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DISCHARGE OF PASTY MATERIAL FROM DECANTER CENTRIFUGES

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When applying solid-bowl centrifuges to slurries with very fine particle size distribution the conveying of the settled solids inside the bowl can cause specific problems. Countercurrent to the movement of the scroll conveyor the sludge can flow back the cone through the clearance between the top of the conveyor blades and the inner surface of the bowl and along the helical canal formed by the conveyor blades and the cone. To investigate these back flow effects two special test centrifuges were designed. The experimental results give acceptable confirmation to the theoretical assumptions. First results of this work show how design and operation of decanters for sludge application can be improved.

INTRODUCTION

When processing suspensions with very fine particle size distributions (x_{50} < 10 µm) in centrifugal decanters, the 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 scroll from the cylindrical section through the conical section of the rotor from where they are discharged (Fig.1), backflow occurs with fine-grained sludges which impairs the clarifying efficiency of the decanter. This backflow also results in higher torque and can lead to increased wear on the scroll.

There are two possible paths which the paste can take on its way back through the conical section in the opposite direction to the effective movement of the scroll.

a) Backflow through the clearance

The paste flows back through the clearance under the influence of centrifugal force and accumulates in front of the next cake which in turn releases paste down the cone and so on.

b) Helical backflow

Even if the clearance were to be completely sealed, which cannot be realised for reasons of safety - metal on metal contact - the sludge could still find its way into the sump. The (imaginary) line of intersection between the cone and the scroll blades can be developed along the periphery. It then becomes evident that a single scroll channel slopes downwards to the larger radius. Just as a small ball

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in the centrifugal field would roll down this channel to the larger radius and into the cylinder, the sludge also will flow down this channel if its consistency is not sufficient.

Each effect individually (in reality, however, it is usually a combination of both effects) means that the forward conveying motion of the scroll is opposed by a backflow which leads to a situation where the height of the solids layer rises significantly in relation to the continuous conveyance of the solids (as calculated using the single particle theory |1|).

Fig. 2 illustrates such a backflow in simplified form. There is a step by step decrease in the level of the sludge deposits between the scroll blades. The deposits extend right into the cylindrical section of the bowl thus considerably impairing the clarifying efficiency of the decanter.

The existence of this backflow has been proven many times. Fig. 3 shows a blocked decanter scroll after removal. The overload protection was triggered during continuous operation and the product feed simultaneously shut off.

Although the decanter was brought to a standstill swiftly by electrically braking the motor, the deposited solids mass cannot maintain the equilibrium present during operation; during run down of the decanter, the sludge flows through the clearances or helically "down" the scroll with the result that the level of the sludge is higher in the cone or reaches further into the cylindrical section of the bowl than would be the case during normal operating conditions with rotating scroll and continuous discharge.

TYPICAL PHENOMENA OBSERVED DURING THE PROCESSING OF PASTY SLUDGES

When product is first fed into an empty decanter running at operating speed, a clear centrate is observed which subsequently becomes increasingly turbid. The situation might arise where centrate but no solids are discharged during the first few minutes of operation. The solids accumulate in the bowl and are ejected abruptly at roughly equal intervals, one portion at a time. The scroll torque, speed, power consumption of the drive motor and the solids content in the centrate all fluctuate with the rhythm of the solids discharge (Fig. 4).

The fluctuations are not, as a rule, influenced by the differential speed.

Every time a portion of solids is discharged, the amount of accumulated sludge is reduced, the effective clarification area is larger and the inflowing suspension fills the available free space. In extreme cases of periodical discharge, the centrate flow even stops completely for a brief moment or at least becomes considerably slower after the accumulated sludge has been dispersed. There is a marked drop both in torque and delivery capacity of the scroll after such a discharge and the main bowl speed recovers.

Fig. 5 is a graph showing the torque curve of a decanter, below which the brief sludge discharge periods are recorded in the form of blocks. The torque peak always coincides with the beginning of the discharge, the lowest point with the end of the discharge. A further typical observation is also reflected: After an initially short discharge of a small amount of sludge at a high torque, when a considerable backflow is present, the average torque drops and discharge periods become more prolonged. Later the machine can display an absolutely uniform discharge pattern with a constant volume of accumulated sludge. This is manifested in the minimal torque fluctuations. This is not accompanied, however, by an improvement in the poor centrate clarity due to backflow.

The machine continues to discharge sludge for a long time after the suspension feed has been shut off, or at any rate for much longer than the retention time as determined by the differential speed would indicate.

The case often arises where the decanter discharges no solids at all after the feed has been shut off. They are discharged during run-down, usually at a very low speed. The amount of backflow can be estimated on the basis of the amount of solids discharged after the feed valve has been shut off until the point when the decanter is at a complete standstill. In an extreme case, the solids can only be discharged below a certain bowl speed. If this bowl speed is exceeded, the solids will gradually build up in the decanter until it is switched off automatically on exceeding the maximum permissible torque or must be stopped because the suspension passes through the machine without being clarified.

If a decanter does not discharge the solids, the liquid level in the decanter must first be adjusted as high as possible.

The zone in which buoyancy inhibits the backflow is thereby enlarged; the backflow decreases accordingly. Secondly, the bowl speed must be lowered in order to reduce the centrifugal force acting against the solids conveyance. This will result in the fine particles being discharged together with the centrate instead of being separated. In addition, problems can occur due to the heightened moisture content in the sludge caused by a reduction in centrifugal acceleration. These problems are particularly acute if the inadequately dewatered sludge is to be subsequently disposed of. Flocculating agents mean extra costs and their use is not permissible if the discharged solids are to be further processed (as, for example, in the foodstuffs industry).

Whereas the transport processes involved with coarse-grained, easily dewaterable solids have largely been investigated by as yet unpublished research projects by the institute, no method has been devised to date which can predict the "conveyance properties" of sludges of different consistencies with machines incorporating different geometrical design parameters or operating parameters. One must be content with a purely empirical approach, whereby conclusions of a general nature which could be applied to other applications with regard to both machine and product can scarcely be drawn.

TEST EQUIPMENT FOR INVESTIGATING THE HELICAL BACKFLOW AND THAT THROUGH THE CLEARANCE

As mentioned earlier, backflow in the conical section of the bowl can take two different forms. Firstly, the medium can flow back helically along the scroll, secondly it can flow through the clearance between the scroll blade and bowl wall along the bowl shell.

Since a realistically dimensioned decanter would be absolutely inaccessible for the purpose of these investigations and also since the two types of backflow must be investigated independently from one another, two separate test stands were constructed with overhung bowls, which I now propose to describe in detail.

Test equipment for investigating the backflow through the clearance

The test equipment for investigating the backflow through the clearance (Fig. 6) consists of an exchangeable set of different solid wall cones which are mounted on the drive assembly of a screen-worm-centrifuge.

Three bowls are available (Pos. 3) with cones having the angles $\beta = 5\,^{\circ}$, $10\,^{\circ}$ and $12.5\,^{\circ}$.

In order that the flow through the clearance alone can be investigated, the "croll blades" were first constructed as annular discs. To vary the clearance s, the disc holder (Pos. 7) can be displaced axially by tightening screws (Pos. 13) and cover (Pos. 5). The discs (Pos. 8) consist of sets containing 3 individual discs of 4 mm thickness. By dispensing with individual discs, blade thicknesses of b = 4 ,8 and 12 mm can be adjusted.

The pitch G can be varied by removing every second "disc set" thereby doubling the pitch from 60 to 120 mm.

Windows are fitted into the disc holding body to enable the individual chambers of the bowl to be monitored at full bowl speed with the aid of an optical instrument.

In contrast to a normal decanter where the sludge is transported from the cylindrical section to the cone, the test machine incorporates the reverse principle. The product is fed into the bowl at the small radius end of the cone through a swivel-type inlet tube. The sludge flows constantly towards the lower end of the cone and is drawn off at the large radius end by means of a paring tube which can be swivelled through 8 $^{\circ}$. The product is continuously recycled (Fig. 7). The sludge is fed into the centrifuge by an eccentric screw pump. After being discharged from the bowl, it flows through a chute back into the tank which is flanged directly above the pump. Different levels of accumulated solids are then present in the individual bowl chambers (depending on operating, machine and product parameters) if stable conditions prevail.

In order to be able to read off these backflow levels, four colour bands, each 5 mm in width, were attached uniformly around the circumference of the discs. Each colour band represents a height of 5 mm. Using an axially displaceable endoscope, the height of the solids backflow in each chamber was able to be read off with an accuracy of up to 1 mm. A stroboscope designed especially for the purpose was introduced into the rotor together with the endoscope for direct illumination. The flashing frequency of the lamp is synchronised with the speed of the disc holding body in order to ensure a steady picture, even in the event of speed fluctuations.

Derivation of a mathematical equation to describe the backflow through the clearance in quantitative terms

It is now proposed to derive a mathematical equation which is capable of calculating the backflow volume $\dot{V}_{RS}$ through the clearance for a Bingham or Newtonian medium as a function of machine and operating parameters. The clearance is taken to be the space between scroll blade and cone wall, through which the pasty material flows in the opposite direction to the conveying motion of the scroll to collect in the cylindrical section of the decanter.

The following considerations are only valid if the scroll blades are in the form of annular rings which correspond to a scroll having a pitch of nought. It is not intended to explain the derivation of the theory in the full. Only the most important steps are pointed out.

An element of volume dV is taken from the medium in the clearance (Fig. 8) and the balance of momentum applied to this for the x and y axes.

Since R >> s and $\frac{R_a}{R_i} \approx 1$, the flow in the clearance can be considered as a two dimensional problem.

Given that the flow in the clearance is a) stationary, b) laminar, fully developed and c) the product is incompressible, the momentum equations are as follows:

$$\frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{zx}}{\partial z} = 0 \qquad \text{for the x axis} \qquad (1)$$

and

$$\frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + \rho \cdot g_y = 0 \qquad \text{for the y axis} \qquad (2)$$

wherein g_y represents the acceleration along the bowl wall.

The flow behaviour of the medium must be taken into consideration at this point. The Bingham formula states that the medium under the influence of a shear rate will not start to flow until an initial shear stress or yield value τ_o has been exceeded (Fig.9).

Sludges and pasty materials which are processed in decanters can primarily be considered as Bingham media. Newtonian media can be considered as a special form of Bingham media without yield value.

The law of friction for a Bingham medium in two dimensional representation is:

$$\tau_{zx} = \frac{\tau_o \cdot (\frac{du}{dz})}{\sqrt{(\frac{du}{dz})^2 + (\frac{dv}{dz})^2}} + \eta_B \cdot (\frac{du}{dz}) \qquad \text{for the x axis} \qquad (3)$$

and

$$\tau_{zy} = \frac{\tau_o \cdot (\frac{dv}{dz})}{\sqrt{(\frac{du}{dz})^2 + (\frac{dv}{dz})^2}} + \eta_B \cdot (\frac{dv}{dz}) \qquad \text{for the y axis} \qquad (4)$$

By combining equation (1) with equation (3) and equation (2) with equation (4), making allowance for the marginal conditions (including adherence to the wall)

$$u\ (z = + \frac{s}{2}) = \omega_i . R_i$$

for the x axis

$$u\ (z = - \frac{s}{2}) = \omega_a . R_a$$

and

$$v\ (z = \pm \frac{s}{2}) = 0 \qquad \text{for the y axis}$$

the following equation for the backflow volume $\dot{V}_{RS}$ in the clearance is obtained after double integration:

$$\dot{V}_{RS} = \frac{-\pi\ R.s^3}{6\ \eta_{eff}} \cdot (\frac{\partial p}{\partial y} - \rho . g_y) \qquad (5)$$

whereby

$$\eta_{eff} = \left| \frac{\tau_o . s}{\omega_i R_i - \omega_a R_a} \right| + \eta_B \qquad (6)$$

Equation (5) applies for the case where the shear rate in the direction of the periphery is much greater than the shear rate along the bowl wall ($\frac{du}{dz} >> \frac{dv}{dz}$).

For the case where the shear rate in the direction of the periphery is much smaller than along the bowl wall ($\frac{du}{dz} << \frac{dv}{dz}$), a distinction must be drawn between the area where shearing forces are present ($\pm z_o \leq z \leq \mp \frac{s}{2}$) and the area where no shearing forces are present, the so-called plug flow ($0 \leq z \leq \pm z_o$). The following then applies for the plug flow:

$$v = v_{max} = \text{const} \qquad \text{or} \qquad \frac{dv}{dz} = 0$$

A calculation analogous to the first case produces the following equation for the backflow volume

$$\dot{V}_{RS} = \frac{-\pi.R}{6\ \eta_B} \cdot (s^3 + 4\ z_o^{\ 3} - 3\ s^2 \cdot z_o) \cdot (\frac{\partial p}{\partial y} - \rho.g_y) \qquad (7)$$

wherein

$$z_o = \frac{\tau_o}{|(\frac{\partial p}{\partial y} - \rho.g_y)|} \qquad (8)$$

In the case of a Newtonian medium ($\tau_o = 0$) equation (5) and equation (7) are identical. That means that the differential speed has no influence on the backflow volume provided that stable conditions prevail:

$$\dot{V}_{RS} = \frac{-\pi.R.s^3}{6\ \eta_N} \cdot (\frac{\partial p}{\partial y} - \rho \cdot g_y) \qquad (9)$$

The pressure drop in the clearance at the scroll blade between the chambers j and j -1 (Fig. 10) can be calculated as follows:

$$(\frac{\partial p}{\partial y} - \rho.g_y) = \frac{2\ \pi^2.\bar{\rho}.n_H^2}{b} (h_j^2 - 2\ R_j h_j + b^2 \sin^2\beta + 2R_j . (h_{j-1} - G \sin\beta) - (h_{j-1} - G \sin\beta)^2) \qquad (10)$$

If atmospheric pressure prevails behind the scroll blade, i.e. the sludge does not come into contact with the reverse face of the scroll blade, the equation (10) can be simplified to

$$(\frac{\partial p}{\partial y} - \rho.g_y) = \frac{2\ \pi^2\bar{\rho}.n_H^2}{b} \cdot (h_j^2 - 2\ R_j.h_j - 2\ R_j b.\sin\beta) \qquad (11)$$

It follows that equation (9) is:

$$\dot{V}_{RS} = \frac{-\pi^3.R_j.s^3.\bar{\rho}.n_H^2}{3\ b\ .\ \eta_N} \cdot (h_j^2 - 2\ R_j h_j + b^2 \sin^2\beta + 2\ R_j (h_{j-1} - G \sin\beta) - (h_{j-1} - G \sin\beta)^2) \qquad (12)$$

or

$$\dot{V}_{RS} = \frac{-\pi^3.R_j\ s^3.\bar{\rho}.n_H^2}{3\ b\ \eta_N} \cdot (h_j^2 - 2\ R_j h_j - 2\ b\ R_j \sin\beta) \qquad (13)$$

From the above equations can be deduced that the backflow volume is proportional to s^3. If one considers the scaling-up of decanters, the clearance can easily be enlarged from 1 mm to 2 mm which brings about an overall increase in the peripheral backflow volume of over one power of ten. This explains why a normal-sized decanter in a particular application will not have discharged any solids whereas normal continuous discharge will be observed in a pilot decanter of similar geometric design operating under identical conditions.

Given the heights of accumulated solids in the test equipment described, equation (12) or equation (13) can be used to calculate the backflow volume in the clearance.

The backflow volumes determined in this way are finally compared with those adjusted by means of the pumpe, thus enabling an assessment as to how far the equation derived after having made certain simplifying assumptions reflects the test results. Fig. 11 shows such a comparison between measurements and calculations.

These investigations were carried out with glycerin as an example of a Newtonian medium. It can be seen that there is a good correlation between theory and practice.

Uncertainties surrounding the assessment of deviations from theory and measurement are largely due to the following:

For production engineering reasons, the clearance around the periphery of an individual disc and between adjacent discs can only be guaranteed to within ± 0.1 mm. This means that the clearances at each disc must be measured and that the calculation must treat each chamber with its individual clearances separately. In order to determine the clearances, special feelers were manufactured which can measure down to a tenth of a millimetre exactly. These were inserted through the windows in the disc holding body.

Each disc was measured at four equidistant positions along its periphery. The bowl shell was then turned 90° in relation to the disc holding body and again the four measurements recorded. This procedure was repeated twice. Sixteen values were therefore obtained for each disc. These values were cubed and the average value, variation and standard deviation determined. The cube roots of these average values were used in the model calculation. If the standard deviation is compared to the average value, a range of tolerance results for the deviation of measurement and calculation on the basis of which the degree of correlation can be easily assessed. The relative deviation of the clearances in the direction of the periphery was ± 30% in the majority of cases. In Fig. 11 this area is demarcated by two straight lines.

The investigations with glycerin were carried out both with and without differential speed. As was to be expected from the theory, the differential speed had no influence on the peripheral backflow.

Investigations are currently being carried out with non-Newtonian media using kaolin sludge as the test material. The more complex flow theories involved with these materials will be dealt with in a later publication.

Test Equipment for Investigating the Helical Backflow

A screen-worm centrifuge was converted in order to investigate the helical backflow of sludge along the scroll blades. The conical screen basket was lined with a metal sheet onto which a scroll blade was soldered. This corresponds to the borderline case clearance s = 0 and differential speed $n_{Diff} = 0$ (Fig. 12).

It is therefore possible to investigate the sludge backflow in the scroll channel as a function of the centrifugal acceleration and the channel angle δ which is formed by the intersection of the cone angle β and the scroll pitch angle α.

The helical backflow volume for a Bingham medium under stable conditions can be calculated using the following formula:

$$\dot{V}_{RK} = \frac{(G-b).\cos\alpha}{6\ \eta_B.(\bar{\rho}.C.g.\sin\delta)^2} (\bar{\rho}.C.g.\sin\delta.h-\tau_o)^2 \cdot (\tau_o + 2\bar{\rho}C.g.\sin\delta.h) \qquad (14)$$

with

$$C = \frac{4\ \pi^2.R.n_H^2}{g} \qquad (15)$$

and

$$\sin\delta = \sin\alpha \cdot \sin\beta \qquad (16)$$

The derivation of equation (14) is based on the following assumptions:

- One-dimensional, laminar, fully developed flow
- Side wall influences are negligible, i.e. (G-b>>h)
- No pressure gradient in flow direction
- No sliding of the sludge on bottom wall

In a state of equilibrium ($\dot{V}_{RK} = 0$) the yield value τ_o can be described thus:

$$\tau_o = 4\ \pi^2.n_H^2\ R\ \sin\delta \cdot \bar{\rho} \cdot h \qquad (17)$$

The investigations carried out up to now have been concerned wholly with this state of equilibrium. The procedure adopted is as follows: the scroll channels of the centrifuge being at a standstill are filled with the pasty material and the machine is slowly brought up to the required speed. During run-up and after the desired constant speed has been reached, the sludge flows helically from the small radius end to the large radius end until the shear stress falls below the yield value τ_o (compare Fig. 9). In this state of equilibrium, the highest possible sludge levels have been reached. The yield value τ_o for the respective paste can be calculated by substituting the measured sludge heights into equation (17). In order to compare the theoretical findings with the experimental results, the calculated yield value τ_o is compared with the value obtained on a special rheometer |2|. Fig. 13 shows the relation between the yield value and the moisture content of the sludge.

It can be seen that the caluclated τ_o values are higher than those measured with the rheometer. In addition, the values for the fine pitch scroll are higher than those for the coarse pitch scroll.

The assumption that the wall influences affecting helical backflow are negligible is confirmed, given that (G-b) >> h.

In the case of fine pitch scroll and especially at low speeds where the height h is large, the wall influences are certainly significant. This is due to the fact that higher values for τ_o were obtained with the fine pitch scroll than with the coarse pitch scroll. The size measured and used for determining the yield value was h_m (see Fig. 14).

In order to take into account the influence of the side walls, h_m was substituted by the formula

$$h_H = \frac{h_1 \cdot (G-b) + \frac{h_2 (G-b)}{2}}{2\,h_1 + h_2 + \frac{(G-b)}{\cos\beta}} \tag{18}$$

in equation (17), whereby h_H is to be understood as an equivalent hydraulic diameter.

Given

$$h_m = \frac{2\,h_1 + h_2}{2}$$

equation (18) becomes

$$h_H = \frac{(G-b) \cdot h_m \cdot \cos\beta}{(G-b) + 2\,h_m \cdot \cos\beta} \tag{19}$$

and equation (17) finally becomes

$$\tau_o = 4 \cdot \pi^2 \cdot n_H^2 \cdot R \cdot \sin\delta \cdot \bar{\rho} \cdot \left[\frac{(G-b) \cdot h_m \cdot \cos\beta}{(G-b) + 2\,h_m \cdot \cos\beta} \right] \tag{20}$$

If the τ_o calculated using formula (20) are plotted against the moisture content RF, it can be seen that the values for the fine pitch scroll correspond with those of the coarse pitch scroll (Fig. 15). Comparison with the rheometer values also shows a high degree of agreement.

The fact that the τ_o values between rheometer and centrifuge diverge to such an extent is due to sludge sliding on the channel bottom or channel walls in the lower moisture content range |2|. Tests are currently being carried out in our institute to determine the yield value τ_o and the slip limit τ_1 of kaolin sludges over a range of different moisture content levels and for different degrees of wall roughness.

FUTURE PROSPECTS

The investigations described here are the partial results of a research project on the problems associated with conveying pasty materials in decanters with which the authors have been occupied for some time.

The construction of two special centrifuges enabled the flow behaviour of different materials in the centrifugal field to be observed directly and optically recorded for the first time.

They have the additional advantage that the parameters which influence the backflow can be easily varied. The influence of these parameters can be quantified by calculation backed up by experiment, therby obtaining information on scale-up factors.

By working out a complete transport calculation, the backflow effect in decanters can be assessed in quantitative terms. This should make it possible to predict the transport behaviour of the sludge once its rheological properties are known and to devise ways of influencing this positively.

EXPRESSIONS OF THANKS

Our thanks are due to the German Society for the Advancement of Scientific Research who provided financial support for the project and to the firm, Westfalia Separator AG who supplied the test equipment.

KEY TO FORMULAE

b	Blade thickness
C	C-value, g-factor
g	Acceleration due to gravity
G	Pitch
h	Level of accumulated sludge
n_H	Main speed
n_{Diff}	Differential speed
R_a	Bowl radius
R_i	Scroll radius
s	Clearance
u, v	Speed components for the x and y axes
$\dot{V}_{KS}$	Backflow volume in the channel
$\dot{V}_{RS}$	Backflow volume through the clearance
α	Scroll pitch angle
β	Cone angle
δ	Channel angle

η	Dynamic viscosity
ρ	Density
τ_o	Yield value
τ_{xx}, τ_{yy}	Normal stress for the x and y axes
τ_{zx}, τ_{zy}	Shear stress for the x and y axes
ω_a	Angular velocity of the rotor
ω_i	Angular velocity of the scroll

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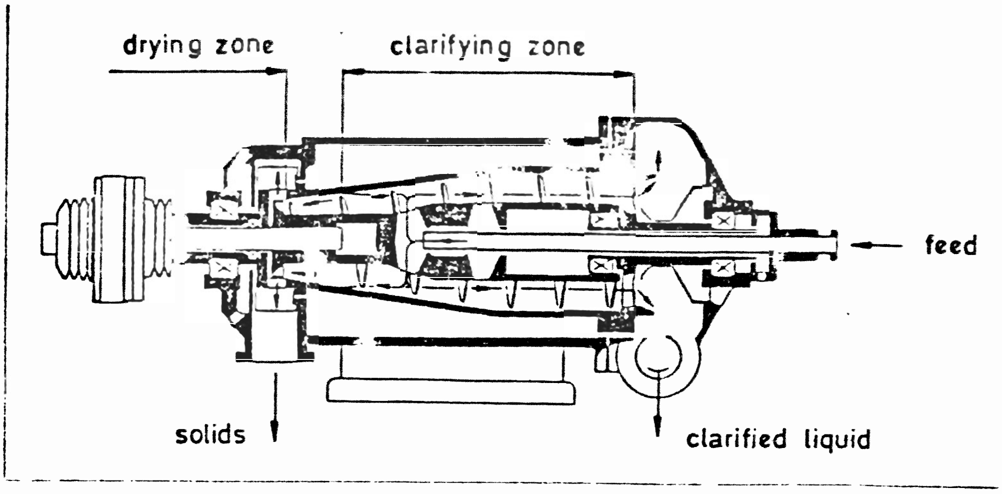

Fig.1: Operating principles of a centrifugal decanter (counter-current principle)

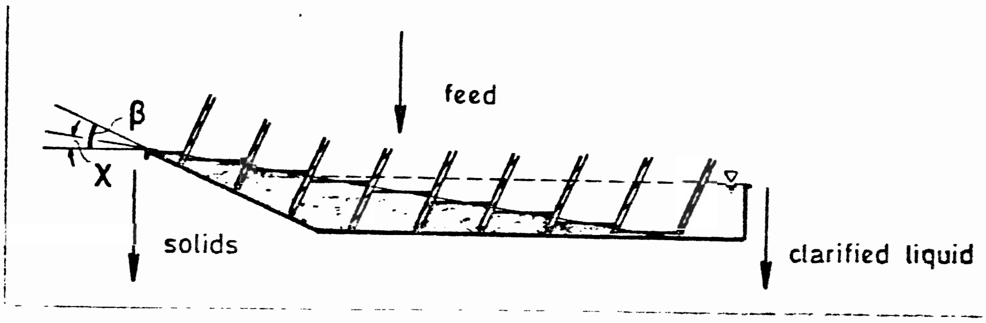

Fig.2: Diagrammatic illustration of the backflow in the decanter

Fig.3: Sludge backflow in a dismantled decanter
(During removal of the scroll, the deposited solids as well as the base layer are scraped off by the reverse face of the scroll blades. The formation of the solids deposits is therefore not an accurate reflection of the conditions during operation. In the area of the inlet zone near the transition from cylinder to cone the not yet concentrated sludge has dripped off into the tub below).

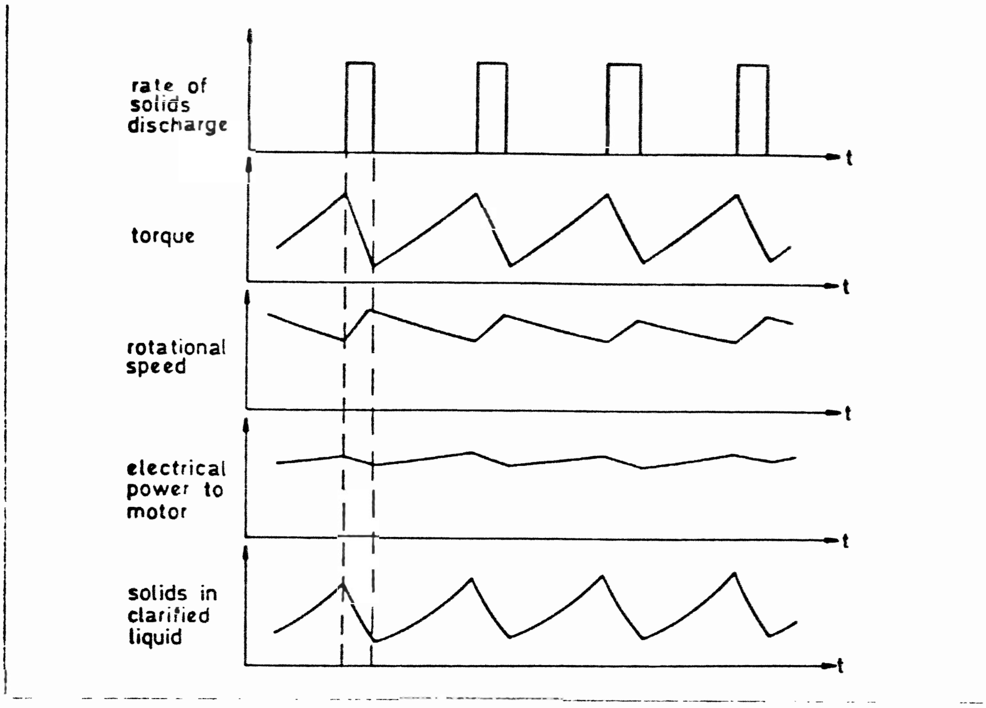

Fig. 4: Qualitative illustration of the typical phenomena during decanter operation

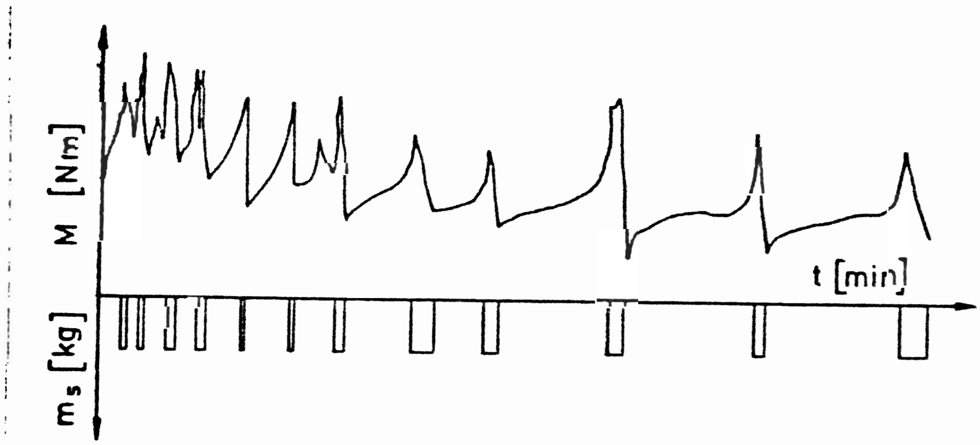

Fig. 5: Graph showing the scroll torque and the solids discharge over the time (g-factor = 3200, $\dot{m}_{s,feed}$ = 320 kg/h)

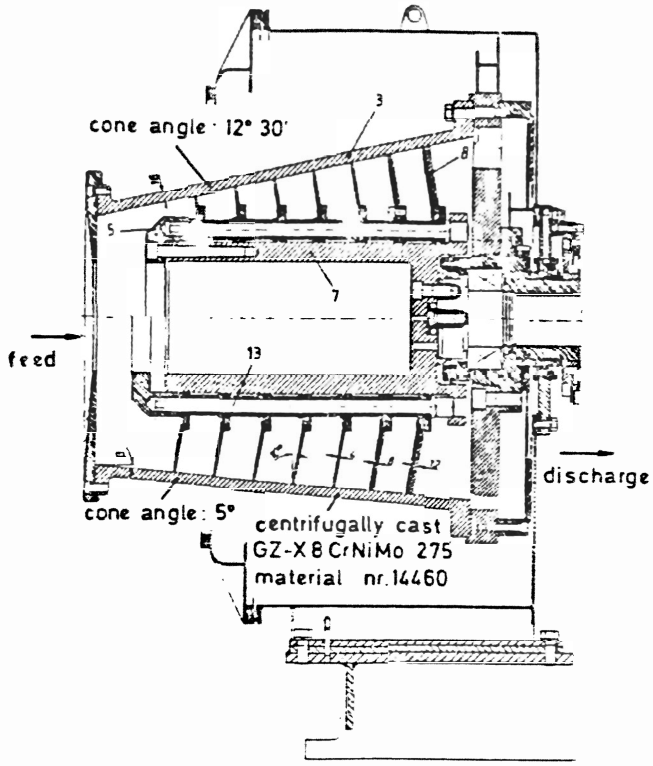

Fig. 6: Cross-section through the test machine for investigating backflow

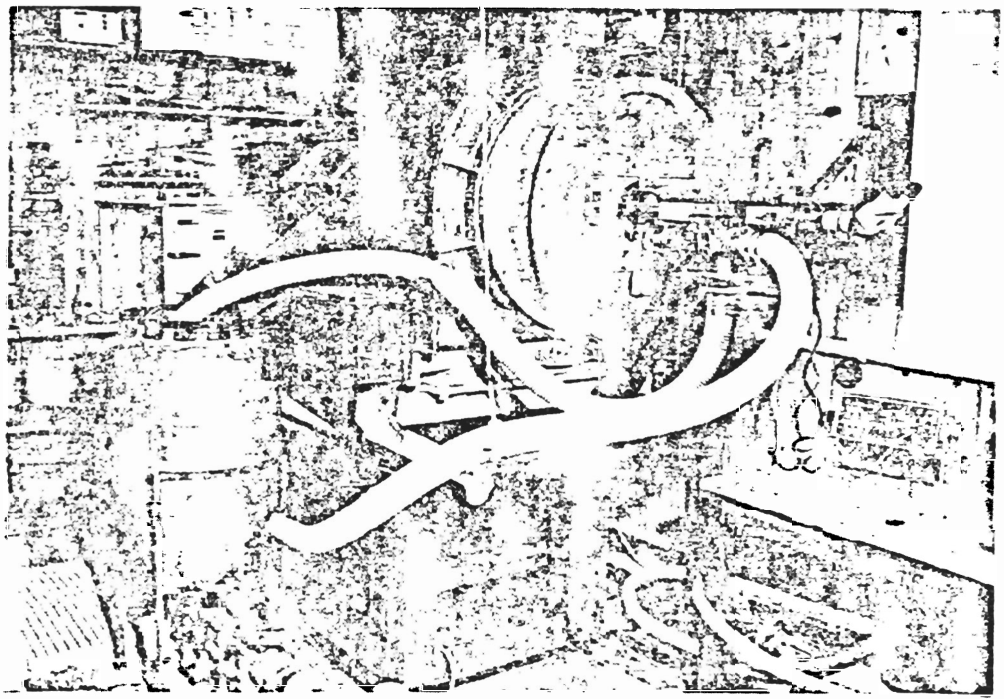

Fig. 7: Test equipment for investigating the backflow through the clearance

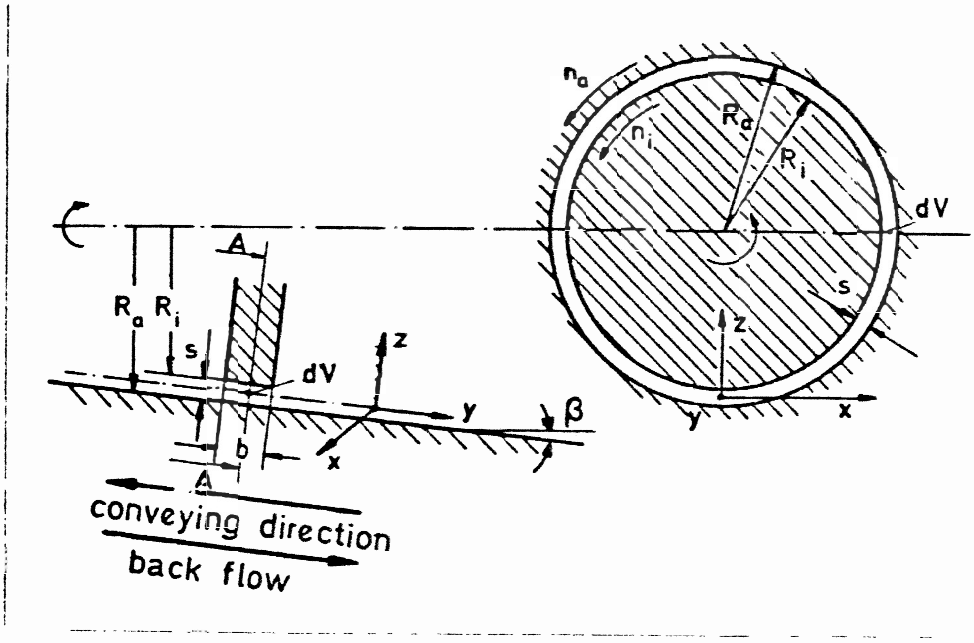

Fig. 8: The flow conditions in the clearance between scroll blade and cone wall

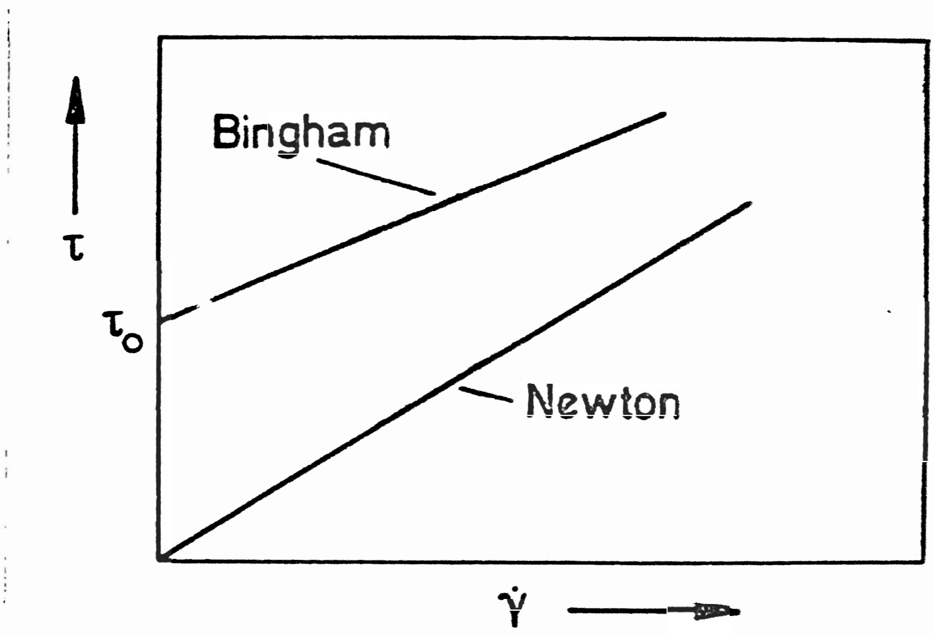

Fig. 9: Diagram illustrating the flow curves for Bingham and Newtonian media

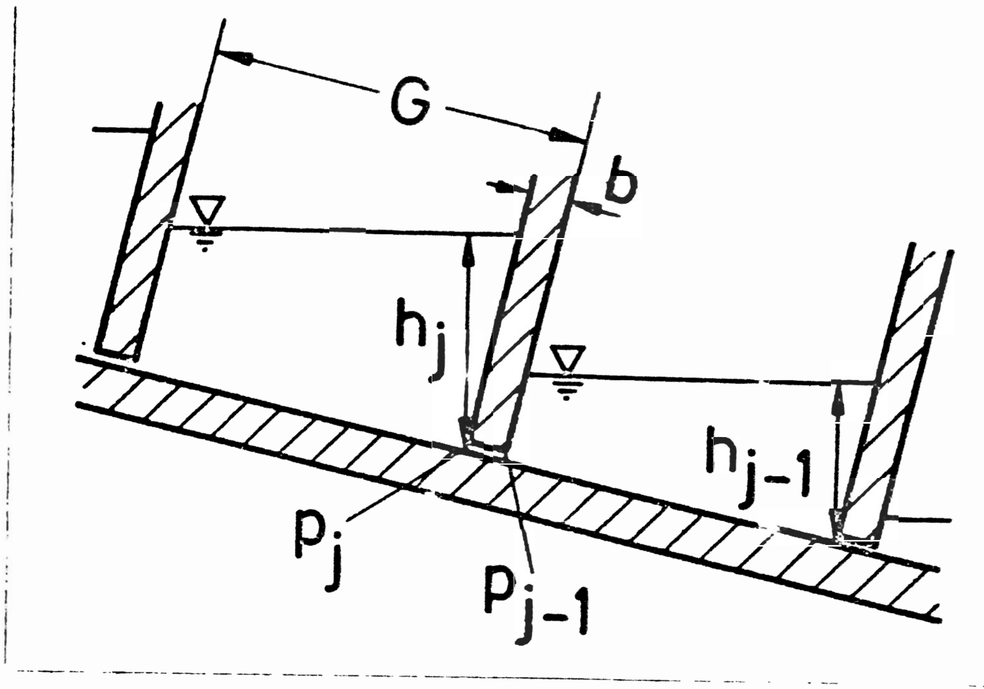

Fig. 10: Backflow in the cone

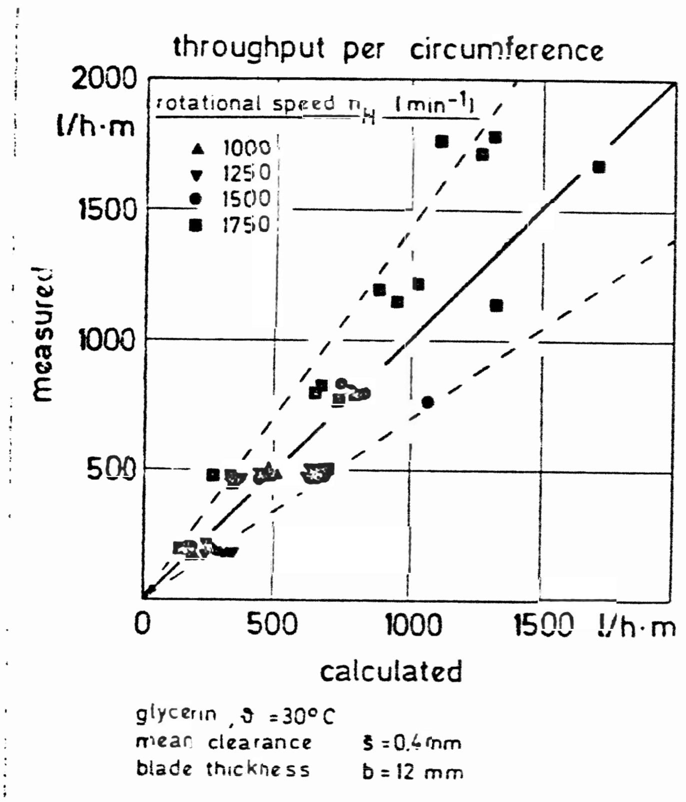

Fig. 11: Comparison between the calculated backflow volumes and the measured throughput of the pump

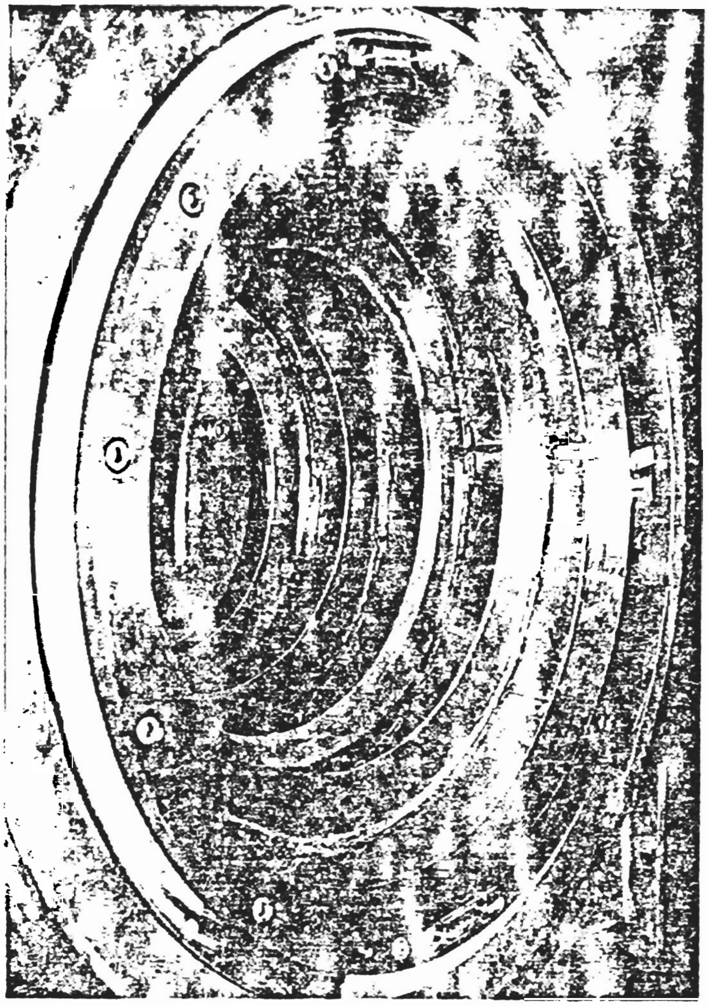

Fig. 12: Test equipment for investigating the sludge backflow in the direction of the scroll channel

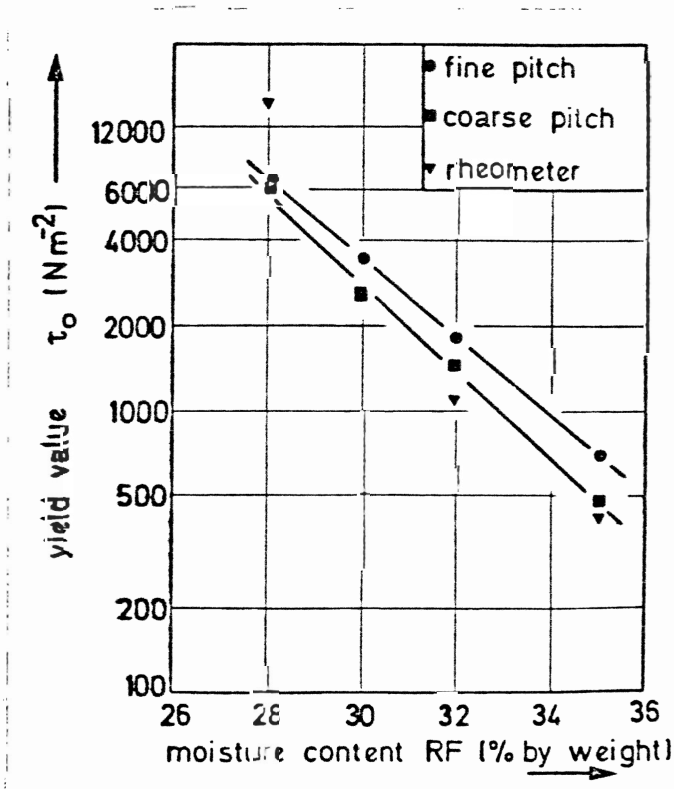

Fig. 13: The yield value τ_o as a function of the moisture content RF of the kaolin sludge

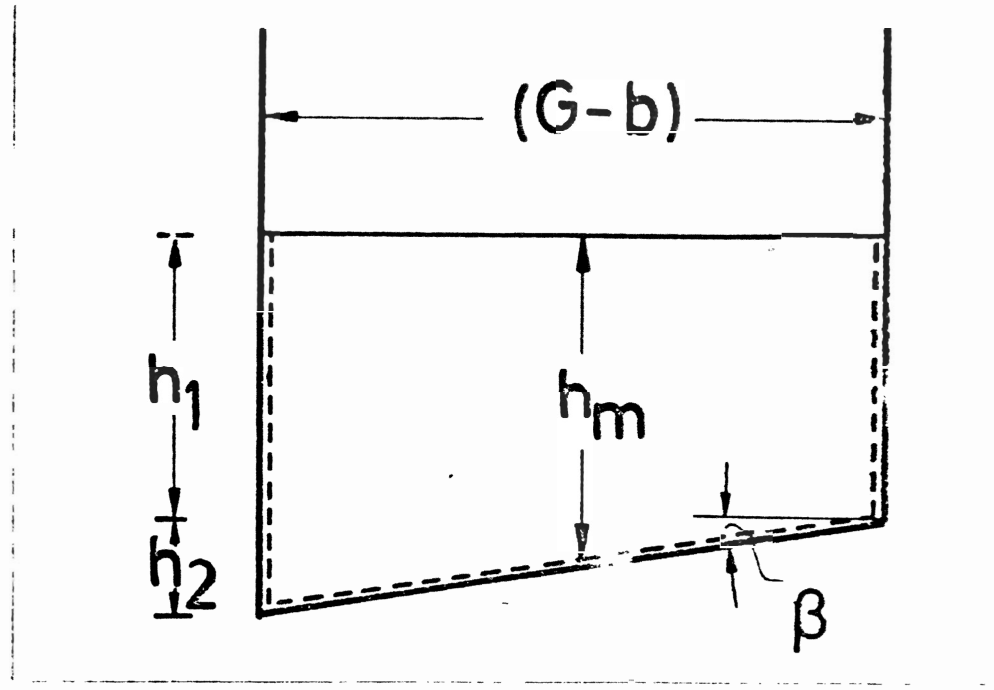

Fig. 14: Inclined scroll channel (geometric conditions)

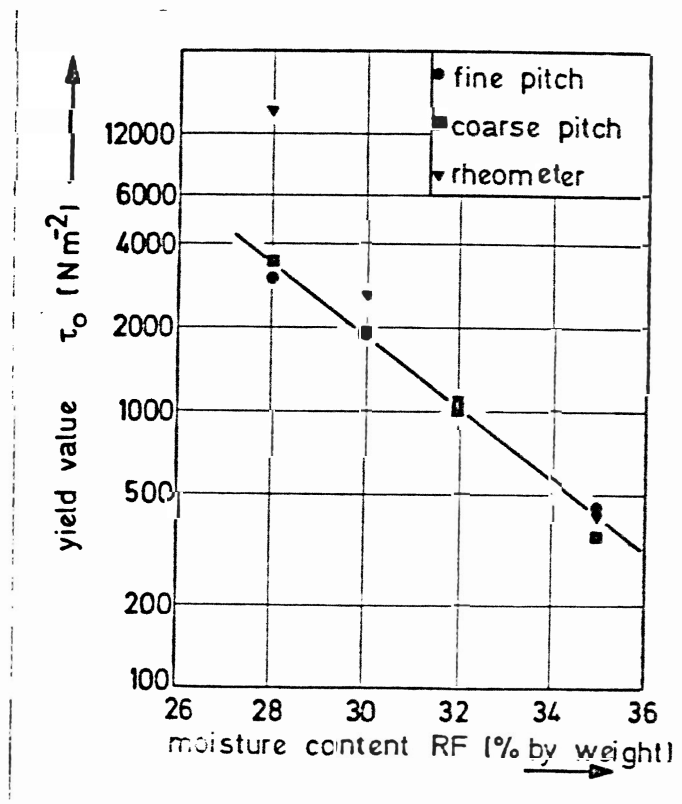

Fig. 15: τ_o values for different moisture content levels calculated using equation (20)