DESIGN OF CENTRIFUGAL HYDRAULIC CLASSIFIERS BASED ON HYDRODYNAMIC SIMILITUDE

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ABSTRACT. Today, the hydrocyclon design starts from some technological parameters and empirical calculus relations. The present paper offers a few mathematical models by hydrodynamic similitude, based on experimental research (at laboratory scale) of quartziferous sands. Based on laboratory results, on the correlations between the hydrodynamic and construction parameters, it was carried out a hydrocyclon to the industrial scale. This new type of hydrocyclon was tested to the quartziferous ores from the Faget-Timisoara processing plant.

ПРОЕКТИРАНЕ НА ЦЕНТРОБЕЖНИ ХИДРАВЛИЧНИ КЛАСИФИКАТОРИ НА БАЗАТА НА ХИДРОДИНАМИЧНА СИМУЛАЦИЯ

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РЕЗЮМЕ. В съвременни условия проектирането на хидроциклони се осъществява при наличието на няколко технологични параметри и емпирично изчислени зависимости. Представения доклад предлага няколко математически модели на хидродинамична симулация, базирайки се на експериментални изследвания (за лабораторен модел), на кварцови пясъци, съдържащи желязо. На базата на лабораторните резултати и установени корелации между хидродинамичните и конструктивни параметри, бе създаден хидроциклон до индустриални размери. Този нов тип хидроциклон беше тестван в обогатителната фабрика на Тимишоара при обогатяването на кварц-желязо съдържащи руди.

1. MANUFACTURE AND HYDRODYNAMICS OF ADDITIONAL WATER FLOW HYDROCYCLON

The special role the hydrocyclon plays in the field of useful mineral substances processing and within the related industries arises from its multilateral usage. This equipment can be used either for classification, thickening, slime pulp de-sludging and finally as concentration equipment.

The additional water flow hydrocyclon (see fig. no 1) consists of one relatively high cylindrical part (1) where the raw slime pulp is fed in by means of a feeding pipe (2) placed tangent to the cylindrical part.

At the bottom of cylindrical part certain concentric cones (3) are placed, which are tangentially fed with an additional water flow by means of the inlet pipe connections (4) placed at the same level with the free spaces between the above mentioned cones.

At the moment when the rotary downward slime pulp flow gets into the concentric cones area, named washing area, the rotary additional water flow interferes with this one involving the following:

- an increase of particles’ tangential motion velocity; this fact brings about an increase of the centrifugal force;
- an increase of dilution which involves a better washing of the fines in the centrifuged material layer and a better aerated re-stratification depending on the sizes;
- driving of slime pulp containing small size particles - onto the hydrocyclon axis, this phenomenon being also favoured by the conic shape of the elements within the washing area.

The slime pulp containing mainly large size particles continues its downward motion, arriving into the lower cylindrical part (5) having larger diameter but lower height which is followed by a conical part (6); these elements can be easily assimilated both in manufacture and operation process with a classical hydrocyclon.

The radius fracture involved by the lower cylindrical part leads to a new re-stratification and re-arrangement of the material on size basis, having as final effect a reduction of under-size grains quantity, and implicitly an increase of classification efficiency.

Close to the cone point, a part of downward slime pulp flow changes its motion direction and it is forming an upward helical flow current which is overlapping over the existing upward flow current within the washing area.

155
calculations.

The equivalent diameter 

reason the equivalent diameter 

overflowing outlet pipe 

diameter of feeding inlet pipe 

diameter of upper cylindrical part 

characteristics:

additional water flow hydrocyclon having the following 

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hydrodynamic characteristics – on the other hand - a set of 14 

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of new additional water flow hydrocyclon allows utilisation of 

drives them to the siphon tube (9).

More over, in comparison with the conventional hydrocyclon, 

the new additional water flow hydrocyclon allows utilisation of 
certain simple and flexible methods for controlling the sizing 

process, it can be easily automatized and makes the sizing 

process be more accurate in accordance with the requirements 
of modern engineering concerning the processing of mineral 

resources.

The disadvantages consisting of more complicated 

construction and additional water consumption are 

compensated by the special results obtained with this 

equipment.

With the aim of improving the sizing efficiencies, and, 
especially, the uniformity rate of the products obtained at Faget – Timis siliceous sand processing plant on one hand and with 
the aim of establishing the interdependences between the 
sizing results and the hydrocyclon constructive and 
hydrodynamic characteristics – on the other hand - a set of 14 
sizing tests on raw sand (grit) have been performed with an 
additional water flow hydrocyclon having the following 
characteristics:

- diameter of upper cylindrical part 

- diameter of feeding inlet pipe 

- diameter of overflowing outlet pipe 

whose values depend on the deflecting cone position. For this 
reason the equivalent diameter \( d_e \) is considered for 
calculations.

With the aim of transposition the laboratory research results 
onto industrial scale, the first step consisted in appraising the 
influence of the constructive characteristics \( d_s \) and \( d_a \) and of 
the technological characteristics (dilution "n", and additional 
water flow rate "\( q_a \)" expressed in percentages of feeding flow 
rate) upon the sizing result expressed by the separation size.

For this purpose the correlation and regression method was 
used, which, as it is very well known, not only allows 
determining the linear dependence (with good approximation) 
but also provides information regarding the intensity with which 
a variable influences the response. /1/

For a better evaluation of all these dependences, and due to 
the fact that the dependent variable is the same for all 
correlations, we proceed to the overlapping of all dependences 
onto the same diagram, (see figure no. 2).

Analyzing the figure no.2, it can be noticed the variation law 
of separation size depending on the constructive and 
technological parameters, as well as their antagonism.

While the separation size increases at the same time with the 
increase of overflow outlet pipe’s equivalent diameter, of 
feeding dilution and of additional water flow rate, it was 
registered the decreasing of the under granulation into the 
thickened product, which leads to the improvement of sizing 
efficiency. At the same time, an increasing of fines content in 
overflow is obtained; all these together lead to the increase of 
the sizing accuracy.

2. TRANSPOSITION OF LABORATORY RESEARCH 
RESULTS ONTO INDUSTRIAL SCALE

For the design of the hydrocyclon main industrial 
subassemblies based on hydrodynamic similitude, it was used 
the mathematical model called “Criterion M” within the 
specialized reference material, which establishes the 
relationship between hydrocyclon constructive parameters and 
processing flow rate.

It will be considered that two models of different dimensions 
will behave identically from hydrodynamic point of view only if 
the criterion M has the same value. /2/

\[
M = (d_2 - d_1) \times \left( \frac{(d_2^2 - d_3^2) + Q'}{Q} \right)^3
\]  

(1)

Where:

\( d_2 \) – diameter of laboratory hydrocyclon’s cylindrical part 

\( d_1 \) – diameter of laboratory hydrocyclon’s siphon pipe 

Q’ – feeding flow rate in laboratory conditions

At the same time it was taken into account the specialized 
reference material recommendation regarding the ratio 

between the feeding pipe diameter “d_s”, the siphon pipe 
diameter “d_1”, the discharging pipe diameter “d_e”, as well as the 
cylindrical part diameter at the level of feeding pipe “d_2”, 

namely:

\[ d_s = (0.4 - 1) d_e \quad d_e = (0.2 - 0.4) d_2 \]  

(2)
Under the conditions of HCCAD (additional water flow hydrocyclon) - laboratory model the value $M = 26.763$ was obtained.

For example: under the condition of a flow rate established by the beneficiary of $Q=100 \text{ m}^3/\text{h}$, for the same $M$ value, the following constructive dimensions have resulted: $d_2 = 0.400 \text{ m}$, $d_s = 0.160 \text{ m}$, and $d_a = 0.128 \text{ m}$.

The slime pulp ingoing velocity at the level of the feeding inlet pipe results from the law of continuity:

$$Q = u_a S_a,$$

from where:

$$u_a = 2.16 \text{ m/sec.}$$

In order to calculate the tangential velocity at the level of siphon pipe, it was used the relationship of Kellsal [2]:

$$u_a = \frac{u_{t2} r_2}{r_1} \left(1 + \ln \left(\frac{r_2}{r_1}\right)\right),$$

This way it was found: $u_{t1} = 2.81 \text{ m/sec}$, and $u_{t2}/u_{t1} = 1.30$.

Dynamic pressure at the siphon pipe level is:

$$P_{si} = \frac{u_a^2 \Delta \rho}{2}$$

Where:

$\Delta \rho$ – slime pulp density

Dynamic pressure considered for 250 gr/l concentration of solid phase in feed is of 4540 N/m².

The separation size achieved by the industrial hydrocyclon results from the condition of equilibrium of centrifugal forces and of forces of resistance to motion into the separation area, resulting from following relationship [2]:

$$d_p = \frac{3}{u_a} \sqrt[3]{\frac{Q \eta_s}{\pi h_i (\delta - \Delta_s)}},$$

Where:

$\eta_s$ = dynamic viscosity of slime pulp,

$$\eta_s = \eta \left(1 - c_v\right)^{25}$$

where:

$\eta$ = water viscosity, $10^{-3}$ [Ns/m²]

$c_v$ = volumetric concentration in parts of unit

$h_i$ = height of rotating fluid coaxial area at the siphon pipe area’s level

$\delta$ = solid phase density

In order to calculate the siphon pipe immersion depth, it is imposed the sizing dimension obtained for laboratory conditions, $0.2 \times 10^{-3}$ m.

Under these conditions, from relationship (8), the siphon pipe immersion depth against the upper level of feeding pipe will be of 0.22 m. Once this height value is known and using its calculus relation [2], the apical angle of hydrocyclon conical part will be obtained:

$$h_i = \frac{r_2 - r_1}{\alpha} + d_a$$

The resulted apical angle is $\alpha = 105^0$, which represent another characteristic of this type of hydrocyclon; this type of angles are met only at the thickening equipment.

Calculation of additional water inlet pipes' diameter and of water penetration tangent speed into the washing area cones'
free spaces results from the condition that the additional water rotaries flow rate dynamic pressure of should be greater than the main slime pulp flow rate. Following the above-presented algorithm it results a diameter of 30 mm for the inlet pipes and an additional water flow velocity of minimum 2.79 m/sec, to which corresponds a dynamic pressure of 3917 N/m².

Based on the above-presented theoretical principles, as well as on the similitude mathematical models and on specialized reference material recommendations was designed the additional water flow hydrocyclon HCCAD 400 presented in figure no.3.

**Conclusion**

Nowadays, for the design of sizing equipment, in general, and of hydrocyclons, especially, it is proceeded from a few technological pre-established parameters and by means of calculus relationships – which generally are of empiric type – the equipment main constructive elements are dimensioned.

In the present paper, based on a correlation and regression study it is established the influence of constructive and process parameters onto the sizing results, and further on, based on the results obtained and using for this purpose the hydrodynamic similitude mathematical models it is designed an industrial hydrocyclon type HCCAD 400 with nominal processing flow rate of 100 m³/h.

The truthfulness of this dimensioning calculation method was verified in practice at Faget – EXTRACERAM – TIMIS Quartziferous Sand Processing Plant.

**Bibliography**