and that $\dot{m}_{screw,o} = \dot{m}_{DS}$, we can simplify Eq. (2) to:

$$\dot{m}_{DS} = \dot{m}_{screw,n} - \dot{m}_{spiral,n} - \dot{m}_{gap,n} \qquad (3)$$

Substituting Eq. (3) into Eq. (1), we get:

$$\dot{m}_{feed} = \dot{m}_{screw,n} - \dot{m}_{spiral,n} - \dot{m}_{gap,n} + \dot{m}_{DC} \qquad (4)$$

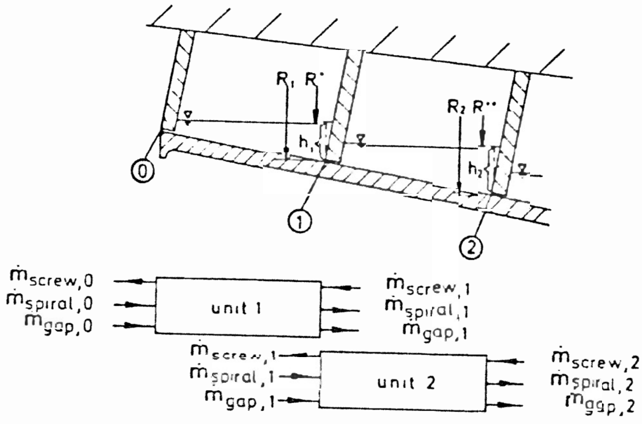


Fig. 2. Mass balance of parts (solids) in decanter

In Eq. (4), $\dot{m}_{screw,n}$, $\dot{m}_{spiral,n}$ and $\dot{m}_{gap,n}$ appear as unkowns.

B. Calculation of the helical backflow ($\dot{m}_{spiral}$)

The flow of high concentrated suspensions as in sludge or, in this case, pastes, can exhibit large differences in flow profiles depending upon the roughness of the walls of the drum.

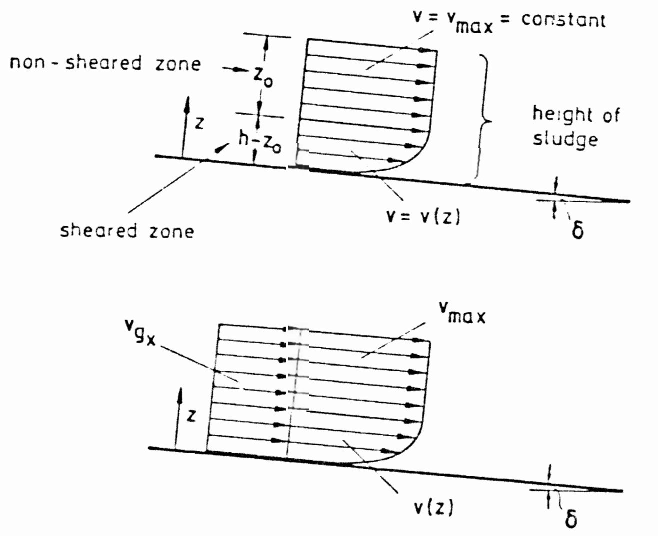


Fig. 3. Velocity profile
a) for the shear flow with yield value τ_o and
b) for the slip- and shear flow

This means the helical backflow can not simply be described by the shear stress function of the medium

$$\tau = \tau_o + K \cdot \dot{\gamma}^n \qquad (5)$$

where adhesion to the wall is assumed (especially when there exists no compact ground layer). Instead, one must also take into account the slip function

$$\tau = C' \cdot v_g^m + \tau_1 \qquad (6)$$

thus taking into respect the effect of the roughness of the surface area of the wall when calculating the helical backflow (Fig. 3) |2|.

The helical backflow along the worm $\dot{m}_{spiral}$ can be calculated as follows |3|:

$$\dot{m}_{spiral}=\bar{\rho}\cdot(1-RF)\Bigg\{(G-b)\cdot\cos\alpha\cdot\frac{n}{n+1}\cdot K^{-1/n}$$
$$\cdot(4\pi^2\cdot\bar{\rho}\cdot R\cdot n_H^2\cdot\sin\alpha\cdot\cos\beta)^{1/n}$$
$$\cdot(\frac{dh}{dl}-\tan\beta)^{1/n}\cdot(-(\frac{h-z_o}{\cos\delta})^{\frac{2n+1}{n}}$$
$$\cdot\left[(\frac{n+1}{2n+1})+(\frac{z_o}{h-z_o})\right]-(G-b)\cdot\cos\alpha$$
$$\cdot h\cdot C'^{-1/m}\cdot\Bigg[4\pi^2\cdot\bar{\rho}\cdot R\cdot n_H^2\cdot\sin\alpha\cdot\cos\beta$$
$$\cdot(\frac{dh}{dl}-\tan\beta)\cdot(-\frac{h}{\cos\delta})-\tau_1\Bigg]^{1/m}\Bigg\} \qquad (7)$$

where

$$z_o = \frac{-\tau_o\cdot\cos\delta}{4\pi^2\cdot n_H^2\cdot\bar{\rho}\cdot R\cdot\sin\alpha\cdot\cos\beta\cdot(\frac{dh}{dl}-\tan\beta)} \qquad (8)$$

and

$$\delta = \arcsin\,(\sin\alpha\cdot\sin\beta) \qquad (9)$$

C. Calculation of backflow between the blades and drum ($\dot{m}_{gap}$)

In calculating the back flow between the blade and drum, $\dot{m}_{gap}$, we must also take shear and slip stress into account. Just as we did for the calculation of the helical backflow, $\dot{m}_{spiral}$. The derivation of $\dot{m}_{gap}$ is made under several assumptions, one of which is that the screw blades are in the form of annular disks corresponding to a screw with a pitch of nought.

The solid mass flow restricted by the shear function is formulated as follows:

$$\dot{m}_{shear}=\bar{\rho}\cdot(1-RF)\cdot\frac{1}{6}\cdot\left[\frac{-\pi\cdot R\cdot s^3\cdot(\frac{dp}{dy}-\bar{\rho}\cdot g_y)^*}{(\frac{\tau_o\cdot s}{|\omega_i R_i-\omega_a\cdot R_a|})+K(|\frac{\omega_i R_i-\omega_a R_a}{s}|)^{n-1}}\right] \qquad (10)$$

Eq. (10) is applicable in the case that the shear gradient in the direction of the periphery is much larger than the shear gradient in the direction of the bowl wall ($\dot{\gamma}_x >> \dot{\gamma}_y$).

Eq. (11) is applicable in the case that the shear gradient in the direction of the bowl wall is much larger than the shear gradient in the direction of the periphery ($\dot{\gamma}_x << \dot{\gamma}_y$).

$$\dot{m}_{shear}=\bar{\rho}\cdot(1-RF)\cdot 4\pi R\frac{n}{n+1}\left[\frac{(\frac{\partial p}{\partial y}-\rho g_y)^*}{K}\cdot(z_o^*-\frac{s}{2})\right]^{\frac{1}{n}}$$
$$\cdot\left[(\frac{s}{2}-z_o^*)\left[\frac{n+1}{2n+1}\cdot(\frac{s}{2}-z_o^*)+z_o^*\right]\right] \qquad (11)$$

The zone in the clearance where the shear stress is not large enough to have an effect is given by z_o^* where

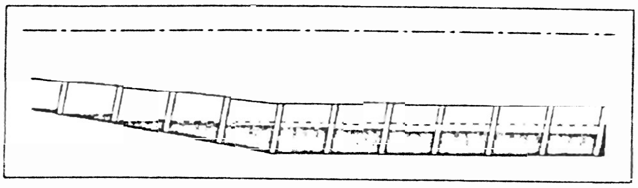
$$z_o^* = \frac{\tau_o}{(|\frac{dp}{dy}-\bar{\rho}\cdot g_y|)^*} \qquad (12)$$

The mass flow of solids caused by sliding on the metal surface can be calculated as follows:

$$\dot{m}_{slide}=\bar{\rho}\cdot(1-RF)\cdot 2\pi\cdot R\cdot s$$
$$\cdot\left(\frac{-\frac{s}{2}\cdot(\frac{dp}{dy}-\bar{\rho}\cdot g_y)^*-\tau_1}{C'}\right)^{1/m} \qquad (13)$$

By experimental analysis on the backflow through the clearance using a centrifuge built specifically for this purpose, it can be determined that the influence of the different rates of rotation between the worm and the drum have little effect on the rate of backflow through the clearance. Thus, for practical purposes, Eq. (11) will be used to calculate the

BACKFLOW PROFILE
(the start is at the point of solid discharge)



Machine type : A

Diameter of cylinder	D_{Cyl}	=	250 mm
D.f solid discharge	D_{DS}	=	165 mm
Diameter of niveau	D_{Niv}	=	190 mm
Length of cylinder	L_{Cyl}	=	340 mm
Cone angle	β	=	10 °
Pitch	G	=	55 mm
Blade thickness	b	=	6 mm
Niveau volume	V_{Niv}	=	7.8 dm^3

Product : CAOLINE

Rotational speed	n_{M}	=	3000 1/min
Differential speed	n_{Diff}	=	30 1/min
Input rate of solid	$\dot{m}_s$	=	300 kg/h
Residual moisture	RF1	=	33 0 weight-%
"	RF2	=	39 2 weight-%
"	RF3	=	48 0 weight-%
Deg of effectivity	NG	=	17 5 %
Deg of fullness	FG	=	4.7

Fig. 4. Calculated backflow profile

volume of solid and fluid as measured from the drum to the surface) and VS1 stands for the volume of the sludge, which displaces the fluid.

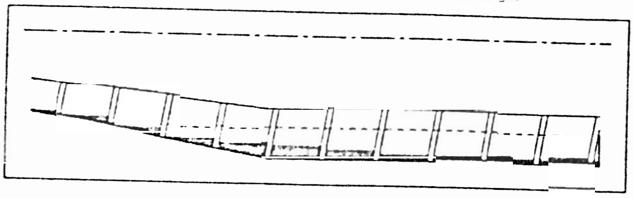
b) Degree of Fullness, FG: This is a factor which allows one to judge the volume of sludge in the decanter in comparison to the ideal situation where there is no backflow. This is a measurement standard for the actual duration of the sediment in the machine and is defined as the relation of the total volume of sludge with backflow (VS) to the total volume of sludge without backflow (VK):

$$FG = VS/VK \tag{20}$$

In Fig.4, RF1 is the residual moisture of the discharge, RF2 is at the point of transition from cone to cylinder, and RF3 is the residual moisture at the end of the cylinder, where the suspension is added in the case of a co-current flow decanter. In the previous example for calculation of the backflow profile Fig. 4, it can be seen that only 17,5% of the total Niveau volume is composed of clear liquid. In this example, the firm material would stay in the centrifuge 4.7 times longer than if the machine functions without any backflow. When the drum revolutions are slowed from 3000 min^{-1} to 2750 min^{-1} (Fig. 5), it can be observed that the "degree of effectivity" increases from 17.5% to 70.0%.

On the other hand, (Fig. 6) one can also improve the degree of effectivity by holding the rate of rotation of the drum constant and raising the differential speed (the difference of the rates of rotation between the worm and drum).

BACKFLOW PROFILE
(the start is at the point of solid discharge)



Machine type : A

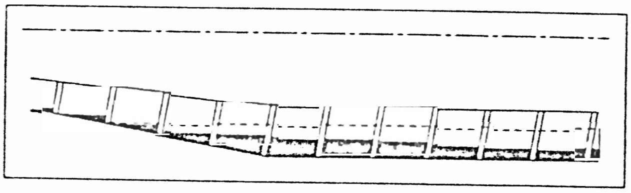
Diameter of cylinder	D_{Cyl}	=	250 mm
D f solid discharge	D_{DS}	=	165 mm
Diameter of niveau	D_{Niv}	=	190 mm
Length of cylinder	L_{Cyl}	=	340 mm
Cone angle	β	=	10 °
Pitch	G	=	55 mm
Blade thickness	b	=	6 mm
Niveau volume	V_{Niv}	=	7 8 dm^3

Product : CAOLINE

Rotational speed	n_{M}	=	2750 1/min
Differential speed	n_{Diff}	=	30 1/min
Input rate of solid	$\dot{m}_s$	=	300 kg/h
Residual moisture	RF1	=	33.0 weight-%
"	RF2	=	39 2 weight-%
"	RF3	=	48 0 weight-%
Deg of effectivity	NG	=	70 0 %
Deg of fullness	FG	=	1 8

Fig. 5. Backflow profile after slowing the rotation of the drum

BACKFLOW PROFILE
(the start is at the point of solid discharge)



Machine type A

Diameter of cylinder	D_{Cyl}	=	250 mm
D f.solid discharge	D_{DS}	=	165 mm
Diameter of niveau	D_{Niv}	=	190 mm
Length of cylinder	L_{Cyl}	=	340 mm
Cone angle	β	=	10 °
Pitch	G	=	55 mm
Blade thickness	b	=	6 mm
Niveau volume	V_{Niv}	=	7 8 dm^3

Product : CAOLINE

Rotational speed	n_{M}	=	3000 1/min
Differential speed	n_{Diff}	=	35 1/min
Input rate of solid	$\dot{m}_s$	=	300 kg/h
Residual moisture	RF1	=	33.0 weight-%
"	RF2	=	39.2 weight-%
"	RF3	=	48 0 weight-%
Deg of effectivity	NG	=	48 9 %
Deg.of fullness	FG	=	3 5

Fig.6. Backflow profile with higher differential speed

When considering these possibilities, one should naturally take into consideration other undesirable effects which could occur: for example, disrupting of the clarification through turbulence caused by the increasing of the differential speed, or making sedimentation more difficult and/or increasing the residual moisture by slowing the speed of rotation of the drum.

The above mentioned examples are simple operational conditions. Fig. 7 shows the dependance of NG on mass flow $\dot{m}_{feed}$ ($\dot{m}_s$) and on variations of centrifuging factor C(g-factor).

III. CONSIDERATIONS FOR THE "SCALE-UP"

The transfering and applying of results from the pilot plant to the large machi-

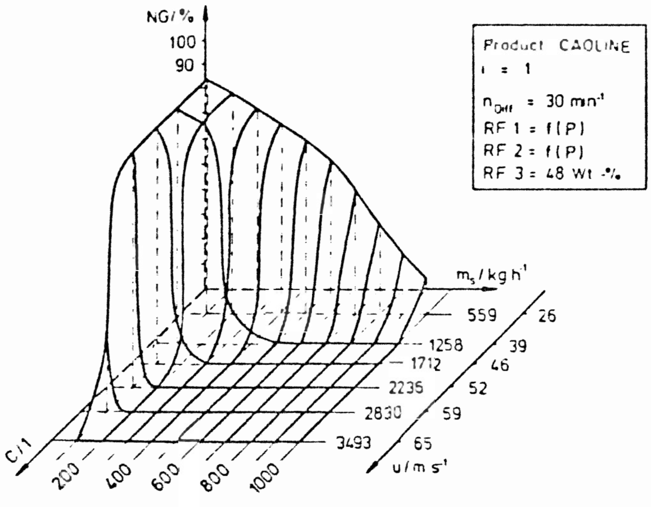


Fig.7. Operational field to judge the functioning capabilities of the decanter

nes (scale-up) are, as is well known in the industry, full of large uncertainties. For example, it could occur that the large industrial-size machines produce absolutely no solid, although the small model machine functioned relatively free of disturbance. This industrially known fact can be theoretically confirmed and can be illustrated through the following example:

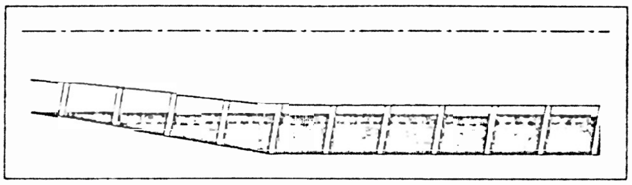
Take the results from Fig. 5 as an example for the small machine: the degree of effectivity, NG, is 70.0%. This means that the decanter functions well with regard to clarification and discharge of solid materials. One can also see that the degree of fullness, FG, is 1.8. This means that the sediment remains in the centrifuge 1.8 times longer as it would if the centrifuge would function completely free of backflow. By "scale-up", the individual particles will be changed as follows:

Table 1

Model performance (M)		Large size performance (G)
C_M	=	C_G
$n_{diff,M}$	=	$n_{diff,G}$
$\dot{m}_{feed,M}$	=	$\dot{m}_{feed,M} \cdot i^3$
G_M	=	$G_M \cdot i$
b_M	=	$b_M \cdot i$
β_M	=	β_G
$D_{cyl,M}$	=	$D_{cyl,M} \cdot i$
$D_{DS,M}$	=	$D_{DS,M} \cdot i$
$D_{niv,M}$	=	$D_{niv,M} \cdot i$

When the pilot machine (Fig.5) is enlarged by a factor of four (i=4), the NG - degree of effectivity - of the enlarged machine is 0% (Fig.8).

BACKFLOW PROFILE
(the start is at the point of solid discharge)



Machine type : A (4x)			Product : CAOLINE		
Diameter of cylinder	D_{cyl}	= 1000 mm	Rotational speed	n_M	= 1375 1/min
D f solid discharge	D_{DS}	= 660 mm	Differential speed	n_{Diff}	= 30 1/min
Diameter of niveau	D_{niv}	= 760 mm	Input rate of solid	$\dot{m}_s$	=19200 kg/h
Length of cylinder	L_{cyl}	= 1360 mm	Residual moisture	RF1	= 33.0 weight-%
Cone angle	β	= 10 °	"	RF2	= 39.2 weight-%
Pitch	G	= 220 mm	"	RF3	= 48.0 weight-%
Blade thickness	b	= 24 mm	Deg of effectivity	NG	= 0.0 %
Niveau volume	V_{niv}	=439.5 dm³	Deg.of fullness	FG	= 7.5

Fig. 8. Backflow profile of the "scale-up"

In Fig.8 it can also be seen that the height of the backflow is higher than the fluid level, or niveau. This means that the solid is also being carried out in the clarified-liquid discharge before the sediment can reach the solid discharge level. This means that the decanter cannot produce the desired solid material, the clarification process is fully disrupted, and the unseparated suspension flow through the fluid outlet.

Fig. 9 shows that it would be thoroughly worthless to install a large machine when the centrifuging factor (g-value) is held constant by the "scale-up". The large machine would only function without backflow within a very small margin.

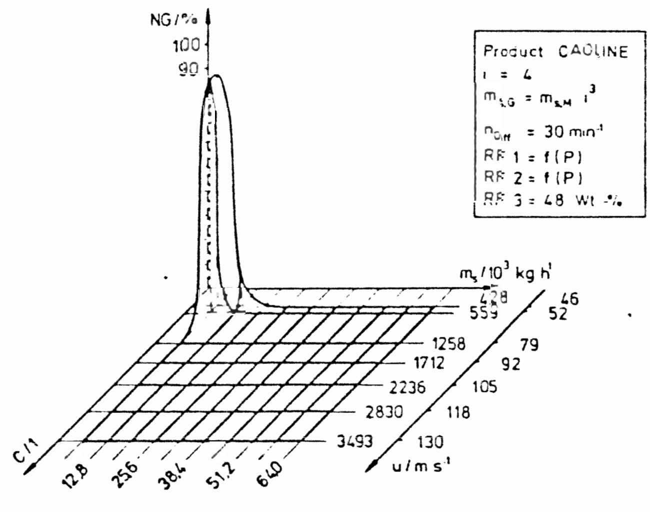


Fig. 9. Operational field due to "scale-up" ($\dot{m}_{s,G} = \dot{m}_{s,M} \cdot i^3$)

backflow in the clearance.

To calculate the driving potential $(\frac{dp}{dy} - \bar{\rho}.g_y)^*$, one must consider two cases:

a) The backflow of mass is not large enough to fully cover the total width between two blades to come into contact with the reverse side of the blade. In this case, calculations of the driving potential yield:

$$(\frac{dp}{dy}-\bar{\rho}.g_y)^*=\frac{\bar{\rho}.\omega^2}{2b}.(h_j^2-2R_j.h_j-2b.R_j.\sin\beta) \quad (14)$$

b) The backflow of mass is high enough that the blockage extends all the way to the reverse side of the preceeding blade. One can calculate the driving potential in this case only when one knows the height of the backflow blockage on the neighboring blade.

$$(\frac{dp}{dy}-\bar{\rho}.g_y)^*=\frac{\bar{\rho}.\omega^2}{2b}.(h_j^2-2R_j.h_j+b^2.\sin^2\beta+2R_j.(h_{j-1}-G.\sin\beta)-(h_{j-1}-G.\sin\beta)^2) \quad (15)$$

The total mass backflow through the clearance can be described by combining Eq.(11) and Eq. (13)

$$\dot{m}_{gap} = \dot{m}_{shear} + \dot{m}_{slide} \quad (16)$$

D. Formulation of the mass flow due to the screw ($\dot{m}_{screw}$)

The mass flow which is advanced by the screw, $\dot{m}_{screw}$, yields, through the difference of rotation rates of the screw and the drum, the following:

$$\dot{m}_{screw}=\bar{\rho}.(1-RF).2.\pi.R.h.(G-b).n_{Diff}.\cos^2\alpha \quad (17)$$

E. Overall transfer equation

One can now insert Eq. (7), Eq. (16) and Eq. (17) into the Balance Equation, Eq. (4). The resulting mass transfer equation is:

$$\dot{m}_{feed}=\bar{\rho}.(1-RF).\Big\{2\pi.R.h.(G-b).n_{Diff}.\cos^2\alpha$$
$$-(G-b).\cos\alpha.\frac{n}{n+1}.K^{-1/n}.(4\pi^2.\bar{\rho}.R.n_H^2.\sin\alpha.\cos\beta)^{1/n}.(\frac{dh}{dl}-\tan\beta)^{1/n}$$
$$.(-(\frac{h-z_0}{\cos\delta}))^{\frac{2n+1}{n}}.\Big[(\frac{n+1}{2n+1})+(\frac{z_0}{h-z_0})\Big]-$$
$$(G-b).\cos\alpha.h.C'^{-1/m}.\Big[4\pi^2.\bar{\rho}.R.n_H^2.\sin\alpha.\cos\beta.(\frac{dh}{dl}-\tan\beta).(-\frac{h}{\cos\delta})-\tau_1\Big]^{1/m}$$
$$-4\pi.R.\frac{n}{n+1}.\Big[\frac{(\frac{dp}{dy}-\bar{\rho}.g_y)^*}{K}.(z_0^*-\frac{s}{2})\Big]^{1/n}$$
$$.\Big[(\frac{s}{2}-z_0^*).\Big[(\frac{n+1}{2n+1}).(\frac{s}{2}-z_0^*)+z_0^*\Big]\Big]$$
$$-2\pi R.s.\Big[\frac{-\frac{s}{2}.(\frac{dp}{dy}-\bar{\rho}.g_y)^*-\tau_1}{C'}\Big]^{1/m}\Big\}$$
$$+\dot{m}_{DC} \quad (18)$$

Eq. (18) deals with an ordinary differential equation of a higher order: an equation which can not be analytically solved. The total height of the back flow at any given point, or, more specifically, the varying of the height h with the changing of the measuring coordinate, appears in the equation as an unkown variable. Thus, to solve Eq.(18), one must employ "numerical methods". For the case where the centrifuge has a firm ground layer between the blades and the drum ($\dot{m}_{gap}$=0), then Eq.(18) can be solved with relative ease. One uses the point of solid discharge as a starting place and calculates the height of the backflow along the channel of the worm through iteration methods.

Fig. 4 shows a calculated backflow profile for a machine of specific geometry and operating parameters.

Two concepts must now be introduced in order to be able to judge the functioning capability of the decanter better.

a) Degree of Effectivity, NG: this is a measurement or standard which measures the volume of the clear liquid in the overall volume of liquid and solid. NG is defined so:

$$NG := (1-\frac{VS1}{VNIV}).100 \text{ in } \% \quad (19)$$

in which VNIV stands for the Niveau Volume (or the level of the total

Comparing Fig. (9) to Fig. (7), it can be recognized that the large machines, in respect to the backflow, would exhibit the same behaviour as when the parameter velocity of the drum, not the centrifuging factor, is held constant. This can also be shown using Table 1 with Eq. 18. For this reason, the centrifugal factor for the large machine is: $C_G = C_M / i$. Now, when the solid mass flow $\dot{m}_S$ ($\dot{m}_{feed}$) is not enlarged by i^3 as in the drag force law |4|, but instead is enlarged by i^2 using the theory of equivalent clear areas |5|, then it becomes obvious that by constant perimeter velocity, the large machines can function even more favorably than the pilot machine (Fig. 10).

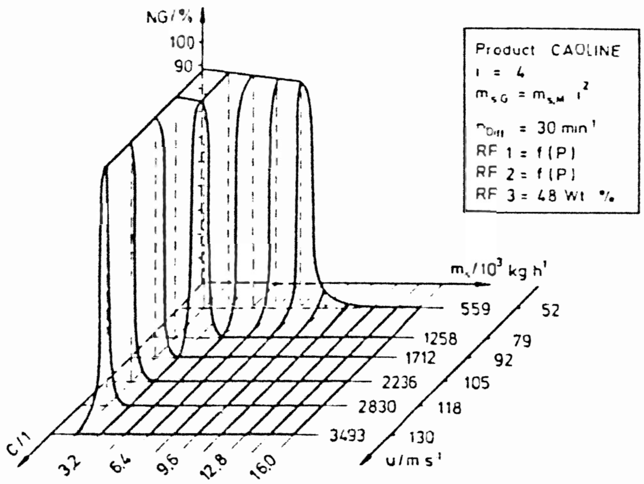


Fig. 10. Operational field due to "scale-up" ($\dot{m}_{S,G} = \dot{m}_{S,M} \cdot i^2$)

IV. INFLUENCE OF THE GAP WIDTH ON THE BACKFLOW

The former examples have been calculated under the assumption that there is a firm ground layer. For the case where the sediment can flow back through the gap between wall and blade as well as flow in a spiral back along the blades, the backflow profile becomes even more unfavorable. This means that the backflow mass is greater than when the gap width s is zero. At this point it should be mentioned, that the addition of the backflow through the gap to the calculation seriously complicates the entire calculating process.

Fig. 11 demonstrates the influence of the gap width on the degree of effectivity.

For s = 0 mm, the degree of effectivity is identical to that in the example in Fig. 6. It can also be seen in Fig. 11

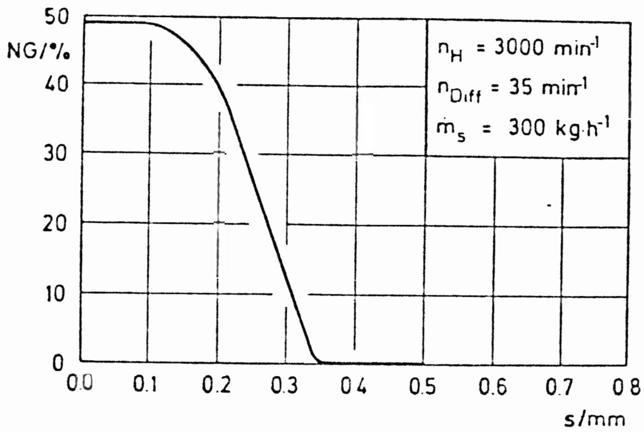


Fig. 11. Dependence of degree of effectivity NG on the gap width s

that enlarging the gap width from 0 mm to 0.35 mm is more than enough to decrease the degree of effectivity from 48.9 % to 0 %.

At first the influence of the gap width upon the solid backflow appears great. In practice, it can be seen that the gap closes itself after a certain amount of time in operation by building up a firm ground layer. This means that, for most cases, the influence of the gap width can be ignored.

Certain assumptions are made for the derivation of the mathematical models, or, in this case, for the calculation of the backflow profile, where quantitative statements can be made with caution. With this mathematical model, one is much better equipped to make precise relative statements, especially when one wishes to apply the experimental results from a pilot machine to an industrial-size machine. One must also look critically at the fact that an extremely large number of experiments are necessary for the determination of the rheological data (τ_0, K, n, τ_1, C', m) since they are continuously coupled with the residual moisture of the sediment. Since the change in the residual moisture of the sludge during the conveying by the screw is not known, it will be estimated as being linear. One can also assume that the residual moisture in the conical section of the decanter is hardly, if at all, changed by the lessening of the centrifugal acceleration. Thus, the value for RF1 und RF2 can be considered to be constant.

The described mathematical model can be checked through experimental data from an industrial test. For this test, the behaviour of a starch suspension in two gemetrically different decanters are employed. Thereby it was determined that the larger machine did not discharge any solid. After investigating the rheological data of the product, these experimental findings could be mathematically proven.

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SYMBOLS

b	blade thickness
C	C-Value, g-factor
C'	slip-factor
FG	degree of fullness
g	acceleration due to gravity
G	pitch
h	height of cake, level of accumulated sludge
i	enlarging factor, scale-up factor
K	shear-factor
m	slip-exponent
$\dot{m}$	solid-mass flow
n	shear-exponent
n_{diff}	differential speed
n_{II}	rotational speed of drum
NG	degree of effectivity
p	pressure
R	radius
RF	residual moisture
s	gap width, clearance
u	perimeter velocity of the drum
v_g	slide velocity
$\dot{V}$	volume flow
x_{50}	mean radius of particles
α	screw pitch angle
β	cone angle
$\dot{\gamma}$	shear gradient
δ	channel angle (formed by intersection of α and β)
ρ	density
$\bar{\rho}$	mean sediment density
ρ_1	fluid density
τ	shear stress
τ_0	yield value, initial shear stress
τ_1	slide limit
τ_w	wall shear stress