| Rudarsko-geološko-naftni zbornik | Vol. 7 | str. 71-75 | Zagreb, 1995. |
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UDC 622.755:622.244.442

*Izvorni znanstveni članak*

*The project "Theory and applications of the hydrocyclone classifier" financed by Ministry of Science and Technology of the Republic of Croatia*

# POSSIBILITIES OF THE EFFICIENT SOLID-LIQUID SEPARATION IN THE HYDROCYCLONE OF 25 mm DIAMETER

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**Key-words**: Hydrocyclone, Solid-liquid separation, Driling mud

The hydrocyclone, of 25 mm diameter has been tested on the laboratory hydrocyclonic device. There have been varied the values of relationship between $D_u/D_o$, the concentration of feed suspension and the greatness of pressure. With the suspension of fine grindeed limestone and water there have been examined 36 combinations of various values for the mentioned variables. The optimal efficiency of the liquid in overflow has been achieved by the relationship $D_u/D_o=0.73$ ranging from 70...80 % with the concentration of the solids in overflow from 0.3...1.5 % and cut size of 0.004...0.006 mm. There have been shown three schemes of separation of drilling fluids proposing the application of multicyclones instead of centrifuges in the final phase of cleaning the fluids.

**Ključne riječi:** Hidrociklon, Separacija krute i tekuće faze, Isplaka

Na laboratorijskom hidrociklonskom uređaju ispitan je hidrociklon promjera 25 mm. Varirane su vrijednosti odnosa $D_u/D_o$, koncentracija ulazne suspenzije, te veličina tlaka. Sa suspenzijom fino mljevenog vapnenca i vode ispitano je 36 kombinacija za različite vrijednosti spomenutih varijabli. Optimalno iskorištenje tekuće faze u prelivu postiže se pri odnosu $D_u/D_o=0.73$ i kreće se od 70 do 80 % uz koncentraciju čvrste faze u prelivu od 0.3 do 1.5 % i veličinu reza od 0.004 do 0.006 mm. Prikazane su tri sheme separiranja bušačkih isplaka u kojima se predlaže uporaba multiciklona umjesto centrifuga u završnoj fazi čišćenja isplaka.

## Introduction

Hydrocyclone is a very simple and efficient device by means of which the separation of solids from suspension is obtained as the result of centrifugal force in spiralal flow of the fluid.

In oil industry hydrocyclone is used for cleaning the fluid from drilled solid particles. Successful cleaning of fluids is particulary important in soft rocks with rapid advance of drilling. Mainly it is a question of uncemented deposits what results in greater quantity of solid particles than they were really drilled. Frequently, these solid particles have size which permits their efficient separation by means of a hydrocyclone (Y o u n g, 1987; M u v r i n and S a l o p e k, 1992). In practice, hidrocyclones of 6 inches diameter (152 mm) have been applied, so called desanders, and hydrocyclones of 4 inches diameter (102 mm), so called desilters. In this way a lower limit of the size of separated particles, i.e. 0.015...0.02 mm has been achieved. For the separation of finer particles the centrifuges have been used by maens of which, theoretically, particles up to 0.002 mm can be separated. Introducing into the equipment for cleaning the fluid from the hydrocyclone of smaller diameter, a lower limit of separation might be decreased what would make possible to reduce a number of centrifuges of their diameter. Therefore, the possibilities of separating solid particles from the suspension in the hydrocyclone of 1 inch (25 mm) diameter have been examined.

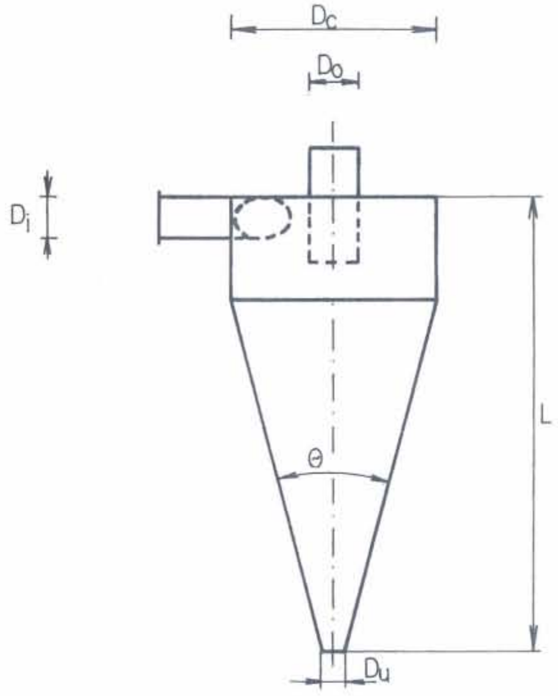


Fig. 1. Schematic diagram of the hydrocyclone with basic dimensional variables
$D_c$ ... cyclone diameter
$D_i$ ... inlet finder diameter
$D_o$ ... vortex finder diameter (overflow)
$D_u$ ... apex finder diameter (underflow)
L ... total lenght of cyclone
$\theta$ ... cone included angle

## Description of hydrocyclone

In spite of its simple construction, an entire description of the function of a hydrocyclone is complex due to a great number of geometrical variables whose influence on its efficiency has not been sufficiently examined (Fig. 1).

Cylindrical and conical part of the hydrocyclone jointly make a separation area. As there are no rotating parts the necessary vortex is produced by pumping the suspension tangentially, under pressure. Geometry of the hydrocyclone and the relative sizes of the outlet orifices cause that the greatest part of water as well as the part of the smallest particles go out as overflow from the device at the orifice on the upper side (vortex), while solid particles with a less part of water go out like an underflow through circular orifice on the bottom of the conus (apex).

The efficiency of the hydrocyclone is evaluated by means of the following indicators:

- total separation efficiency, $E_T$
- grade separation efficiency, $E_{a(i)}$
- cut size, $d_{50}$

Total efficiency is obtained as the ratio of mass percentage of the solids in underflow and feed:

$E_T$ = (razlomak) $$E_T = \frac{Mc}{M} \quad (1)$$

$M_c$ ... mass flowrate of solids in underflow, kg/s

M ... mass flowrate of solids in feed, kg/s

Grade separation efficiency is defined as the recowery of solids in underflow in relationship to the feed for a determined particle size $d_i$:

$E_{a(i)}$= (razlomak) $$E_{a(i)} = \frac{M_c \ W_{u(i)}}{M \ W_{(i)}} \quad (2)$$

$W_{u(i)}$ ... concentration of particles of size $d_i$ in underflow, %

$W_u$ ... concentracion of particles of size $d_i$ in feed, %

Values of the grade efficiency have a character of probability and represent a series of values of 1.0 approx. for solid particles, till 0.0 approx. for fine particles. Graphical description of these values is called *Tromp curve* or grade efficiency curve (partition probability curve) (Fig. 2).

Cut size $d_{50}$ is that size of particles whose probability of separation in underflow is equal to the probability of being drawn into overflow together with liquid, i.e. 0.5.

The section mede by the Tromp curve on the ordinate is attributed to the so called short circuit (by-pass). Numely, a certain quantity of solids entering the hydrocyclone pass through the device in a way that they avoid classification and finish into underflow.

K e l l s a l (1952) asserted that the quantity of particles in short circuit is directly proportional to the part of water, $R_f$, which is separated in underflow, for a unit volume of the feed suspension. It is presumed that the same part of each particle size $d_i$, proportional to $R_f$ ends into underflow without classification. In this way, the concept of corrected grade efficiency $E_{c(i)}$ has been introduced what represents the value of grade efficiency $E_{a(i)}$ corrected for the amount of short-circuit of the solids in underflow caused by fluid flow (B r a d l e y, 1958).

The value of the corrected grade efficiency, and hence the corrected Tromp curve is obtained according to the expression:

$E_{c(i)}$= $$E_{c(i)} = \frac{E_{a(i)} - R_f}{1 - R_f} \quad (3)$$

and $R_f$ is calculated on the basis of measuring flowrate of the overflow and underfow. From the Fig. 2 it seen that the corrected curve has been shifted to the right, and hence the corrected $d_{50c}$ is greater than a real one.

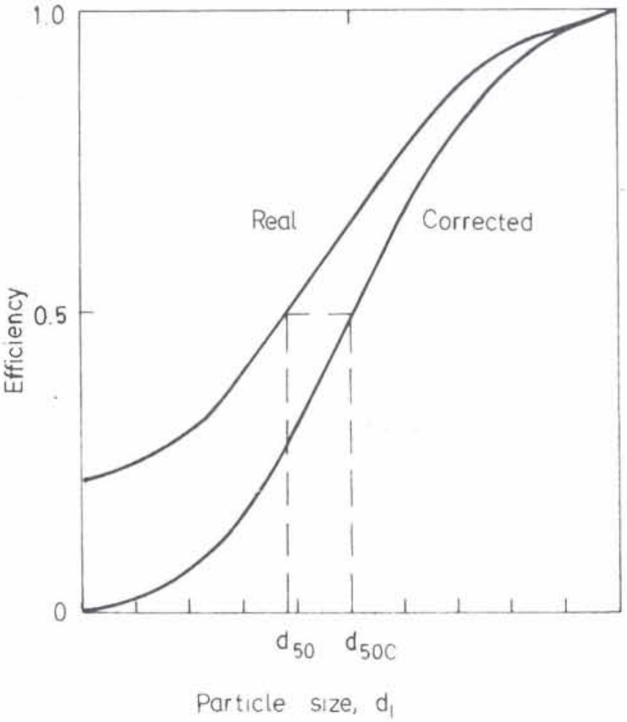


Fig. 2. Tromp curve

**Experimental work**

Experimental work has been performed on the laboratory device with the hydrocyclone of 25 mm diameter. It was designed in a way that size of the vortex and apex and with this their relationship could be modified. Four ratios of $D_u/D_o$ have been taken, i.e. 0.21; 0.46; 0.73; and 1.06. Suspension has been made from water and fine grindeed limestone, particle size from 0.002...0.1 mm in the concentration of 5; 10; and 18 %. In the work the pressures of 180; 250 and 400 kPa have been applied. Totally, there have been examined 36 combinations of the mentioned variables and 90 tests performed (F i l i p o v i ć, 1992; K r a s i ć and F i l i p o v i ć, 1992). The device Particle Sizer 3600 E of the firm "Malvern" has been used for working out grano-analyses, with measurements in the extent from 0.0005--0.564 mm. For each test there have been performed grano-analyses of the overflow and underflow, the value of $d_{50}$ defined and estimated the values of the capacity and concentration of the solids at the inlet and outlet of the hydrocyclone on the basis of measured flowrate in the vortex and apex.

## Analysis of the results

The regime of the hydrocyclone work is in large part regulated by the size of the apex and vortex, by their ratio. If the apex is extremely wide, almost all the flowrate is carried out through the apex and the underflow suspesion is nearly identical to the feed suspension. As the apex is being reduced, the underflow becomes more dense (Fig. 3), but total quantity of the separated solids is being slowly decreased. When the suspension becomes too dense, more and greater part of the solids go to the overflow, what represents an undesirable effect.

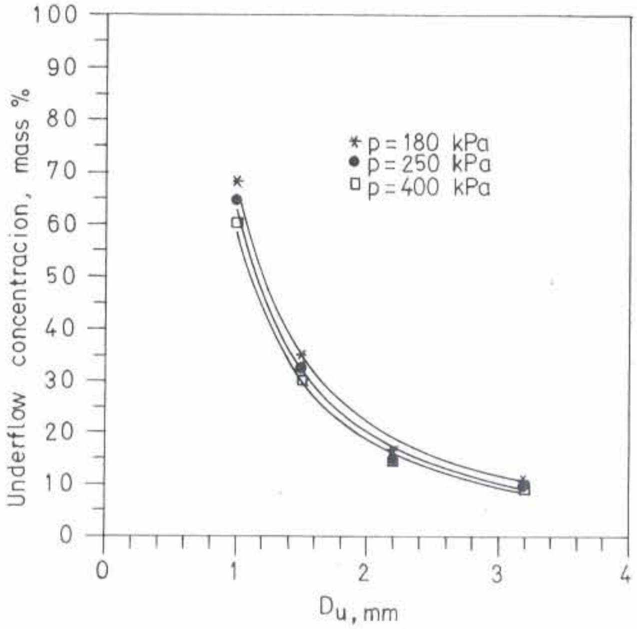


Fig. 3. The effect of the changed apex size on the concentration of the underflow for various values of pressure

The quantity of water separated in the apex $R_f$ essentially effected by the ratio of the apex and vortex size. By increasing that relation, $R_f$ is being also increased for 3-50 and more percentages (Fig. 4). It is desirable to have $R_f$ as small as possible, as by this a greater part of water is being separated in the overflow.

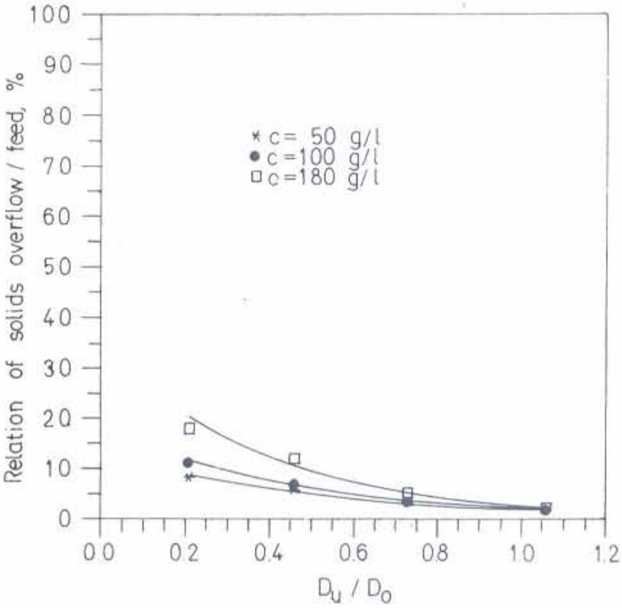


Fig. 5. The effect of the $D_u/D_o$ ratio on the quantity of separated solids for various concentration of feed suspension

In the procedure of separating solids - liquid, the aim is to achieve as much as possible clean overflow, what means that separation of the solids in overflow

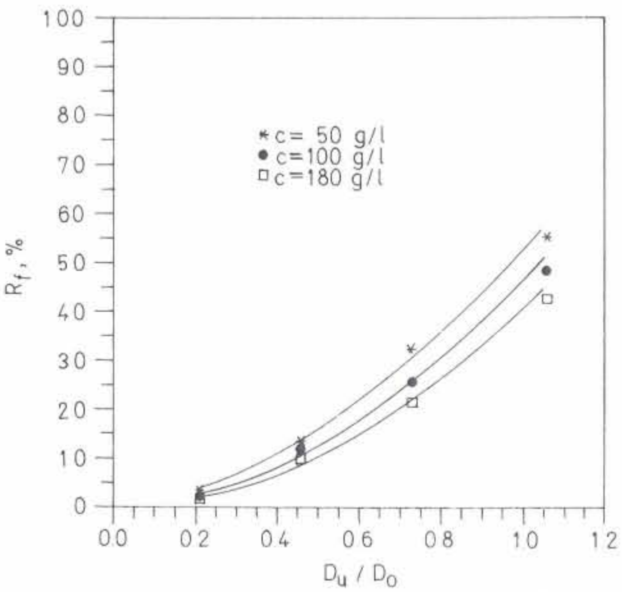


Fig. 4. The effect of the $D_u/D_o$ ratio on the quantity of water separated in underflow for various concentrations of feed suspension

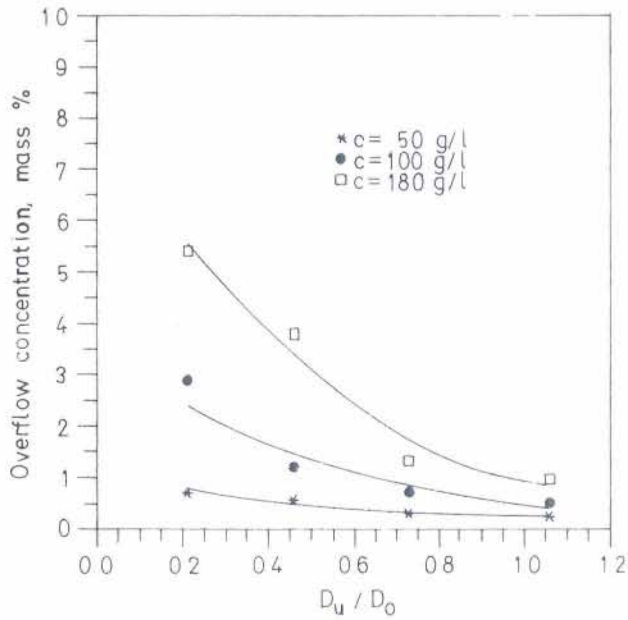


Fig. 6. The effect of the ratio $D_u/D_o$ on the concentration of overflow, for various concentrations of feed suspension

is to be reduced to the least degree. It is obtained by increasing the ratio $D_u/D_o$ (Fig. 5).

The concentration of the overflow is the most relevant indicator of the overflow cleanness. The greater ratio of $D_u/D_o$, the less concentration (Fig. 6). Herewith, the concentration of the feed suspension becomes significant as, under the same conditions, lower concentrtation of the feed gives much lower concentration of the overflow.

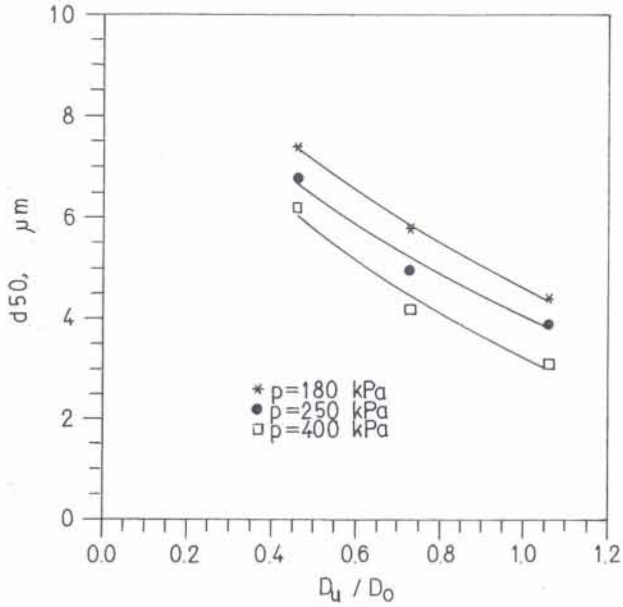


Fig. 7. Change of cut size $d_{50}$ with the change of $D_u/D_o$ ratio for various values of pressure

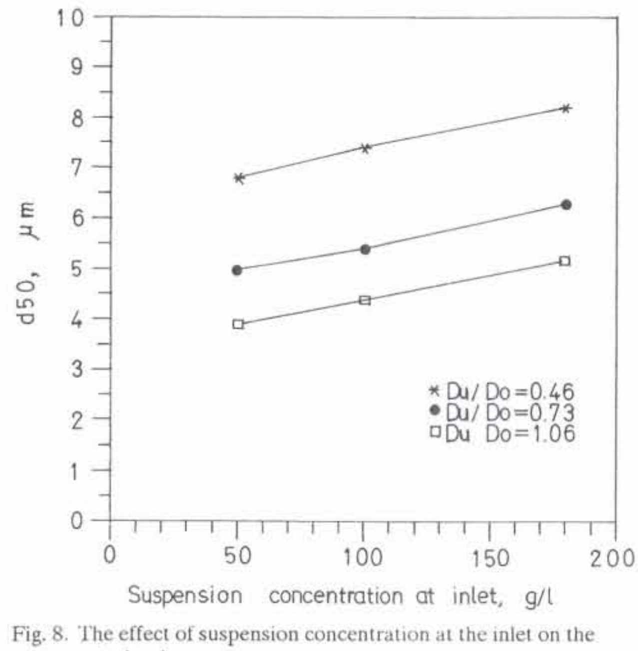


Fig. 8. The effect of suspension concentration at the inlet on the cut size $d_{50}$

The cut size $d_{50}$ is decreased by increasing the ratio $D_u/D_o$, as well as by increasing the pressure. At the same time, the increase of the suspension concentation at the inlet gives rise to the increase of $d_{50}$ (Figs. 7 and 8).

From the obtained results it is seen that the cleanest overflow has been achieved at the ratio $D_u/D_o$=1.06, when the least quantity of the solids has been separated in the overfow. At the same time, however, the quatity of water separated in overflow is the least, ranging from 40...50 % approx. Therefore it is proposed to perform separation at the ratio of $D_u/D_o$=0.73 by which the recowery of the liquid in overflow has been achieved by 70...80 %, with the concentration of the solids in overflow from 0.3...1.5 % and the cut size $d_{50}$ of 0.004...0.006 mm.

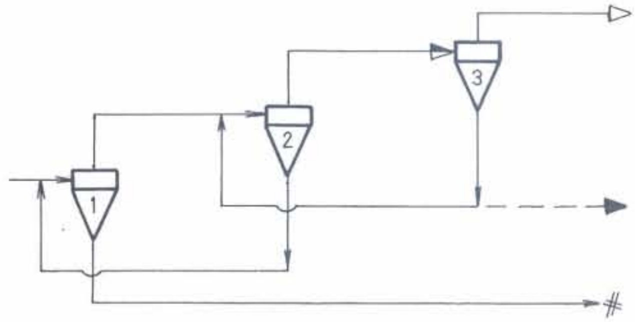

Fig. 9. Scheme of separation with maximal liquid recowery
1 ... desander
2 ... desilter
3 ... multicyclone
overflow
underflow
feed
# waste

**Proposed schemes of separation**

For the separation of the solids and liquid from the drilled fluids by means of the hydrocyclone of 25 mm diameter, the three schemes have been proposed, depending on what is wished to be achieved by separation.

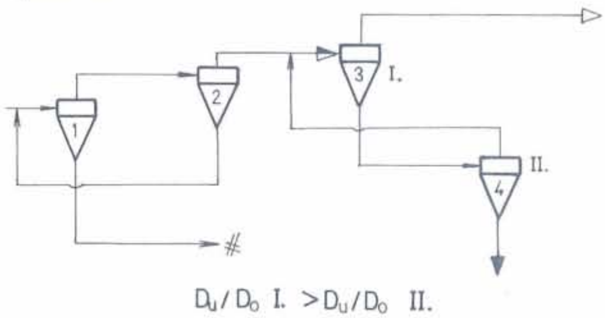


Fig. 10. Scheme of separation with maximal density of underflow
1 ... desander
2 ... desilter
3 ... multicyclones I.
4 ... multicyclones II.
overflow
underflow
feed
# waste

According to the Fig. 9, the maximal recowery of the liquid in overflow has been achieved in the way that the overflow of desilter is introduced into so called multicyclonic arrangement, where 10...20 hydrocyclones of the same geometric variables have been parallelly connected in one unit. Overflow goes into operation while underflow goes back to the feed entry of desilter.

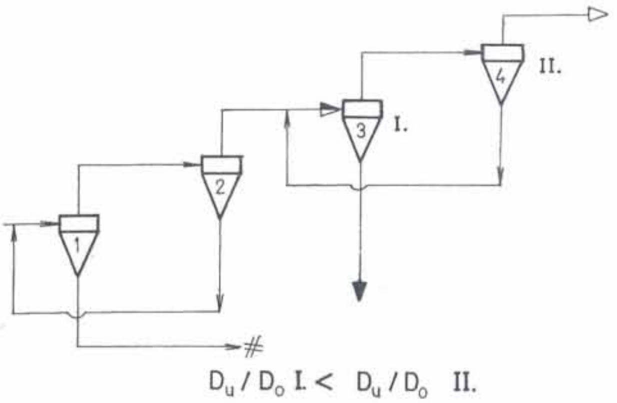


Fig. 11. Scheme of separation with maximal cleanness of the overflow

1 ... desander
2 ... desilter
3 ... multicyclones I.
4 ... multicyclone II.

overflow
underflow
feed
\# waste

The Fig. 10 shows the scheme which makes possible to get maximally dense underfow, so that the first stage of the multicyclone works with greater ratio of $D_u/D_o$ and the second stage with smaller one. Here the overflow of the desilter has been brought into the first stage of the multicyclone, where the overflow is separated, while the underfolw goes to the second stage of the multicyclone where the underflow is separated. The overflow of the second stage goes back to the feed entry of the first stage of the multicyclone.

By means of the scheme shown on the Fig. 11 the maximal cleanness of the overflow has been obtained. Hereby are also two stages of multicyclones, the first one with the smaller ratio of $D_u/D_o$, and the other one with greater one. The overflow of desander enters the first stage of the multicyclone where the underflow is separated, while the overflow is carried on into the second stage of the multicyclone; in it the overflow goes back to operation while the underflow is carried out to the feed entry of the first stage of the multicyclone.

In cases when baryte is used for the preparation of fluid, its largest part will be separated in the underflows of the multicyclone. The scheme on the Fig. 9 makes also possible the separation of baryte, but then the underflow of the multicyclone doesn't go back to the feed entry of the desilter.

### Conclusion

Hydrocyclone of 25 mm diameter can be successfully applied in the solid-liquid separation of fine suspensions and thus substitute centrifuges in the process of regeneration of drilling fluids.

Optimal results have been obtained with the ratio $D_u/D_o$=0.73 by which, depending on the concentration of feed suspension and the pressure, the recowery of the liquid in amount of 70-80 % has been achieved, with the contents of the solids in overflow from 0.3-1.3 % and the cut size $d_{50}$ from 0.004...0.006 mm.

Proposed schemes make possible to obtain in one or two stages of separation, depending on the required and aimed values, maximal recowery of the liquid in overflow, i.e. maximal density of underflow or cleanness of overflow. There are, of course, possible other combinations, not only with number and size of the hydrocyclones, but with the other operational and geometrical variables, depending on grano-size and other physical-chemical characteristics of the drilling fluid as well as on the results wanted to be obtained by separation.

### Acknowledgements

The autors wish to acknowledge Ms. Branka Vranješević from the INA-Naftaplin Co. for having mode the particle-size analysis of the fest samples.

*Received: 15.III.1995.*
*Accepted: 20.VI.1995.*

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