ROMAI J., **6**, 2(2010), 69–81

ON THE 3D-FLOW OF THE HEAVY AND VISCOUS LIQUID IN A SUCTION PUMP CHAMBER

Mircea Dimitrie Cazacu[1], Cabiria Andreian Cazacu[2]

[1] *Polytechnic University of Bucharest, Romania*

[2] *"Simion Stoilow" Institute of Mathematics of the Romanian Academy, Bucharest, Romania*

cazacumircea@yahoo.com, cabiria.andreian@imar.ro

Abstract We present the essence of the theoretical and experimental researches, developed in the field of the three-dimensional flow with free surface of a heavy and viscous liquid in the suction chamber of a pump, with or without air carrying away or appearance of the dangerous cavitational phenomenon, problem of a special importance for a faultless working of a pump plant, especially of these relevant to the nuclear electric power plants, which constituted the object of our former preoccupations.

From the mathematical point of view we present the solving particularities of the two-dimensional boundary problems, specific to the three-dimensional domain limits of the pump suction chamber flow, as well as the possibility to obtain a stable numerical solution.

From the practical point of view, we show the possibilities of laboratory modelling of this complex phenomenon, by simultaneously use of many similitude criterions, as well as the manner to determine the characteristic curves, specific to each designed pump suction chamber.

Because the drawings of the pump station of Romanian nuclear power station Cernavoda on Danube are classified, we shall present the theoretical and experimental researches performed on the model existent in the Laboratory of New Technologies of Energy Conversion and Magneto-Hydrodynamics, founded after the world energetic crisis from 1973 [1] in the POLITEHNICA University of Bucharest, Power Engineering Faculty, Hydraulics, Hydraulic Machines and Environment Engineering Department.

Keywords: liquid three-dimensional flow with free surface, three-dimensional flow in the pump suction chamber, complex modelling of liquid three-dimensional flow with free surface.

2000 MSC: 35 G 30, 35 J 25, 35 J 40, 35 Q 30, 65 N 12, 76 D 17.

1. INTRODUCTION

The theoretical research concerning the three-dimensional flow of the real liquid in a suction chamber of a pump, [2], [3], is justified by the flow effect with or without appearance of whirls, with or without air training [4] or by the appearance of the cavitation destructive phenomenon at the liquid entry in a pump, as well as by their negative influence on the hydraulic and energetic pump efficiency, the quick cavitational erosions, the machine vibrations followed by the fast wear, eventually by the pump suction less and by their pumping cease, extremely dangerous for the pumping station, for instance of a nuclear electric power plant [1].

These situations may come in the sight in special work conditions linked with the low level of the water in the river bed or in the pump suction chamber, or by an inefficient design of this installation for different cases of pumps working [5], [6].

2. NUMERICAL INTEGRATION OF THE HEAVY AND VISCOUS LIQUID THREE-DIMENSIONAL FLOW IN A PUMP SUCTION CHAMBER

We present the mathematical specific boundary conditions [2], [3], which intervene in the problem of the three-dimensional viscous liquid steady flow into the suction chamber of a pump plant, represented in the Figure 1.

Thus, for the uniform flow of the viscous and heavy liquid in the entrance and going out sections of the domain, we must consider the two-dimensional special boundary problems:

- for the fluid **entrance section** we must solve a mixed Dirichlet-Neumann problem for a Poisson equation with an unknown *a priori* constant, depending of the slope angle α of the suction chamber bottom, which can be determined by a successive calculus cycle of the computer program, satisfying a **normalization condition**, which, for the given value of mean input velocity and entrance section dimensions, ensures the desired flow-rate,

- for the fluid **going out pipe section** we must solve a Dirichlet problem for another Poisson equation, having the pressure drop gradient p'_z in the suction pipe also as unknown *a priori* constant, which can be determined also by a successive calculus cycle satisfying a normalization condition and which establishes the pressure drop gradient on the pipe length for the same flow-rate, satisfying another **normalization condition**.

2.1. PARTIAL DIFFERENTIAL EQUATIONS OF A VISCOUS AND HEAVY LIQUID STEADY FLOW

The three-dimensional **motion equations** in Cartesian trihedron (Fig.1) are

$$U'_T + U'_X U + U'_Y V + U'_Z W + \frac{1}{\rho} P'_X = \nu(U''_{X^2} + U''_{Y^2} + U''_{Z^2}) + g \sin\alpha, \tag{1}$$

$$V'_T + V'_X U + V'_Y V = V'_Z W + \frac{1}{\rho} P'_Y = \nu(V''_{X^2} + V''_{Y^2} + V''_{Z^2}), \tag{2}$$

$$W'_T + W'_X U + W'_Y V + W'_Z W + \frac{1}{\rho} = \nu(W''_{X^2} + W''_{Y^2} + W''_{Z^2}) + g \cos\alpha, \tag{3}$$

the **mass conservation equation** for an incompressible fluid being

$$U'_X + V'_Y + W'_Z = 0, \tag{4}$$

where, as usual, (U, V, W) is the velocity of the fluid, P is its the pressure, ρ - the fluid density, and ν - its kinematical viscosity. T and X, Y, Z represent time and spatial independent variables, respectively.

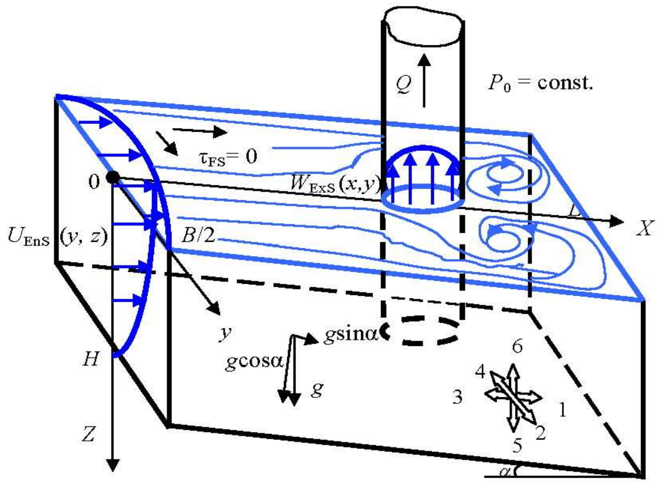

Fig. 1. Scheme of the studied pump suction chamber and the character of the liquid flow

2.2. THE DIMENSIONLESS FORM OF THE EQUATION SYSTEM

For more generality of the numerical solving [3], [5] - [8] we shall work with dimensionless equations, by using the characteristic physical magnitudes of flow:

- the suction chamber width $B \cong H$, approximately equal with its height,
- the liquid mean velocity of the entrance in suction chamber $U_m = Q/BH$,
- the air atmospheric pressure on its free surface P_0,
- and the period T_0 of whirl appearance in the three dimensional flow.

With the new dimensionless variables and functions:

$$x = \frac{X}{H}, y = \frac{Y}{H}, z = \frac{Z}{H}, t = \frac{T}{T_0}, u = \frac{U}{U_m}, v = \frac{V}{U_m}, w = \frac{W}{U_m}, p = \frac{P}{P_0}, \tag{5}$$

the partial differential equations (1) to (4) become in the dimensionless form:

$$\text{Sh}\, u'_t + u'_x u + u'_y v + u'_z w + \text{Eu}\, p'_x = \frac{1}{\text{Re}} \underset{x,y,z}{\Delta} u + \frac{\sin\alpha}{\text{Fr}}, \tag{1'}$$

$$\text{Sh } v'_t + v'_x u + v'_y v + v'_z w + \text{Eu } p'_y = \frac{1}{\text{Re}} \underset{x,y,z}{\Delta} v, \tag{2'}$$

$$\text{Sh } w'_t + w'_x u + w'_y v + w'_z w + \text{Eu } p'_z = \frac{1}{\text{Re}} \underset{x,y,z}{\Delta} w + \frac{\cos\alpha}{\text{Fr}}, \tag{3'}$$

in which one puts into evidence the following criteria of hydrodynamic flow similarity, numbers of: Strouhal $\text{Sh} = H/T_0 U_m$, Euler $\text{Eu} = P_0/\rho U_m^2$, Reynolds $\text{Re} = HU_m/\nu$ and Froude $\text{Fr} = U_m^2/gH$; the mass conservation equation is an invariant

$$u'_x + v'_y + w'_z = 0. \tag{4'}$$

2.3. THE NUMERICAL SOLVING METHOD

The numerical integration of partial differential equation system was performed by an iterative calculus of unknown functions u, v and w, given by the algebraic relations associated to the partial differential equations, by introducing their expressions deduced from the finite Taylor's series developments [8] in a cubical grid, having the same step $\delta x = \delta y = \delta z = \chi$:

$$f'_{x,y,z} = \frac{f_{1,2,5} - f_{3,4,6}}{2\chi} \qquad \text{and} \qquad f''_{x^2,y^2,z^2} = \frac{f_{1,2,5} - 2f_0 + f_{3,4,6}}{\chi^2}. \tag{6}$$

2.4. THE BOUNDARY CONDITIONS FOR THE THREE-DIMENSIONAL STEADY FLOW

- **on the solid walls**, due to the molecular adhesion condition, we consider

$$u_{\text{SW}} = v_{\text{SW}} = w_{\text{SW}} = 0 \tag{7}$$

and consequently, from equation (3') for $\alpha \approx 0$ the hydrostatic pressure distribution becomes

$$p_{\text{SW}}(z) = 1 + \frac{\gamma H}{P_0} z = 1 + \text{Ar } z, \tag{8}$$

in which we introduced the **hydrostatic similarity number** $\text{Ar} = \gamma H/P_0$, dedicated to the Archimedean lift discoverer,

- **on the free surface**, considered to be a plane due to the liquid important weight and small flow velocities, we have the conditions

$$p_{\text{FS}}(x, y, 0) = 1 \qquad \text{and} \qquad w_{\text{FS}}(x, y, 0) = 0, \tag{9}$$

excepting a null measure set of points constituted by the whirl centers on the free surface, in whose neighbourhood the fluid has a descent motion (Fig. 1).

Neglecting the liquid friction with the air, we shall cancel both shearing stress components, obtaining:

$$\begin{aligned} \tau_{\text{zx}} \,|_{\text{FS}} &= u'_z + w'_x = u'_z \,|_{\text{FS}} = 0, \rightarrow u_6 = u_5 \\ \tau_{\text{xy}} \,|_{\text{FS}} &= v'_x + w'_y = v'_z \,|_{\text{FS}} = 0, \rightarrow v_6 = v_5. \end{aligned} \tag{10}$$

The value w_6 is calculated from the mass conservation equation (4'), written in finite differences (that is not unstable in this local appliance [5] [6])

$$\frac{u_1 - u_3}{2x} + \frac{v_2 - v_4}{2x} + \frac{w_5 - w_6}{2x} = 0 \rightarrow w_6 \,|_{FS} = w_5 + u_1 - u_3 + v_2 - v_4, \tag{11}$$

- **in the entrance section**, we consider the uniformly and steady flow at the normal depth of the current parallel with the channel bottom slope $i = \sin\alpha$, which leads us to the condition $v\,|_{ES} = w\,|_{ES} = 0$ and to the hydrostatic pressure repartition, the distribution of $u(y, z)$ velocity component being obtained from the first motion equation (1'), which in these boundary conditions become a **Poisson** type equation with the constant α *a priori* unknown, written also in finite differences

$$\underset{x,z}{\Delta} u + \frac{\mathrm{Re}}{\mathrm{Fr}} \sin\alpha = 0 \rightarrow u_0 = \frac{1}{4}\sum_{\mathrm{i}=1}^{4} u_{\mathrm{i}} + \frac{\chi^2}{4}\frac{\mathrm{Re}}{\mathrm{Fr}} \sin\alpha. \tag{12}$$

The numerical solving is possible by an iterative cycle on the computer, until to the obtaining of slope value i, necessary to the given Re and Fr numbers corresponding to the flow velocity U_m, when the heavy force component $g \sin\alpha$ is balanced by the interior friction forces, acting by the liquid adhesion to the channel bottom and its solid walls.

The boundary conditions for the Poisson equation (12) for solving in the frame of plane the mixed problem **Dirichlet-Neumann**

$$U_{\mathrm{SW}} = 0 \text{ on the solid walls,}$$
$$\mathfrak{I}_{\mathrm{zx}}|_{\mathrm{FS}} = \mu U'_z = 0 \text{ on the free surface,}$$

lead us to solve a **mixed problem Dirichlet-Neumann**, whose **normalization condition** is

$$\int_0^B \int_0^H U_i(Y, Z)\,dY dZ = Q = BHU_{\mathrm{m}}, \tag{13}$$

or, in the iterative numerical calculus for the dimensionless case,

$$\chi^2 \sum_{\mathrm{k}=2}^{\mathrm{k_M}-1} \sum_{\mathrm{j}=2}^{\mathrm{j_N}-1} u_{\mathrm{k,j}} + \frac{\chi^2}{2} \sum_{\mathrm{j}=2}^{\mathrm{j_N}-1} u_{\mathrm{k_M,j}} + \frac{\chi^2}{8} \sum_{\mathrm{j}=2}^{\mathrm{j_N}-1} u_{\mathrm{k=2,j}} + \frac{\chi^2}{4} \sum_{\mathrm{k}=2}^{\mathrm{k_M}-1} u_{\mathrm{k,j=2}} = q = 1, \tag{13'}$$

representing the flow-rate which is brought by this velocity repartition in the entrance section, for the given values of U_m, therefore Re and Fr numbers, as well the considered grid step χ.

For the starting of the calculus it is necessary to introduce only a single velocity value in a point as a seed, for instance $u_S = 2$ in the point $j = 20$ and $k = 40$ in the middle of the free surface, in the rest of the domain the initial arbitrary values being equal with zero, or, by admittance of a paraboloidal repartition a the initial given arbitrary values concerning the velocity distribution in the domain, in the shape

$$\begin{aligned} u_{\mathrm{va}}(y,z) &= 8(1-z^2)\cdot(\frac{1}{2}-y)\cdot(\frac{1}{2}+y) = 8(1-z^2)\cdot(\frac{1}{4}-y^2), \\ u_{\mathrm{va}}(j,k) &= 4u_s\cdot a^2(j-1)\cdot(k-1)\cdot[2(k-1)\cdot a][2(j-1)\cdot a], \end{aligned} \tag{14}$$

because we have

$$y = (j-1)a - \frac{1}{2} \qquad \text{and} \qquad y = 1-(k-1)a, \tag{15}$$

- **in the exit section**, we shall consider that the streamlines are parallel with the vertical pipeline walls, $u_{\mathrm{ES}} = v_{\mathrm{ES}} = 0$, the velocity component $w(x,y)$ distribution in the uniformly and steady flow verifying also a Poisson type equation with an *a priori* unknown constant p'_{z}, but this time due to the ignorance of the pressure drop on the vertical pipeline p'_{z}, deduced from the third motion equation (3') in approximation $\cos\alpha \approx 1$, determined above by solving the entry section problem

$$\mathrm{Re\,Eu}\; p'_{\mathrm{z}} = \frac{\mathrm{Re}}{\mathrm{Fr}}\cos\alpha + \underset{\mathrm{x,y}}{\Delta} w, \rightarrow w_0 = \frac{1}{4}[\sum_{\mathrm{i}=1}^{4} w_{\mathrm{i}} + \chi^2\mathrm{Re}(\frac{1}{\mathrm{Fr}} - \mathrm{Eu}\; p'_{\mathrm{z}})]. \tag{16}$$

The boundary condition to solve the Poisson equation (16) in the frame of **Dirichlet problem**, is given by the liquid adhesion $w_{\mathrm{ES}} = 0$ on the interior solid wall of suction pipe.

The Poisson type equation solving, in which one does not know *a priori* the pressure drop p'_{z} along the pipe, can be made by numerical way, also by an iterative cycle on computer, yielding up to the arbitrary values $p'_{\mathrm{z}} \gtrsim 0.1$, which exceed a few the pressure distribution deduced from the hydrostatic repartition (8), until the velocity integration w_{ES} in the exit section (Fig. 2) shall equalize the unitary value of dimensionless flow-rate, calculated in the case of non-symmetrical or symmetrical supposed velocity repartitions, using the forms of [6]

$$\begin{aligned} q_{\mathrm{nonsym}} &\approx \chi^2\cdot\left(\sum_{\mathrm{i}=17}^{20}\sum_{\mathrm{j}=7}^{10} w_{\mathrm{ij}} + \frac{1}{8}\cdot\sum_{\mathrm{i}\in\{17,2\}}\sum_{\mathrm{j}=8}^{9} w_{\mathrm{ij}} + \frac{1}{8}\cdot\sum_{\mathrm{i}=18}^{20}\sum_{\mathrm{j}\in\{7,1\}} w_{\mathrm{ij}}\right) = 1, \\ q_{\mathrm{sym}} &\approx \chi^2\cdot[9w_{17,8} + 4(w_{18,8} + w_{17,7})] = 1. \end{aligned} \tag{17}$$

2.5. CONCLUSIONS ON THE USED BOUNDARY SPECIFIC PROBLEMS IN THE 3D-FLOWS

The **Dirichlet problem**, proposed by the German mathematician Peter Gustav Lejeune Dirichlet, being generally specific to the equations of elliptic type, corresponding to the repartition of scalar physic magnitudes given by harmonic functions (for example of the temperature distribution in a homogeneous medium, without convection i.e. $U = V = 0$, and without interior heat sources in virtue of Laplace equation) has here a specific character.

The **Neumann problem** formulated by the German physicist Carl Gottfried Neumann, consists in giving, on the boundary C of the domain D, the **values of the normal derivative of the function**, f'_{n}.

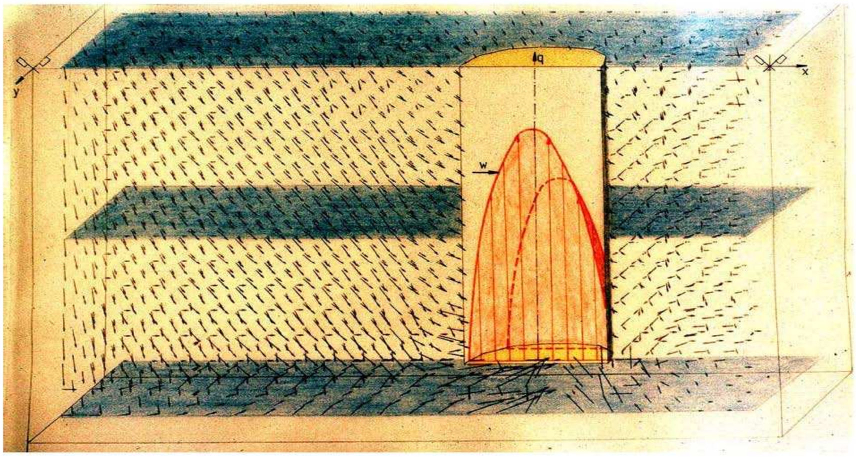

Fig. 2. The three-dimensional repartition of the velocity components for Re = 100

To specify the unknown function values in the domain, it is necessary also in this case to fulfil the so-called normalization condition, giving the flux through the frontier line

$$\phi = \int_C f'_{\mathrm{n}} \mathrm{d}l. \tag{18}$$

In the three-dimensional case of **mixed boundary problems**, by combination of these two classical problems, to solve the Poisson equations with unknown constants, intervene the well-known normalization conditions, even for the Dirichlet problem only.

Initially, the computational program has been made in Cobol [4]], due to the great number of the data, working successively to relax the three velocity components values in a plane, considering their values also in the two neighbouring planes, the graphical representation of the three-dimension flow being shown by the three velocity components as in Figure 2.

2.6. THE IMPORTANCE OF THE COMPLEX PHENOMENA FROM A PUMP SUCTION CHAMBER FLOW

The faultless working of the pump plant for the nuclear electric power stations, which must work even in the case of nuclear reaction stopping, yet 10 to 12 hours till the complete cooling of the reactor, is the main aim to ensure the nuclear security.

In the second part of this paper we present the experimental research performed, regarding the complex modelling of the spatial flow and the specific phenomena, which can be produced in the pump suction chamber. The research has been started in the year 1977 together with my former student and then collaborator Dr. Eng. Costel Iancu [2] for the pump station design of the nuclear power station Cernavoda in Romania [1] and continued by the construction of the Model installation endowed with the measuring apparatus for a good working research of a pump suction (Fig. 1 to 3) in the *Laboratory of new technologies of energy conversion and environment protection*, realized in the year 1979 with the help of the former Eng. PhD student Dumitru Ispas [3]-[6].

3. THE COMPLEX MODELLING OF THE HEAVY AND VISCOUS LIQUID 3D- FLOW IN A PUMP SUCTION CHAMBER

After doctoral Thesis defending in 1957, M.D.Cazacu published a work on the laboratory complex modelling of the complicated water-hammer phenomenon [9], considering not only the dimensionless motion equation, but also the mass conservation and state equation of the compressible liquid, as well as the pipe elastic deformation with influence upon the sound propagation velocity.

He decided at that time to pay attention to this very important phenomenon, taking into consideration the high security level of a pump plant for a nuclear electric power plant, since the research on the laboratory model was not conclusive in the consulted technical literature in this field.

3.1. THE EXPERIMENTAL INSTALLATION DESCRIPTION AND MEASURING APPARATUS

The experimental installation is presented in Fig. 3, and it consists in *1-stained glass chamber, 2-supporting feet, 3-tightening cap, 4-air tap, 5-flow reassure, 6- centrifugal pump, 7-direct current electric motor, 8-pump pressing pipeline, 9-discharge control valve, 10-flow meter, 11-pump suction pipeline, 12-suction basket, 13-emptying tap, 14-air carrying away whirl, 15-whirl on the bottom, 16-blades against the whirls.*

The water level in the pump suction chamber may be changed through the tap 13, the water leaving the chamber through the pump suction pipe 12 producing two whirls without or with air carrying away 14, which due to the rotational flow ω caused by the pump suction flow rates, smaller then the nominal flow rate, change their positions: one remaining on the free surface, but at the other chamber side the second removing on the chamber bottom, where with the solid particles uncoupled from the concrete and concentrated in the whirl axis, due to the bigger flow velocities, leads at a strong erosion of the pump suction chamber.

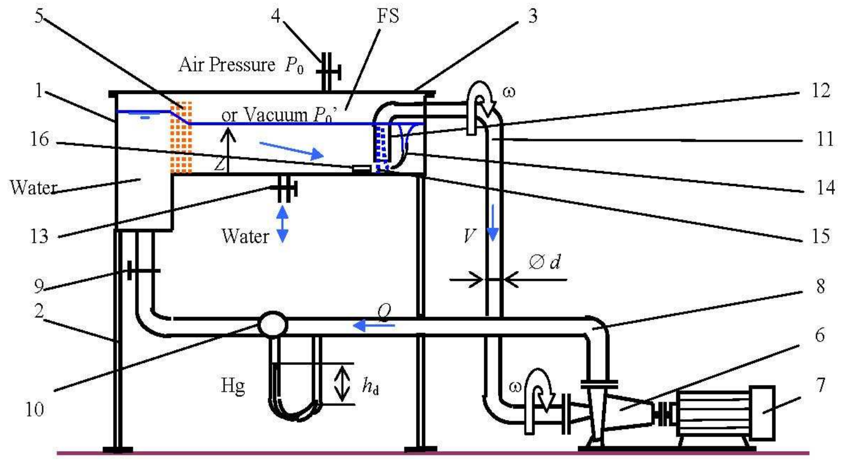

Fig. 3. Laboratory Model of the pump suction chamber, for the complex hydrodynamic similarity study

For the measuring of different physical magnitudes we utilized the apparatus:

- a mechanic tachometer contacted with the electric motor shaft end, to measure the **pump number of rotations** n,

- a diaphragm to measure the **pump flow rate** Q,

- a graduated rule from transparent plastic to measure the **water level** Z in the suction chamber, fixed at the suction chamber glass,

- a manual chronometer to measure the **frequency** of whirl appearance,

- a precision metallic mano-vacuum-meter or a mercury manometer tube to measure the **air pressure** at the suction chamber **free surface**.

3.2. THE FLOW COMPLEX MODELLING USING MORE SIMILARITY CRITERIONS

The short history concerning these inefficient foregoing modelling attempts began any decades before, when the researchers tried to utilize the very known **Froude's criterion** for the modelling of this gravitational flow in a pump suction chamber, but which gave on the Model, smaller then the Reality, built at the length scale

$\lambda = H/H' = D/D' > 1$, lesser velocities at which the whirls could not to appear

$$\mathrm{Fr} = \frac{V^2}{gH} = \mathrm{Fr}' = \frac{V'^2}{g'H'} \ \rightarrow\ \beta = \frac{V}{V'} = \lambda^{0,5} \geq 1 \text{ and } \mathrm{k} = \frac{Q}{Q'} = \lambda^2\beta = \lambda^{2,5}, \tag{19}$$

in which we noted with β the velocity ratio and with k the flow rate ratio.

For this reason, in the last decade of that period, the researchers, without no justification, have enlarged the velocities on the Model till the same values as the velocities of the Reality, introducing the so called **equal velocity criterion**, for which M. D. Cazacu gave a proof considering **Weber's criterion**, thinking at the free surface whirls with air carrying away similarity

$$\mathrm{We} = \frac{\sigma}{\rho V^2} = \mathrm{We}' = \frac{\sigma'}{\rho' V'^2} \ \rightarrow\ \beta = 1 = \lambda^0 \text{ and then } \mathrm{k} = \lambda^2, \tag{20}$$

where σ is the air-water superficial tension.

As a good expert in the recommendations of the pump manufacturers and pump station designers, that the water access to the pump suction baskets must be as possible direct and because the estimation of the separation of viscous fluid flow is given by **Reynold's number**, he considered also this kind of modelling, supposing that the water cinematic viscosity is the same

$$\mathrm{Re} = \frac{VD}{\upsilon} = \mathrm{Re}' = \frac{V'D'}{\upsilon'} \ \rightarrow\ \beta = \frac{V}{V'} = \frac{\upsilon}{\upsilon'}\lambda^{-1} \approx \lambda^{-1} \text{ and } \mathrm{k} = \lambda, \tag{21}$$

in which the velocities on the Model are greater than those from the Reality.

Another very important problem was the modelling of the influence of pump working, especially at lesser flow rates than that nominal. He introduced the pump modelling by its **rapidity criterion** n_{q}

$$n_{\mathrm{q}} = \frac{nQ^{1/2}}{H^{3/4}} = n'_{\mathrm{q}} = \frac{n'Q'^{1/2}}{H'^{3/4}}, \tag{22}$$

from which we can choose the pump number of rotations on the laboratory Model

$$n' = n\frac{\mathrm{k}^{1/2}}{\lambda^{3/4}} = n\lambda^{1/4}\beta^{1/2} \tag{23}$$

and determine the convenient geometric scale in the case of composed similarity Froude and pump rapidity n_{q}, in which case he gave in Table 1 the pressure P'_0 necessary at the water free surface in suction chamber, to benefit also of the cavitation phenomenon modelling at pump or at the strong erosive whirl, which ends on a side wall or on the bottom of the suction chamber built from the concrete, in the aim to eliminate his appearance in the Reality [5].

Table 1

n'[rot/min]	3.000	1.500	**1.000**	750	600	n = 500
$\lambda = (n'/n)^2$	36	9	**4**	2,25	1,44	1
$\frac{P'_0 - P'_v(T')}{P_0 - P_v(T)} = 1/\beta^2 = 1/\lambda = \sigma/\sigma'$	0,0277	0,111	**0,25**	0,444	0,6944	1
P'_0(bar)	0,261	0,342	**0,43**	0,5778	0,7678	1

In this table one sees the advantage of the length scale $\lambda = 4$, corresponding to the standardized number of rotations 1,000 rot/min of the pump model, inclusively under pressure that we must assure at the model free surface, as well as that which assures only the cavitational phenomenon similarity, for which we must have also accomplished the equality relation of the cavitational criterion

$$\sigma = \frac{P_0 - P_v(T)}{\rho v^2/2} = \sigma' = \frac{P'_0 - P'_v(T')}{\rho' v'^2/2}. \tag{24}$$

Finally, in the case of Strouhal's similarity, concerning the whirl appearance frequency in time, we shall have the relation, from which we can deduce the frequency of whirl appearance in reality as function of that obtained on the model

$$\mathrm{Sh} = \frac{Df}{V} = \mathrm{Sh}' = \frac{D'f'}{V'} \ \rightarrow \ f = f'\frac{D'V}{V'D}. \tag{25}$$

The symmetrical position (Fig. 1) of the two whirls from the right part can be modified by the pump working at littler flow rates (Fig. 3), by ω rotation impressed to the chamber flow as in the left part, when one whirl arrive to us and the other being disposed vertically on the bottom chamber (Fig. 4), causing its accelerated wear.

3.3. CONCLUSIONS AND IMPORTANT REMARKS

With this occasion we shall observe that the greater models become too expensive and the smaller models introduce forces of other nature, which modify completely the development of the hydrodynamic process.

On the basis of this modelling method one sees, that we can study a complex hydro-aerodynamic similarity using 6 criterions, as: Froude, Weber, Reynolds, pump rapidity, cavitation criterion and Strouhal, not only individually but also simultaneously.

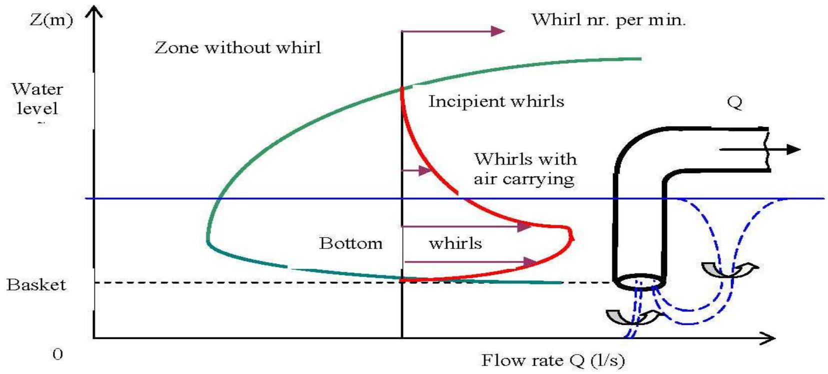

Fig. 4. The characteristic of the pump suction chamber tested in our laboratory, with the determination of the zones without and with whirl apparitions, as well as the frequencies of incipient, on the free surface without or with air carrying away and of bottom whirls

In this way we can also determine the convenient technical-economically length scale of the Model, to have also a good modelling similarity. In the same time we can determine the whirl apparition frequency in reality, that is very important because the erosion of the pump suction chamber walls is however a problem of time and we can also determine the zones that can be covered with metallic plates and one can determine for any pump plant, working at different exploitation situations its characteristic curves (Fig. 4), which determine the region of a good operation.

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