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Theoretical basis of head loss definition in hydro cycle

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Abstract

One of the important issues of hydro cyclone pumping plants in the hydraulic is the definition of the specific energy loss (pressure) in the hydro cyclone. Hydro cyclone as a (thickening) unit is presented itself a short, hollow cylinder-conical tube, which is widely used almost in all industries (Figure 1). Scope of hydro cyclone's usage in recent decades is expanding faster in connection with the creating a new class of vacuum hydro cyclone pumping plants (Figure 2). The technological and economic efficiency of the vacuum hydro cyclone pumping plants is entirely dependent on the value of the specific energy loss in the classification (thickening) of slurry in hydro cyclone. Until now, theoretical definition of head loss in the hydraulic was succeeded only in a few cases: the sudden expansion of the flow in the pipeline (Borda-Carnot's theorem) and in perfect hydraulic jump. In all other cases, the head loss is determined empirically. This often makes difficulty to design new hydro cyclone pumping plants in advance. The problem is compounded by the fact that the available research results are related to the direct-flow streams, while flow is mainly swirled in hydro cyclone pumping plants. In general, all the issues related to the head loss that solutions have been found for direct-flow (axial) flows, should be reviewed from the twisted flow's perspective. The volume of work is very large and requires huge theoretical and experimental studies. In this respect, this work is only the beginning of the series of similar developments.

Keywords: hydro cyclone pumping plant, the vacuum hydro cyclone, head loss, straight-through flow, swirling flow, quasi surface.

Introduction

Hydro cyclone chamber is presented itself as a complicated pipe [1, 2]. Hydro cyclone without cover (Free-flow hydro cyclone) is combination of two cylindrical tubes (cylindrical part and sand tube) with truncated cone (confuser). The cylindrical portion with cover, comprising the outer pipe in the middle for leaving stream has sudden narrowing.

Existence of drain connection in the form of flooded inner axial pipe in cylindrical portion turns the hydro cyclone's upper half into a short circular tube. If this axial pipe reaches the mouth of the cone, the hydro cyclone presents itself as a circular pipe with a variable radius (Figure 1 and Figure 2). Sometimes drain connection is done as a diffuser and an inlet in the form of a confuser [3, 4].

Transition flow from cylindrical portion to conical is made as a narrowing of the swirling flow confusor, and if there is a near-axis longitudinal pipe, it turns into narrowing swirling flow in annular confuser. The peripherally-downdraft stream can be presented as a stream in the annular confusor with variable flow along the surface forming a quasi zero axial velocity (ZAV), while the inner rising flow-the flow in annular quasi diffuser, confined between the surface ZAV and the surface of air column.

The essence of proposed method is that the calculation of head loss in the hydro cyclone is performed on the basis of the account of fluid motion's peculiarities in the apparatus. To illustrate the argument, we introduce so-called quasi surface of zero axial velocity that separates the external near-wall flow from the inner paraxial power. It gives opportunity for separate consideration of the motion of each of streams in hydro cyclone separately, and then synthesizes them into a set to get a general idea about the mechanism of this complex movement.

As the length of drain connection is equal to the height of the cylindrical part, in the latter, fluid movement should be considered as the swirling movement between two coaxial cylindrical tubes. This stream, passing into the conical part of the apparatus, moves both toward sand hole and a discharge side with variable costs along the way as well.

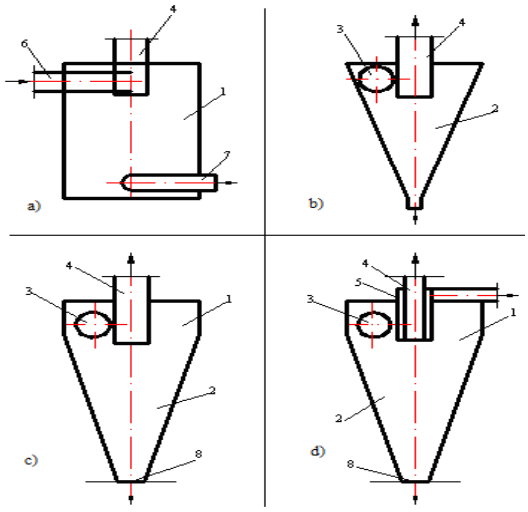

Figure 1: Hydro cyclones a-cylindrical; b-conic ; c-cylinder conical, two product; d-cylinder conical, three product, 1-cylindrical part; 2-conical part; 3-inlet pole; 4-drain nozzle; 5-nozzle for the second outflow; 6-inlet nozzle; 7-sandy nozzle; 8-sandy pole.

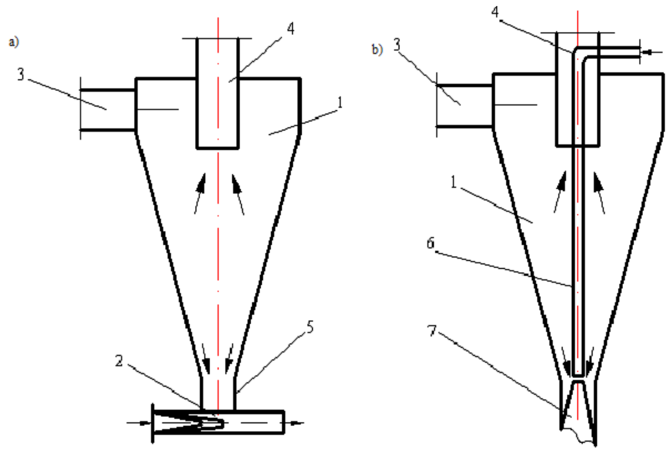

Figure 2: Vacuum hydro cyclones a) with transversal hydro elevator; b) with axial hydro elevator; 1-corpus of hydro cyclone; 2-hydro elevator; 3-inlet nozzle; 4-drain nozzle; 5-sandy pole ; 6-axial pressure pipe; 7-sandy nozzle (chamber of hydro elevator mixing)

This exterior, trim stream is located between the cone's parries and quasi surface of ZAV and an inner, axial flow occupies the area between quasi surface of ZAV and boundary of water-air mixture.

Separate accounting for hydraulic and geometric parameters of internal and external flows will lead to a better understanding of the liquid movement's mechanism in the cyclone chamber and head loss definition in the hydro cyclone and ultimately it gives opportunity for establishment of optimum machine settings.

Hydro cyclone pumping plants consist of a pump, hydro cyclone, jet apparatus and pipes (bends, changes in pipe diameters, various forms of holes, cracks). In addition to these plants, there is a different kinds of movement (straight, spiral, vortex, circulation). All this requires consideration of head loss therein. Some of them have been studied mainly for straight stream, but due to the swirling flow, the head loss therein has not been defined.

Methods

Formula is theoretically deduced to determine the head loss in the hydro cyclone [5, 6, 7, 8, 9, 10]. Total head losses in the hydro cyclone are composed of losses on mixing the mass loss in the cyclone $h_{w.c.}$, for local resistance $h_{w.l.}$ for an intrinsic viscosity of $h_{w.v.}$ on friction against the apparatus' parries $h_{w.f.}$, so

$$\sum h_w = h_{w.c.} + h_{w.l.} + h_{w.v.} + h_{w.f.}. \quad (1)$$

Head loss for mixing flow is being performed in a conical part of the apparatus, where the movement of each flow is being made with variable flow along the way.

Head loss for local resistance [11, 12] is composed from the losses at water inlet into a cylindrical chamber (unilateral compression) for narrowing flow during its transition from the cylindrical chamber into conical $\left(R_{c.}^2 - r_{outf.}^2\right) \rangle\rangle \left(r_{c.}^2 - r_w^2\right)$, head loss by entrance of internally ascending stream into outlet (quasi narrowing) and loss by exit from the discharge outlets. However, the determination of head loss in the specified path is very difficult, therefore, head loss of peripheral and internal flows are considered alone (Table 1; Figure 3).

Head loss for an intrinsic viscosity by liquid swirling in the hydro cyclone are defined by M. V [13] for the kinematic coefficient of turbulent viscosity in a tube of circular cross section (ν) and slope falling energy in the event of open longitudinal helical flow (i).

Head loss on friction at apparatus' parries [14]. This type of loss in the hydro cyclone is composed of loss on friction of hydro cyclone's lid surface $\Delta H_{cov.}$, and the cylindrical portion of apparatus $\Delta h_{cyl.}$ and the conical portion of the hydro cyclone $\Delta h_{con.}$.

-*Head loss on friction of hydro cyclone's cover.* This process takes place only by liquid's rotational motion. For simple calculation, we will find the head loss at the dynamic and static rotations individually, and then sum up them (Table 2; Figure 4).

We know that the law $\vartheta r = C_1$ characterizes the rotational motion of an ideal fluid, which is caused by the vortex. In hydro cyclone flow rotation is caused not only by the influence of the vortex (air column), but also a tangential slurry inlet in the chamber. Therefore, the law of dynamic rotation, $\vartheta = C_2 r$ in its pure form is not respected. There is a combination of two movements: the movement on law of dynamic rotation and movement on law of static rotation.

-*Head loss on friction of cylindrical and conical surfaces* is composed of the head loss in the translational and rotational motion of fluid (Table 3, Figure 5 and Figure 6).

Results

Total head losses in the hydro cyclone are received on the basis of this methodology [15, 16, 17].

$$\Sigma h_w = \left\{ 1{,}5 + \frac{0{,}53 \Pi A^2 \sqrt{\lambda}}{0{,}25\sqrt{8}} \left[\frac{1}{k^2 - k_1^2} \left(k \ln T - \frac{r_{s.}}{T} \right) + \frac{1}{2} \times \right.\right.$$

$$\left.\left. \times \left(\ln\left| 1 - \frac{k_1 h_{r.}^2}{r_{fr.}^2} \right| - \frac{1}{\sqrt{\frac{k_1}{r_{fr.}}}} \ln \left| \frac{1 + \sqrt{\frac{k_1}{r_{fr.}}} h_{r.}}{1 - \sqrt{\frac{k_1}{r_{fr.}}} h_{r.}} \right| \right) \right] + \right.$$

$$\left. + \frac{5}{2} \frac{A^2 R_{c.}}{\left(r_{fr.} + k_1 h_{r.} \right)} + \frac{\Pi A^2 \lambda R_{c.}^{\frac{3}{2}} \left(R_c^{\frac{1}{2}} - r_{outf.}^{\frac{1}{2}} \right)}{\rho g \omega_{ent.}} + \frac{\lambda \Omega_{cyl.} \vartheta_{ent.}}{4 Q_{ent.}} \right\} \frac{\vartheta_{ent.}^2}{2g}$$

$$+ 2 \frac{\vartheta_{Zoutf.}^2}{2g} + \left\{ \frac{\lambda}{4 \overline{\omega}_{con}} \left(\frac{H_{con}^2}{2} - \frac{H_{con}^3}{3T} \right) + \right.$$

$$\left. + \frac{\lambda \delta^3}{k} \left[\ln\left| r_{s.} + k H_{con} \right| \times \left(1 + \frac{r_{s.}}{kT} \right) \right] \right\} \frac{\vartheta_Z^2}{2g}$$

$$+ \frac{\Pi \lambda \vartheta_{cyl.}}{16 \rho g Q_{ent.} R_{c.}^6} \times \left(R_{c.}^8 - r_{outf.}^8 \right) \frac{\vartheta_{cyl.}^2}{2g} + \frac{\lambda}{2} \frac{H_{cyl.}}{R_{c.}} \frac{\vartheta_{Z.cyl.}^2}{2g} \qquad (2)$$

Indexes:

ent.-entrance; ovf.-overflow; s-sandy; ent.-s-between entrance and sandy nozzle; ent.-outf.-between the inlet and drain nozzle; w-on n ZAV's surface; c-cyclone; fr.-free surface; air-air column; con.-cone; cyl.-cylinder; r-rising flow.

Designation:

k-the degree of flow's turbulence in the hydro cyclone; k_1-coefficient T-length; $h_{r.}$-the length of rising flow; $r_{fr.}$-radius of stream's free surface; R_c-radius of the cyclone; ρ-pressure, fluid density; $\vartheta_{Zovf.}$-the average speed in drain nozzle; $\varpi_{con.}$-the average cross of conical portion's sectional area; $H_{con.}$-height of the conical portion; $r_{s.}$-radius of sand holes; ϑ_Z-axial velocity; $\vartheta_{cyl.}$-average flow velocity in the cylindrical portion; $\overline{\vartheta}_{ent.}, \overline{\vartheta}_{outf.}$-the average velocity of the slurry, respectively, at entrance of the hydro cyclone in the drain nozzle; $r_{ent.}, r_{outf.}, r_{air.}$-radius, respectively inlet and drain nozzle and the air column (the free space in the vacuum hydro cyclone); $Q_{s.}$-flow rate for sand holes; τ-tangential stress; λ-coefficient of hydraulic resistance; $\overline{\vartheta}_{z.cyl.}$-flow's average axial velocity in the cylindrical portion of the hydro cyclone; $H_{cyl.}$ -he length of the hydro cyclone's cylindrical part; $\vartheta_{s.}$ -section average speed for sand tube; $Q_{ent.}$ -liquid flow through inlet nozzle of the hydro cyclone; $\vartheta_{cyl.p.}$ -average speed over the cross section of the cylindrical part; $\omega_{cyl.p.}$ -open area section of the hydro cyclone's cylindrical part; $\vartheta_{ent.}$ -average speed over the cross section of inlet nozzle.

Table 1: Calculation of head loss in the local resistance by formula $h_{w.l.} = \left(\frac{3}{2} + \frac{5}{2} A^2 \frac{R_{c.}}{r_{air} + k_1 h_{r.}}\right) \frac{\vartheta_{ent.}^2}{2g} = \xi_{w.l.} \frac{\vartheta_{ent.}^2}{2g}$

№	A	$R_{c.}$, m	$r_{air.}$, m	K_1	$h_{r.}$, m	$\vartheta_{ent.}$, m/c	g, m/c^2	$\xi_{w.l.}$	$R_{c.} / (r_{air} + K_1 h_{r.})$	$h_{w.l.}$, m
The experimental data of A. A. Abduramanov [18]										
1	0, 36	0, 170	0, 0255	0, 16	0, 47	1, 02	9, 8	2, 0469	1, 688	0, 1084
2	0, 36	0, 170	0, 0255	0, 16	0, 47	1, 22	9, 8	2, 0469	1, 688	0, 1554
3	0, 36	0, 170	0, 0255	0, 16	0, 47	1, 50	9, 8	2, 0469	1, 688	0, 2349
4	0, 36	0, 170	0, 0255	0, 16	0, 47	2, 00	9, 8	2, 0469	1, 688	0, 4173
The experimental data of A. I. Zhangarin [19]										
5	0, 36	0, 2	0, 01875	0, 12	0, 5	1, 49	9, 8	2, 323	2, 54	0, 263
6	0, 36	0, 2	0, 01875	0, 12	0, 5	1, 59	9, 8	2, 323	2, 54	0, 299
7	0, 36	0, 2	0, 03	0, 12	0, 5	2, 10	9, 8	2, 22	2, 22	0, 499

Table 2: Calculation of head loss on friction of hydro cyclone's cover by formula $\Delta H_{cov.} = \frac{A^3 \Pi \lambda R_{c.}^{\frac{3}{n}} \left(R_{c.}^{\frac{1}{2}} - r_{outf.}^{\frac{1}{2}}\right)}{\rho g \omega_{ent.}} \frac{\vartheta_{ent.}^2}{2g} + \frac{\Pi \lambda \vartheta_{outf.}}{16 \rho g Q_{ent.} R_{c.}^6} \left(R_{c.}^8 - r_{outf.}^8\right) \frac{\vartheta_{outf.}^2}{2g}$

№	Π	A	λ	$R_{c.}$, m	$r_{outf.}$, m	ρ, kg/m^3	g, m/c^2	$\omega_{ent.}$, m^2	$\vartheta_{ent.}$, m/c	$\vartheta_{outf.}$, m/c	$Q_{ent.}$, m^3/c	$\xi_{cov.}$	$\frac{\vartheta_{outf.}^2}{2g}$	$\Delta H_{cov.}$, m
The experimental data of A. A. Abduramanov [18]														
1	3, 14	0, 36	0, 035	0, 170	0, 034	1000	9, 8	0, 0036	1, 02	1, 0	0, 0037	7, 85	0, 05	0, 400
2	3, 14	0, 36	0, 035	0, 170	0, 034	1000	9, 8	0, 0036	1, 22	1, 22	0, 0043	8, 236	0, 076	0, 626
3	3, 14	0, 36	0, 035	0, 170	0, 034	1000	9, 8	0, 0036	1, 50	1, 50	0, 0054	8, 069	0, 1148	0, 9263
4	3, 14	0, 36	0, 035	0, 170	0, 034	1000	9, 8	0, 0036	2, 00	2, 00	0, 0072	8, 066	0, 20	1, 613
The experimental data of A. I. Zhangarin [19]														
5	3, 14	0, 36	0, 035	0, 2	0, 025	1000	9, 8	0, 063	1, 49	1, 49	0, 0029	5, 646	0, 1132	0, 639
6	3, 14	0, 36	0, 035	0, 2	0, 025	1000	9, 8	0, 063	1, 59	1, 59	0, 0031	5, 635	0, 1289	0, 7268
7	3, 14	0, 36	0, 035	0, 2	0, 040	1000	9, 8	0, 063	2, 10	2, 10	0, 0041	5, 63	0, 225	1, 2660

Table 3: Calculation of head loss on friction of cylindrical part's surface by formula $\Delta h_{cyl.} = \Delta h_{cyl._1} + \Delta h_{cyl._2} = \frac{\lambda H_{cyl.}}{D_{cyl.}} \frac{\vartheta^2_{z.cyl..}}{2g} + \frac{\lambda \Omega_{cyl.} \vartheta_{ent.}}{4Q_{ent.}} \frac{\vartheta^2_{ent.}}{2g}$

№	λ	$H_{cyl.}$, m	$D_{cyl.}$, m	$\Omega_{cyl.}$, m	$\vartheta_{ent.}$, m/c	$Q_{ent.}$, m³/c	$\vartheta_{z.cyl.}$, m/c	g, m/c²	$\Delta h_{cyl.}$, m	ξ_1	ξ_2	$\frac{\Delta h_{cyl.}}{\vartheta^2_{z.cyl.}/2g}$	$\frac{\Delta h_{cyl.}}{\vartheta^2_{ent.}/2g}$
The experimental data of A. A. Abduramanov [18]													
1	0, 035	0, 23	0, 34	0, 091	1, 02	0, 0037	0, 040	9, 8	0, 011	0, 0236	0, 216	143, 12	0, 216
2	0, 035	0, 23	0, 34	0, 091	1, 22	0, 0043	0, 042	9, 8	0, 016	0, 0236	0, 212	190, 33	0, 2256
3	0, 035	0, 23	0, 34	0, 091	1, 50	0, 0054	0, 044	9, 8	0, 025	0, 0236	0, 221	258, 77	0, 221
4	0, 035	0, 23	0, 34	0, 091	2, 00	0, 0072	0, 050	9, 8	0, 044	0, 0236	0, 222	375, 83	0, 221
The experimental data of A. I. Zhangarin [19]													
5	0, 035	0, 2	0, 4	0, 126	1, 49	0, 0029	0, 030	9, 8	0, 063	0, 0175	0, 566	1394, 3	0, 5648
6	0, 035	0, 2	0, 4	0, 126	1, 59	0, 0031	0, 032	9, 8	0, 072	0, 0175	0, 564	1400, 0	0, 5644
7	0, 035	0, 2	0, 4	0, 126	2, 10	0, 0041	0, 040	9, 8	0, 127	0, 0175	0, 564	1587, 5	0, 5644

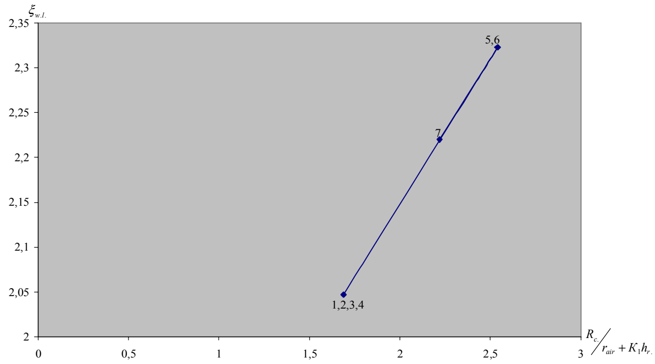

Figure 3: Graph of dependency $\xi_{w.l.} = f\left(R_{c.}/r_{air} + K_1 h_{r.} \right)$

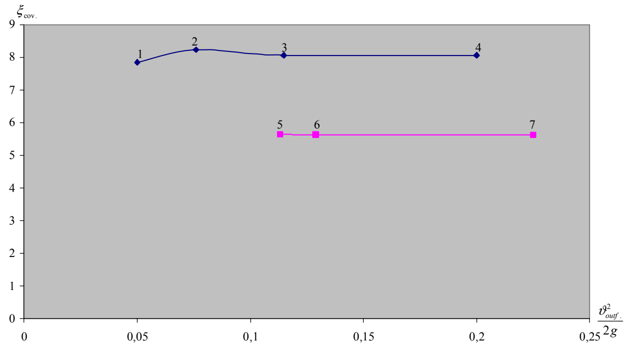

Figure 4: Graph of dependency $\xi_{cov.} = f\left(\frac{\vartheta^2_{outf.}}{2g} \right)$

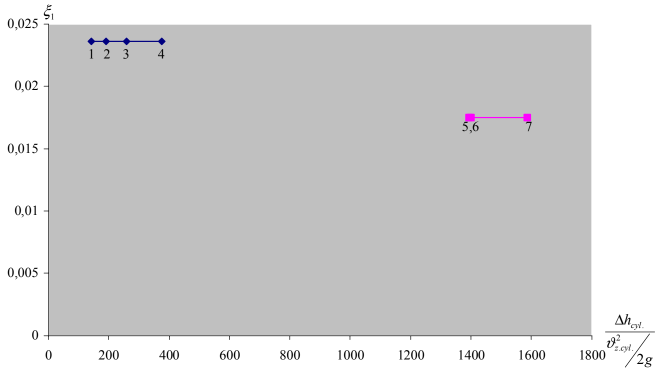

Figure 5: Graph of dependency $\xi_1 = f\left(\frac{\vartheta^2_{z.cyl.}}{2g}\right)$

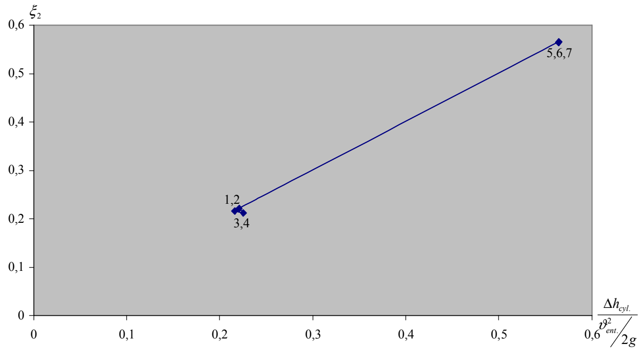

Figure 6: Graph of dependency $\xi_2 = f\left(\frac{\vartheta^2_{ent.}}{2g}\right)$

Discussion

One of the important issues of hydro cyclone pumping plants in the hydraulic is the definition of the specific energy loss (pressure) in the hydro cyclone.

The technological and economic efficiency of the hydro cyclone pumping plants is entirely dependent on the value of the specific energy loss in the classification (thickening) of slurry in hydro cyclone.

Until now, theoretical definition of head loss in the hydraulic was succeeded only in a few cases: the sudden expansion of the flow in the pipeline (Borda-Carnot's theorem) and in perfect hydraulic jump.

In all other cases, the head loss is determined empirically. This often makes difficulty to design new hydro cyclone pumping plants in advance. The problem is compounded by the fact that the available research results are related to the direct-flow streams, while flow is mainly swirled in hydro cyclone pump plants.

In general, all the issues related to the head loss that solutions have been found for direct-flow (axial) flows, should be reviewed from the twisted flow's perspective. The volume of work is very large and requires huge theoretical and experimental studies. Held research in hydro cyclone's elements is the beginning of multiple researches of hydro cyclone, vacuum hydro cyclone plumping plants used in hydro engineering. Experimental data of A. A. Abduramanova Zhangarina [18, 19], applied in research, have been tested and used by researchers in many countries, published in the press.

Conclusion

The results of our study will be used to investigate energy issues of hydro cyclone plumping plants. The general formula for determining head loss will be used by researchers in the study of the head loss in various hydro cyclone's designs and hydro cyclones pumping plants.

The theoretical basis for determining head loss in the hydro cyclone are elaborated, in particular: head loss on mixing flow in the hydro cyclone, for local resistance (narrowing and expansion of the cyclone flows) for internal viscosity by liquid swirling in hydro cyclone and on friction against the apparatus' parries. General formulas for calculating the head loss in the hydro cyclone have been got.

The analysis was given, included in the general expression for determining the specific energy (pressure) loss in a hydro cyclone, in particular: formula by definition: energy losses on mixing peripheral descending and inner paraxial flow, specific energy loss at the transition from the hydro cyclone's cylindrical part into conical, narrowing swirling cyclonic flow, entering from the conical portion into drain connection, the head loss at transition from the conical part into the cylindrical sand nozzle, loss of specific energy on internal resistance during liquid swirl in hydro cyclone chamber, energy losses on friction of the apparatus' parries.

Our results can be applied by determining the head loss in the new hydro cyclone pumping plants, in filter cyclone, filter cyclone-pumping plants, vacuum hydro cyclone pumping plants, one surface and two surface vortex and jet devices, hydro cyclone-jet devices [20].

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