# The power performance's improvement of the water catching fronts

A. Alexandrescu

***Abstract*—The paper presents an analysis method based on the utilization of the analytical characteristics of the system's components that facilitate the evaluation of its working conditions and allows at the same time the establishment of adequate measures for an efficacious control of the working regime. Suitable criterions have also been inserted in this analysis (such as maximum efficiency of the hydro mechanical equipment respectively the optimum diameter of the collecting pipe), in order to improve the energetic and economical performance of the ensemble of the ground water front through drilling and making it easier to establish optimal capacity of the ensemble fronts – pressure pipe. Case study: a tapping of ground water front constituted of a battery of 20 drilling wells equipped with submerged pumps HEBE 65x2, equidistantly disposed into two branches, on the left bank of the Moldova river. When determining the resulting head characteristics of the hydraulic systems with numerous elements coupled in parallel on a collecting pipe made of piping tracts with different diameters, calculating the local head loss at confluences, usually produces great discomfort to the specialist conducting the calculations, therefore he usually neglects or rudely approximates these values, thus diminishing the precision of the results. In order to facilitate the calculation of the working regimes of such installations, this paper presents the way for determining relations that in practical conditions can express the local head loss at confluences, and the local hydraulic resistance modules, as simple order's numbers functions of the singularities, comparative to the upstream end of the collector.

***Keywords*—**Collecting pipe, flow, head, hydraulic resistance module, local head loss, pressure, tank.

## I. Introduction

Operational efficiency for a pumping supply system at deep well is determined by the type of pump used. Best performances are obtained when, so that user's needs to be met, submersible pumps are set to operate at ratings located in the neighbourhood of their maximal efficiency which at its turn must have optimal values for the best machines located in the respective class. As to reach that goal the process of the deep well pump choice has to be based on a thorough acknowledge of all operating parameters of such supply, that is the relations between flow $Q$ and specific hydraulic energy that has to be released towards this flow by the pump $H,$ in all different possible operational configurations, [1, 7].

The ground water resources are generally exploited by using a battery of drilling wells equipped with submerged pumps whose working function leads to energetic costs that are dependent on their working conditions during the evaluation period- for example the calendar year. A frequently encountered case is the tapping of the ground water front – that is relatively homogenous – from the major stream bed, shaped as a battery of wells with quasi-identical features (same hydrodynamic level, same value for the average discharge, same type and dimensions of the submerged pump, same pressure pipes linked to a collector, whose nominal diameter of the tubing length increases towards its downstream end), [2, 13].

Such an approach will lead to normal results for the water intake working at nominal capacity, but it will have poor economical and energetic performance. Due to pressure loss between the collector's nodes and also because of the variation of the local hydraulic resistance in bounds, in fact, the hydrodynamic head of each pump differs from one well to another, meaning that both the discharge and the efficiency, thus, the power consumption will differ, [9, 10].

In the studied case, all working regimes for each well must be analyzed, in real functioning conditions, which can become very laborious when the number of wells $n$ increases.

In the following, by taking on a systematically approach of the functioning of the battery of quasi-identical pumping wells, it is advised the use of an analysis method based on the mathematical modelling of the system, facilitated by the use of the analytical characteristics of its own components, [5, 8]. The practical way of the method is exemplified on the concrete case of the Motca 1 water catchment's of the Pascani municipally water supply, the obtained results being confirmed by the data from the on-site measurements concluded on some of the wells from the specific installation.

## II. Analysis of Working Regimes

The links between the discharge and head are studied in Motca system of $n$ wells (Fig. 1) that admits usual estimates from practice:

- Battery of drilled wells, equipped with identical submerged pumps, linked to a collecting pipe through identical pressure pipes;
- The submerged pump is specifically chosen to ensure the user's needs so that the well's potential discharge isn't exceeded;
- Water is pumped from an aquiferous with a quasi-horizontal free surface.

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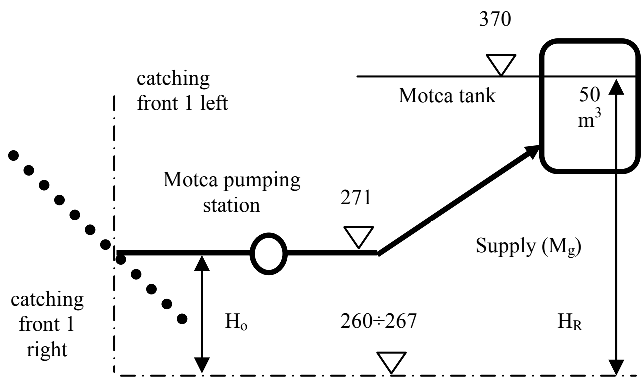


Fig. 1. Wells battery from Motca pumping station.

The head characteristic of the pump has the following form:

$$H = H_{pf} - K_p \cdot Q^2. \tag{1}$$

The efficiency characteristic of the pump can be calculated with the equation:

$$\eta = R_1 \cdot Q - R_2 \cdot Q^2 \tag{2}$$

The equivalent head characteristic of the group (1, …, *j*) is represented as follows:

$$H = H_{gf_j} - K_{g_j} \cdot Q^2 \tag{3}$$

The equivalent head characteristic $H$ of the active wells group upstream (1 - $j$) depending on flow $Q$ is represented as follows, (Fig. 2):

$$H = H_{gf_{l-1}} - (K_{g_{j-1}} + M_{r_{j-1,j}} + M_{r\zeta_{lj}}) \cdot Q^2 \tag{4}$$

In (4) are used the notations: the hydraulic resistance module of the joints: on the lateral branch $M_{r\zeta lj}$; on the main branch $M_{r\zeta tj}$ .

The wells head characteristic $H$, reduced at $j$ node has the following mathematical relation, [3, 4]:

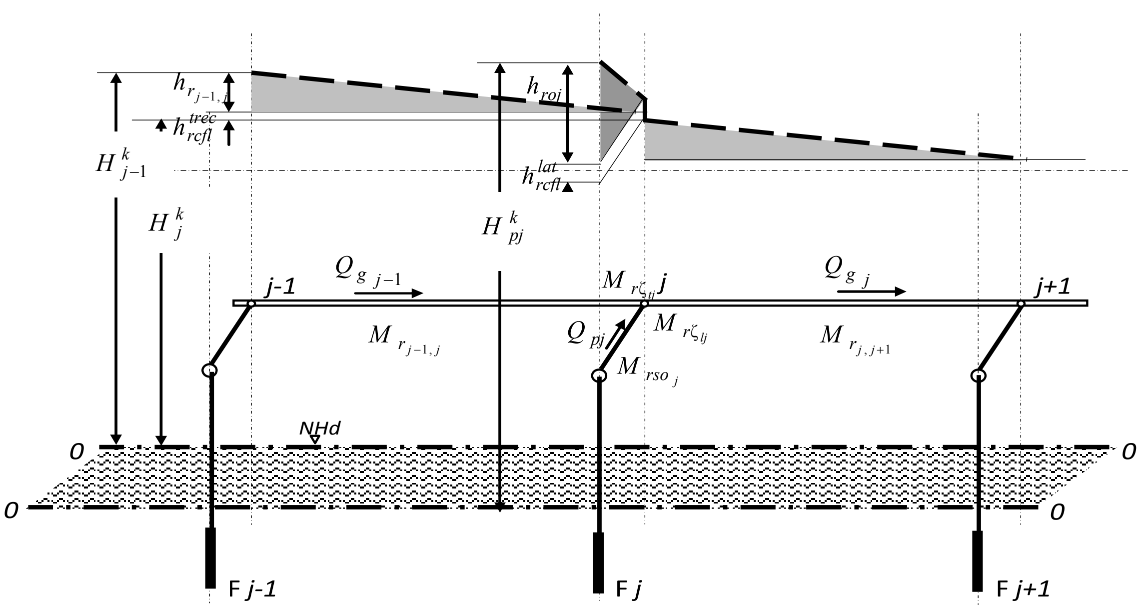


Fig.2. Schema for the relation between $H$ - $Q$ for a drilling wells battery.

$$H = H_{pf} - (K_p + M_{ro_j} + M_{r\zeta_{lj}}) \cdot Q^2. \tag{5}$$

The continuity equation for the $j$ node can be written likeness, [6]:

$$Q_{gj} = Q_{gj-1} + Q_{pj}. \tag{6}$$

The upstream group's discharge, under the current $H$ head in the $j$ node:

$$Q_{gj-1} = \sqrt{\frac{H_{gf_{j-1}} - H}{K_{g_{j-1}} + M_{r_{j-1,j}} + M_{r\zeta_{tj}}}}. \tag{7}$$

It is calculating the F$j$ well's discharge $Q_{pj}$, under the same $H$ head in $j$:

$$Q_{pj} = \sqrt{\frac{H_{pf} - H}{K_p + M_{ro_j} + M_{r\zeta_{lj}}}} \tag{8}$$

And the discharge of the (1 ÷ $j$) group under the given head

$Q_{gj}$:

$$Q_{gj} = \sqrt{\frac{H_{gf_j} - H}{K_{g_j}}}. \tag{9}$$

The continuity equation accordingly to the head H can be written likeness:

$$\sqrt{\frac{H_{gf_j} - H}{K_{g_j}}} = \sqrt{\frac{H_{gf_{j-1}} - H}{K_{g_{j-1}} + M_{r_{j-1,j}} + M_{r\zeta_{tj}}}} + \sqrt{\frac{H_{pf} - H}{K_p + M_{ro_j} + M_{r\zeta_{lj}}}}. \tag{10}$$

Respectively:

$$\sqrt{\frac{H_{gf_j} - H}{K_{g_j}}} = \sqrt{\frac{H_{gf_{j-1}} - H}{K_{g_{j-1}}}} . \frac{1}{\sqrt{1 + \frac{M_{r_{j-1,j}} + M_{r\zeta_{tj}}}{K_{g_{j-1}}}}} + \sqrt{\frac{H_{pf} - H}{K_p}} . \frac{1}{\sqrt{1 + \frac{M_{ro_j} + M_{r\zeta_{lj}}}{K_p}}}. \tag{11}$$

If the pumps are identical and placed in wells exploiting the same aquiferous having the free surface quasi-horizontal: $H_{gf_j} = H_{gf_{j-1}} = H_{pf}$ so that by using identical pressure pipes, $M_{ro_j} = M_{ro} = \text{const}$, the equation's resulting is:

$$\sqrt{\frac{1}{K_{g_j}}} = \sqrt{\frac{1}{K_{g_{j-1}}}} . \frac{1}{\sqrt{1 + \frac{M_{r_{j-1,j}} + M_{r\zeta_{tj}}}{K_{g_{j-1}}}}} + \sqrt{\frac{1}{K_p}} . \frac{1}{\sqrt{1 + \frac{M_{ro_j} + M_{r\zeta_{lj}}}{K_p}}}, \tag{12}$$

Respectively:

$$\sqrt{\frac{K_p}{K_{g_j}}} = \sqrt{\frac{K_p}{K_{g_{j-1}}}} \cdot \frac{1}{\sqrt{1 + \frac{M_{r_{j-1,j}} + M_{r\zeta_{tj}}}{K_{g_{j-1}}}}} + \frac{1}{\sqrt{1 + \frac{M_{ro_j} + M_{r\zeta_{lj}}}{K_p}}} . \tag{13}$$

By using the notation $v_k = \sqrt{\frac{K_p}{K_{g_k}}}$ the following recursion formula is obtained, that links the hydraulic resistance coefficients:

$$\nu_j = \frac{\nu_{j-1}}{\sqrt{1 + \frac{M_{r_{j-1,j}} + M_{r\zeta_{tj}}}{K_{g_{j-1}}}}} + \frac{1}{\sqrt{1 + \frac{M_{ro_j} + M_{r\zeta_{lj}}}{K_p}}} , \tag{14}$$

Where:

$$K_{g_j} = \frac{K_{g_{j-1}}}{\nu_{j-1}^2}. \tag{15}$$

Allows the head characteristic of the wells group (*1 ÷ j*) to be defined as in (3).

The following notations are used in (15): the hydraulic resistance module of one well's pressure pipe: $M_{roj}$ and the hydraulic resistance module of the tubing lengths between the well's branching $M_{rj-1,j}$.

The calculation begins at the farthest well from the downstream end *O* of the collecting pipe – branched to the $j$ = 1 node, having: $n_o = 0$; $M_{r0,1}$ $M_{r\zeta\, l1} = 0$; and continues for each node accordingly to (14) and (15) – until is reached the section for which is determined the equivalent hydraulic resistance module of the active wells group. A program for automated calculations has been written for practical applications using the above equations, using the Basic language programming. The equivalent hydraulic resistance module can be determined by using the same program for 6 ÷ 8 values of $j \le n$: $K_{gk}$, $K_{gl}$ , …, $K_{gn}$ so that afterwards, for the multiple well tapping fronts, considering $k_g \approx n$ a relation such as can be determined in given conditions:

$$K_{gn} = \frac{K_{go}}{n^{\alpha}} \tag{16}$$

It is calculated the discharge $Q$ of the well's battery depending on the head $H_0$ , (Fig. 2):

$$Q(n,Z_i)=\sqrt{\frac{H_{gf_n}-H_O}{K_{g_n}+M_{rosp}}}=\sqrt{\frac{H_{pf}+Z_i-Z_p}{K_{g_n}+M_{rosp}}}; \quad (17)$$

$$H_O=Z_p-Z_i\ .$$

In (17) are used the following symbols: the hydrodynamic level of the aquiferous –same in all wells $Z_i$ and the energetic level for the outflow section of the collecting pipe, ex: the reservoir's water level $Z_p$.

The head in the section $O$ $H_{fcO}$ is calculated with the form:

$$H_{fcO}(n,Z_i)=H_{pf}-K_{g_n}\cdot\frac{H_{pf}+Z_i-Z_p}{K_{g_n}+M_{rosp}} \quad (18)$$

The average discharge of one well from the active battery of $n$ wells, $q$ can be written with the equation:

$$q(n,Z_i)=\frac{Q(n,Z_i)}{n} \quad (19)$$

The local head loss on the specified tubing length passing through the confluence $h_{rj-1,j}$ is calculated with the form:

$$h_{rj-1,j}=(M_{rj-1,j}+M_{r\zeta tr_j})\cdot[q(n,Z_i)\cdot j]^2. \quad (20)$$

The hydraulic resistance module $M_{r\zeta trj}$ is established likeness:

$$M_{r\zeta \mathrm{tr_j}}=\frac{8}{\pi^2 g}\cdot\frac{\zeta_{ctr_j}}{D_j^4}\ . \quad (21)$$

Pressure loss on the pressure pipe $F_k$-$k$ is calculated likeness, [15, 16]:

$$h_{rlP_k k}=M_{rP_k k}\cdot[q(n,Z_i)\cdot k]^2. \quad (22)$$

In formula (22) the hydraulic resistance module of the pressure pipe $F_k$-$k$, is:

$$M_{rF_k k}=M_{ro}+\frac{8}{\pi^2 g}\frac{\zeta_{cl}}{D_o^4} \quad (23)$$

The head $H_n$ in the node $n$ has the form:

$$H_n=H_O+h_{rleg};\ h_{rleg}=M_{rleg}.Q^2. \quad (24)$$

It is with $M_{rleg}$ the hydraulic resistance module of the connecting tubing length ($nO$) in (24).

The head of current node $H_{j-1}$, commencing from the $n$ node is written with the form:

$$H_{j-1}=H_j+h_{r_{j-1,j}}\ . \quad (25)$$

The head $H_{pk}$ at the pressure pipe has the equation:

$$H_{pk}=H_k+h_{rlP_k k} \quad (26)$$

The pumping flow $Q_{pk}$ from the drilling well $F_k$, of the group of $n$ active drillings has the form:

$$Q_{pk}(n,Z_i)=\sqrt{\frac{H_{pf}-H_{pk}}{K_p}}. \quad (27)$$

The pump efficiency $\eta$ can be calculated with following mathematical form:

$$\eta(n,Z_i)=R_1\cdot\sqrt{\frac{H_{pf}-H_{pk}}{K_p}}-R_2\cdot\frac{H_{pf}-H_{pk}}{K_p}. \quad (28)$$

The power-handling capacity of the shaft pump $N$ can be calculated with following mathematical form, [14]:

$$N(n,Z_i)=\frac{981\cdot H_{pk}}{R_1-R_2\cdot\sqrt{\frac{H_{pf}-H_{pk}}{K_p}}}\ . \quad (29)$$

## III. Problem's Solution

The establishment of the final head characteristic of the battery of wells with k active drilling reckon with following problems:

All the relative data of the constructive and functional characteristics of the battery of wells – the diagram of the functional and energetic characteristics of the used pump (same type and dimensions), the structure (pipes, elbows, valves, no return valve, water – meter) and the dimensions ($L_i$, $D_i$) of the pressure pipes between the pump and the collector and also of the tubing lengths between the nodes, are added and systemized, [17].

Using specific computer programs (such as the Mat Cad of author), the hydraulic resistance modules are calculated and the parameters for the head characteristics and efficiency of the pumps are established ($H_{pf}$, $K_p$, $R_1$, $R_2$).

By using the Math Lab program of author and the results from the analysis, the equivalent resistance modules are determined for different exploiting configurations of the battery of wells ($K_{gk}$, $k = 1, 2, \ldots, n$).

If the ensemble front has two branches linked to the same *reservoir front* junction pumping station *PS* the equivalent hydraulic resistance modules according to the different exploitation configurations of this ensemble are established by using computation methodology properly to the pump in parallel connection and an adequate computer program.

Using a statistical approach for processing the connecting sleeves array ($k$, $K_{gk}$), adequate coefficients such as $K_{go}$ and $\alpha$ are established by adjusting to this a power function (16), the Microcal Origin programming system of author can be used for this calculation.

Considering the fact that $H_{gfk} = H_{pf}$, the equivalent head characteristics of the well battery are built for different exploiting configurations with $k$ active drillings:

$$H = H_{pf} - \frac{K_{go}}{k^{\alpha}} \cdot Q^2 \qquad (30)$$

The analysis of working regimes under a given head ought to allowance following rules:

- Knowing the head characteristics of the active well battery (30), for the particular case $k = n_o$ and considering the energetic levels of the two characteristic water races of the water project, by using Math Cad of author, the first step is to determine:

- The discharge of the active wells:

$$Q(n, Z_i) = \sqrt{\frac{H_{pf} + Z_i - Z_p}{\frac{K_{go}}{n_o^{\alpha}} + M_{rosp}}} \qquad (31)$$

- The head in the confluence section of the tapping front's branches:

$$H_{fcO}(n, Z_i) = H_{pf} - \frac{K_{g_n}}{n_o^{\alpha}} \cdot \frac{H_{pf} + Z_i - Z_p}{\frac{K_{g_n}}{n_o^{\alpha}} + M_{rosp}} \qquad (32)$$

- The average discharge of each active well:

$$q(n, Z_i) = \frac{Q(n, Z_i)}{n_o} \qquad (33)$$

Once the effective head in the confluence section of the tapping front's branches and the average discharge of each active well are known, the head losses are evaluated for the connecting tubing length Pn-O and head of each one's last nodes.

Using the equations (20), (25) and (26) in the Math Cad programming system of author, passing from one node to another the head for each node is calculated and finally the head for the junction of the active pumps $H_{pk}$.

Accordingly to the effective head $H_{pk}$ by using relations (27) ÷ (29) for each active pump is calculated the flow $Q_{pk}$, the efficiency $\eta_{pk}$, and the power-handling capacity of the shaft pump $N_{pk}$.

The calculation of the working regimes of the installations can express the local head loss at confluences and the local hydraulic resistance modules, as simple order's numbers functions of the singularities, comparative to the upstream end of the collector.

The mentioned situation is determined by the particularities of those singularities, making their quantitative characterization extremely laborious, (Fig. 3):

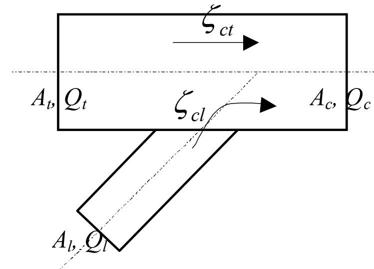


Fig.3. The schematics for the confluence of the flows

- for each confluence, the values for two local head coefficients must be established – one for the *lateral* $\zeta_{cl}$ side, the other for the *main passing* $\zeta_{ct}$, both expressing the local head loss at confluences in terms of the specific kinetic energy of the flow on the associated components;

- the values of these coefficients depend on a relatively large number of factors: the angle of the confluence $\alpha$, the rapport between the transversal section surfaces of the flows that come in contact in the given section surfaces ($a_l = A_l / A_c$; $a_t = A_t / A_c$) and the rapport of the significant flows ($q_l = Q_l / Q_c$), all their values being different from one collector's confluence to another;

- The tables and diagrams presented in the specialty literature give the values of the two coefficients for the specific kinetic energy of the flow transported by the collectors ($v_c^2 / 2g$), so that for determining the lateral head loss, its value has to be recalculated, so that it can be associated to the kinetic energy of that specific flow: $\zeta^{l}_{cl} = \zeta_{cl} (a_l / q_l)^2$.

- The local hydraulic resistance modules involved in the analysis have to be calculated according to the modifications from one confluence to another of the channel diameters.

In order to facilitate the calculation of the working regimes of such installations, the results obtained trying to establish relations between the local hydraulic resistance modules, as simple functions of ordering numbers of singularity $j$ of the upstream end of the collector are presented in the following.

In order to evaluate the local head loss at flow confluences, besides tables and diagrams, the specialty literature presents also some formulas such as those proposed by Levin and Taliev, that, by having a solid theoretical base, contain also the corrections imposed by the calculation comparison of experimental results obtained by Levin, Gardel, Kinne, Petermann and Vogel [12].

For the lateral pipe-line, the coefficient of the locale head loss $\zeta_{cl}$ is given by the following relation:

$$\zeta_{cl} = h_{rcl} / \left(v_c^2 / 2.g\right) = K_{lt} + +B.\left[1 + \left(\frac{q_l}{a_l}\right)^2 - 2.\frac{(1-q_l)^2}{a_t} - 2.\frac{q_l^2}{a_l} \cdot \cos\alpha\right] \quad (34)$$

And the coefficient of the local head loss of the passing $\zeta_{ct}$ results from the following relation:

$$\zeta_{ct} = h_{rct} / \left(v_c^2 / 2g\right) = 1 + \left(\frac{1-q_l}{a_l}\right)^2 - -2.\frac{(1-q_l)^2}{a_t} - 2.\frac{q_l^2}{a_l} \cdot \cos\alpha + K_t \quad (35)$$

The values of the coefficients $B$, $K_l$, $K_t$ are systematized in Tables I and II. The coefficients $K_l$ and $K_t$ for the confluences with $A_l + A_t > A_c$, become nulls $K_l = K_t = 0$.

TABLE I
THE VALUES OF THE COEFFICIENT *B*

| $a_l$ | ≤ 0,35 | > 0,35 | |
|---|---|---|---|
| $q_l$ | 0,1 | ≤ 0,4 | > 0,4 |
| B | 1,0 | 0,9(1-$q_l$) | 0,55 |

TABLE II
THE VALUES OF $K_L$ AND $K_T$ COEFFICIENTS WHEN $A_L + A_T = A_C$

| α | $a_l$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0,10 | | 0,20 | | 0,33 | | 0,5 | |
| | $K_l$ | $K_t$ | $K_l$ | $K_t$ | $K_l$ | $K_t$ | $K_l$ | $K_t$ |
| 30 | 0 | 0 | 0 | 0 | 0,17 | 0,14 | 0 | 0,35 |
| 45 | 0 | 0,05 | 0 | 0,14 | 0 | 0,14 | 0 | 0,30 |
| 60 | 0 | 0 | 0 | 0 | 0 | 0,10 | 0,10 | 0,25 |
| 90 | 0 | 0 | 0,1 | 0 | 0,20 | 0 | 0,25 | 0 |

For the lateral pie-line, the coefficient of the head loss at the confluence is expressed in terms of the specific kinetic energy, by the following relation:

$$\zeta_{cl}^{lat} = h_{rcl} / \left(v_l^2 / 2g\right) = \zeta_{cl} \cdot \left(\frac{a_l}{q_l}\right)^2 \quad (36)$$

The confluence of the pipes with circular section is characterized by the diameters $D_l$, $D_t$, $D_c$, respectively associated to the passing of the lateral canalization and the tubing length collector; this is the reason how is determined the particularization of the values used for the determination of the coefficients of the locale head loss, [11]:

$$a_l = \frac{A_l}{A_c} = \left(\frac{D_l}{D_c}\right)^2 ; \; a_t = \frac{A_t}{A_c} = \left(\frac{D_t}{D_c}\right)^2 . \quad (37)$$

For a collector with $n$ confluences whose *laterals* have the same diameter $D_c = d$ and transporting the same flow $Q_l = q$ (Fig. 1) the relative discharge $q_l$ becomes a function of $k$ (his ordering number); the nods are numbered starting with the farthest upstream confluence:

$$q_l(k) = \frac{Q_l(k)}{Q_c(k)} = \frac{q}{k.q} = \frac{1}{k} \quad , \quad k = 1,2,...,n \quad (38)$$

For certain values of the relative area of the *lateral* $a_l \in \{0.2, 0.4, 0.6, 0.8, 1\}$, in the case of the confluence under an angle $\alpha \in \{30^0, 45^0, 60^0, 90^0\}$, for collectors with $a_l$=1 – structures with $D_l$=$D_c$ – usually found in practice, by using the Math Cad program and based on the relations (34) and (35), the diagrams of the coefficients of the locale head loss at the confluences $\zeta_{cl}$, $\zeta_{ct}$, are obtained the Figures 4, 5, 6, 7.

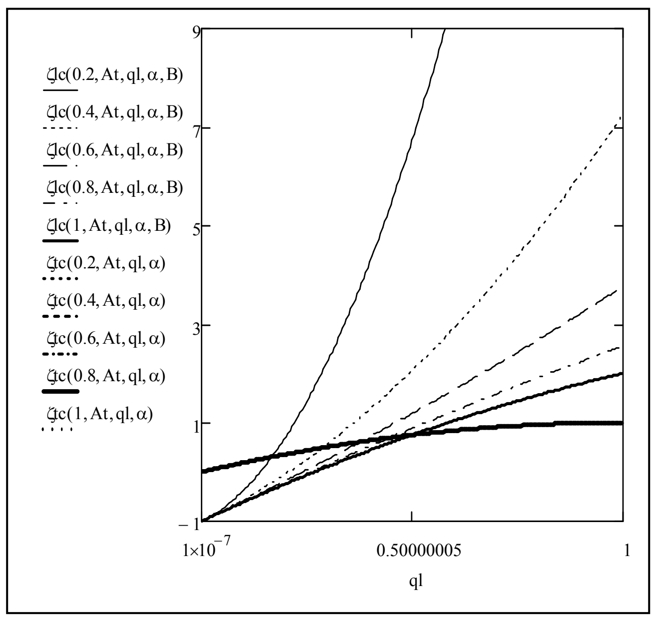


Fig.4. Local head loss coefficient for the 90° confluence reported to collector

Local head loss depends on the effective discharge according to the locale hydraulic resistance modules – on the lateral pipeline and on the passing. The relations are:

$$M_{r\zeta cl}(D_l, D_c, \alpha, k) = \frac{8.B.(k.a_l)^2}{\pi^2.g} . \left[1 + \left(\frac{1}{k.a_l}\right)^2 - 2.\frac{\left(1-k^{-1}\right)^2}{a_t} - 2.\frac{k^{-2}}{a_l} \cdot \cos\alpha\right] \quad (39)$$

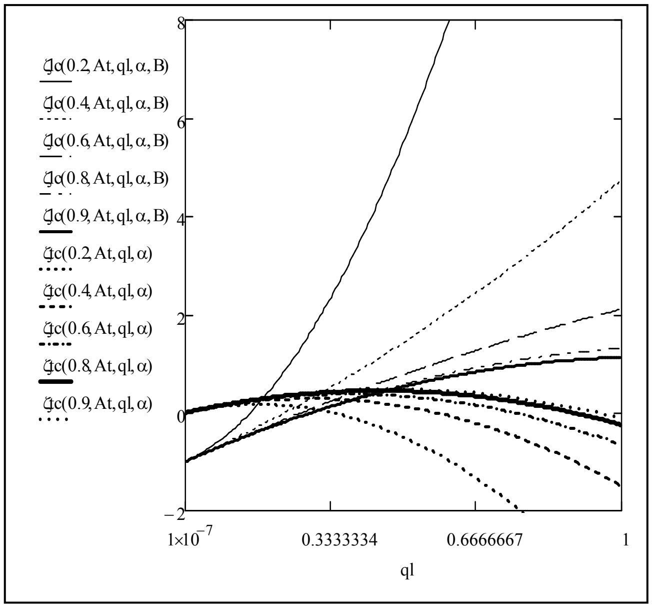


Fig.5. Local head loss coefficient for the 60° confluence reported to collector

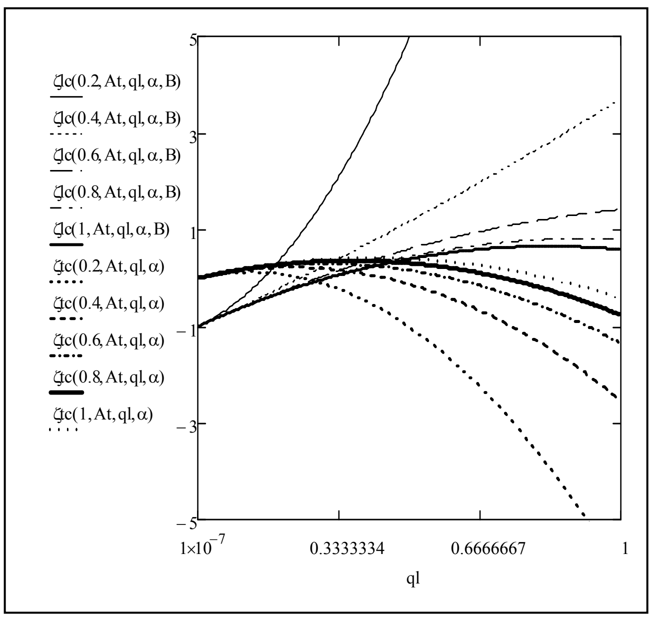


Fig.6. Local head loss coefficient for the 45o confluence reported to collect

$$M_r\zeta_{ct}(D_l,D_c,\alpha,k)=\frac{8}{\pi^2.g}\cdot \left[1+\left(\frac{1-k^{-1}}{a_t}\right)^2-2.\frac{\left(1-k^{-1}\right)^2}{a_t}-2.\frac{k^{-2}}{a_l}\cdot\cos\alpha\right] \qquad (40)$$

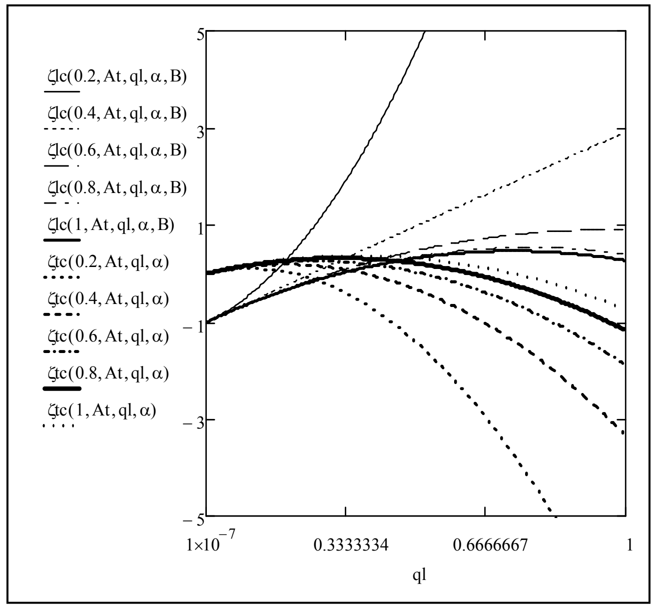


Fig. 7. Local head loss coefficient for the 30° confluence reported to collect

In the same condition, by using the relation (36) the corresponding diagrams of the locale head loss are obtained at the confluence expressed in terms of the specific kinetic energy of the directional water-flow $\zeta_{cl}^{lat}$, $\zeta^{col}{}_{ct}$. The diagrams are presented in the Figures 8, 9, 10, 11.

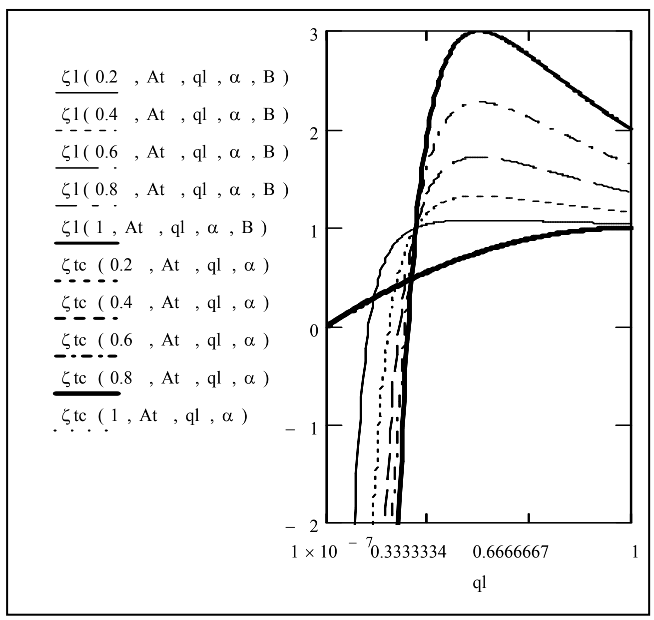


Fig. 8. Local head loss coefficient for the 90° confluence reported to interested communications

The specific values for a practical case can be easily determined by using the same program Math Cad, therefore obtaining pair orders ($k$, $M_{r\ \zeta cl}$), respectively ($k$, $M_{r\ \zeta ct}$), with $k$ = 1, 2, …, $n$.

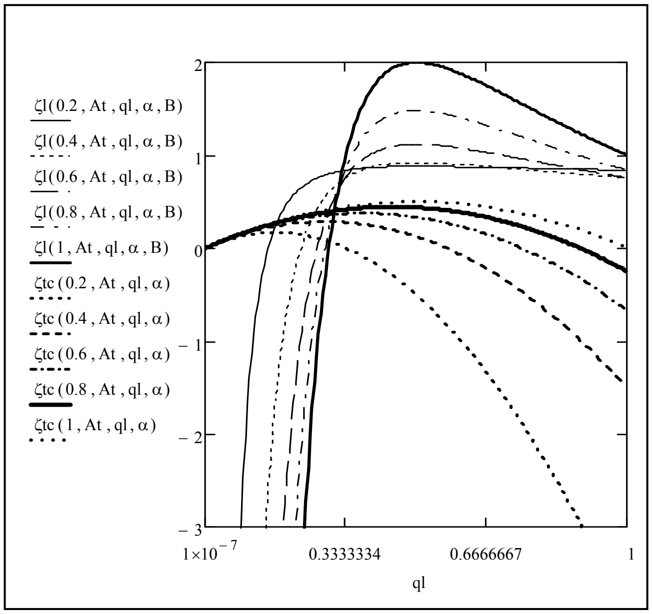


Fig. 9. Local head loss coefficient for the 60° confluence reported to interested communications

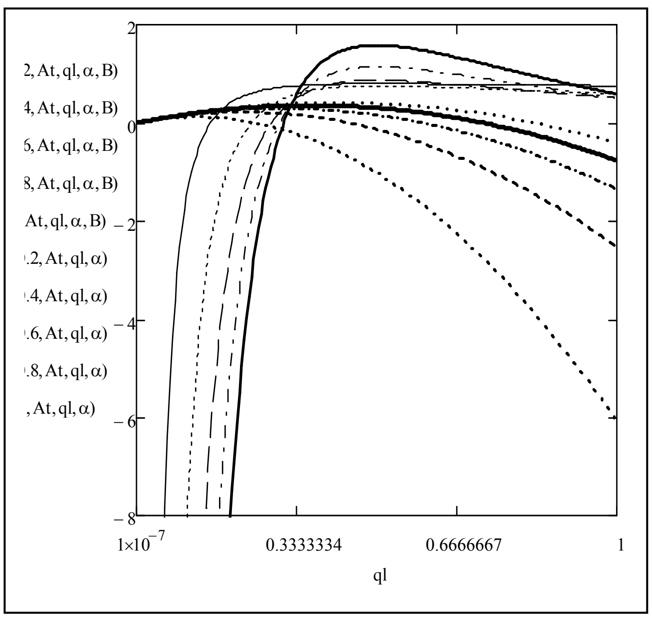


Fig. 10. Local head loss coefficient for the 45° confluence reported to interested communications

In order to facilitate the analysis of the working regimes for such hydraulic systems with different operating configurations, the use of the suitable analytical functions for expressing ($k \sim M_{r\,\zeta cl}$), respectively ($k \sim M_{r\,\zeta ct}$), is recommended. Therefore, by analyzing the value orders using numerical methods (such as the method of the smallest squares), relations can be obtained in the following forms:

- The local hydraulic resistance module at the lateral pipe - line of the confluence:

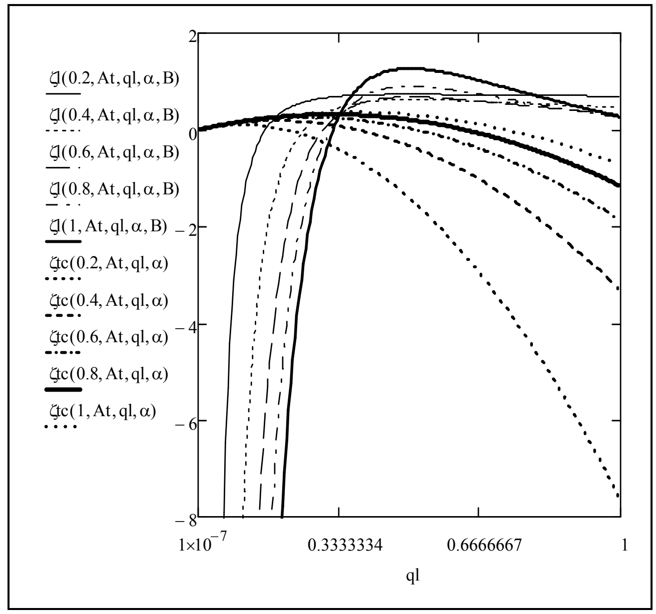


Fig. 11 Local head loss coefficient for the 30° confluence reported to interested communications

$$M_{r\zeta cl}(k) = M_{r\zeta lo} - M_1.k - M_2.k^2 \qquad (41)$$

- The local hydraulic resistance module of the *passing*:

$$M_{r\zeta ct} = \frac{M_{r\zeta cto}}{k^b}. \qquad (42)$$

The ground water front 1 ensemble Motca - Pascani placed on the left bank of the Moldova river is constituted of a battery of 20 drilling wells equidistantly disposed in two branches: the front 1 – on the right bank with 13 wells and the front 1 – on the left side, with 7 wells (Fig. 2).

The water pumping from the wells is made with submerged pumps HEBE 65x2 with quasi – identical energetic and functional characteristics.

The Dn 100 pressure pipes are 10 meters in length, have three - 90° elbow, one paddle flow meter, a valve and a non-return valve. Due to equivalent roughness $k$ = 0,8 mm and local resistances $\Sigma\zeta_i$ = 9,64, these are characterized by a hydraulic resistance module $M_{ro}$ = 11040,6 $s^2.m^{-5}$.

By using the calculation program developed for the Math Cad programming system, considering the mathematical model presented, the values for the coefficient of the local head loss at confluences and their hydraulic resistance modules have been determined and the resulting values are systemized in Table III.

TABLE III
THE LOCAL HEAD LOSS COEFFICIENTS AND THE LOCAL HYDRAULIC RESISTANCE MODULES AT THE TAPPING FRONT CONFLUENCES 1 MOTCA – PASCANI, CHARACTERIZED BY $D_L = D = 100$ MM, $D_T=D_C$, $\alpha = 90^o$ ŞI $Q_L(K) = Q_L/Q_C = 1/K$

| Nod $k$ | $D_c$ (mm) | $a_l=(D_l/D_c)^2$ | $q_l$ | $\zeta_{cl}^{lat}$ | $\zeta_{ct}^{col}$ | $M_{r\zeta cl}$ | $M_{r\zeta ct}$ |
|---|---|---|---|---|---|---|---|
| 1 | 100 | 1,000 | 1 | 0,589 | 0 | 486,51 | 0 |
| 2 | 150 | 0,444 | 0,5 | 0,767 | 0,75 | 633,78 | 122,37 |
| 3 | 150 | 0,444 | 0,333 | 1,198 | 0,556 | 986,16 | 90,645 |
| 4 | 200 | 0,250 | 0,25 | 0,875 | 0,437 | 722,75 | 22,586 |
| 5 | 200 | 0,250 | 0,2 | 0,562 | 0,360 | 464,63 | 18,585 |
| 6 | 200 | 0,250 | 0,167 | 0,125 | 0,306 | 103,25 | 15,774 |
| 7 | 200 | 0,250 | 0,143 | -0,438 | 0,265 | -362,38 | 13,696 |
| 8 | 250 | 0,160 | 0,125 | 0,130 | 0,234 | 107,05 | 4,956 |
| 9 | 250 | 0,160 | 0,112 | -0,203 | 0,210 | -167,84 | 4,438 |
| 10 | 250 | 0,160 | 0,1 | -0,587 | 0,190 | -485,03 | 4,018 |
| 11 | 250 | 0,160 | 0,091 | -1,022 | 0,174 | -844,50 | 3,670 |
| 12 | 300 | 0,111 | 0,083 | -1,509 | 0,160 | -1246 | 3,377 |
| 13 | 300 | 0,111 | 0,077 | -2,046 | 0,148 | -1690 | 3,128 |

The variation of the specific values along the collector can be easily detected by representing them in graphs as functions of the order numbering of the confluence node that is associated the number 1, corresponding to the first upstream node. The variation of the local head loss coefficients is presented in the Fig. 12 and the variation of the hydraulic resistance modules, in the Fig. 13.

The analysis through numerical methods of the value couples represented in Fig. 12, 13, in order to adjust the function for the best approximation, have led (by using the Microcal Origin programming environment) to the determination with good precision for practical cases to relations such as (41) and (42) whose coefficients are:

$$M_{r\varsigma 10} = 878{,}77;\ M_1 = 15{,}40;\ M_2 = 13{,}37, \tag{43}$$

Respectively:

$$M_{r\varsigma\, to} = 458{,}82\ \ ;\ b = 1{,}82207, \tag{44}$$

In the case of the tapping front working at nominal capacity ($q \cong 0{,}008$ m$^3$/s; $Q(k) = k.\ q$), its lateral head loss are given by the expression:

$$h_{rcl} = 0{,}763 - 0{,}00099.k - 0{,}00086.k^2 \tag{45}$$

where $h_{rel}$ varies between $h_{r\zeta} = 0{,}76$ m – on the first well pipe connection $P_1$ and $h_{r\zeta} = 0{,}60$m – on the $P_{13}$ well pipe connection, whilst the local head loss at confluences that has reduced values (smaller than 5cm), reduces to negligible values for the last confluences.

## IV. EXPERIMENTAL RESULTS

The head characteristics and working regime of the ground water front 1 ensemble Motca – Pascani are established considering the alimentation of a reservoir with bed level $Z_p$.

The ground water front 1 ensemble Motca - Pascani is made of a battery placed on the left bank of the Moldova River, of 20 drilled wells placed equidistantly in two branches: front 1 - right, with 13 wells and tapping front 1 –left, with 7 wells (Fig. 2).

The submersible HEBE 65x2 electro pumps are being used to pump water from the wells and these pump's functional and energetic characteristics are analytically represented by the parameters of the head curve ($H_{pf} = 31{,}22$ m; $K_p = 327571{,}5$ s$^2$.m$^{-5}$) and those of the efficiency curve ($R_1 = 18464$; $R_2 = 1903360$).

The pipes Dn 100 are 10 meters in length have three - 90$^o$ elbow, one paddle flow meter, a valve and a non-return valve. Due to equivalent roughness $k = 0{,}8$ mm and local resistances $\Sigma\zeta_i = 9{,}64$, these are characterized by a hydraulic resistance module $M_{ro} = 11040{,}6$ s$^2$.m$^{-5}$.

The collecting pipes, having the absolute equivalent roughness of its composing pipes estimated $k = 0.8$ mm, are characterized – according to nominal diameters, their length and the design discharge – by the hydraulics resistance modules of the pipes $M_{r_{j-1,j}}$ (Fig. 14) and those of the confluences ($M_{r\zeta cl_j}, M_{r\zeta ct_j}$). Their values are calculated using Mat Lab program of author and the results are in the first three columns of Tables IV and V.

Using the Math Lab calculation program with the previously determined data the resistance modules $K_{gj}$ for the active well group ($F_1$ , …, $F_j$) upstream from the current node $j$ are established and shown – with the corresponding $v_j$ coefficients – in the same tables. Math Lab calculation program with the previously determined data the resistance modules $K_{gj}$ for the active well group ($P_1$ , …, $P_j$) upstream from the current node $j$ are established and shown – with the corresponding $v_j$ coefficients – in the Tables IV and V.

In order to analyze the working regimes of the front ensemble in the system, starting from the hydraulic resistance modules $K_{gj}$, (the resistance modules according to the head characteristics for confluence section of the two branches $K_{gOj}$) are also determined and represented in the last column of Tables IV and V, next to the resistance modules of the (*j-O*) tubing length of the collecting pipes.

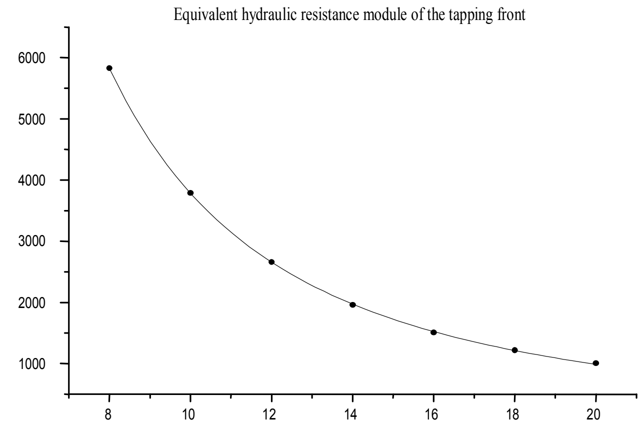


Fig. 14. The variation of the equivalent hydraulic resistance module of the front ensemble, accordingly to the number of active wells.

Based on the equivalent head characteristics, whose parameters ( $H_{gfO_k} = H_{pf}$ and $K_{gO_k}$ ) have been determined, the head curves of the battery of wells that function on the left (Fig. 15) and right branch (Fig. 16) of the front ensemble are calculated.

The resulting characteristics of the system made of the two branches, in given conditions, are determined by using the equivalent hydraulic resistance modules, for the exploiting configurations of each branch ( $K^s_{gO_m}, K^d_{gO_l}$ ), according to the classic relation for the group of pumps connected in parallel, when $H^s_{gf_m} = H^d_{gf_k} = H_{fp}$ :

$$\frac{1}{\sqrt{K_{gO_{m+k}}}} = \frac{1}{\sqrt{K^d_{gO_m}}} + \frac{1}{\sqrt{K^s_{gO_k}}} \qquad (46)$$

Considering the reasonable combinations of m active wells on the right branch of the tapping front and k active wells on the left branch, so that $m + k = 8, 10, \ldots, 20$ the results from table 3 are obtained. The equivalent hydraulic resistance modules of the front 1 ensemble Motca - Pascani in a couple of exploiting configurations with 8 ÷ 20 active wells.

The analysis of the results from Tables IV, V and VI indicate close values of the $K_{gO}$ modules obtained in different combinations with the same total number of active wells; therefore the results have been systemized in Table VII.

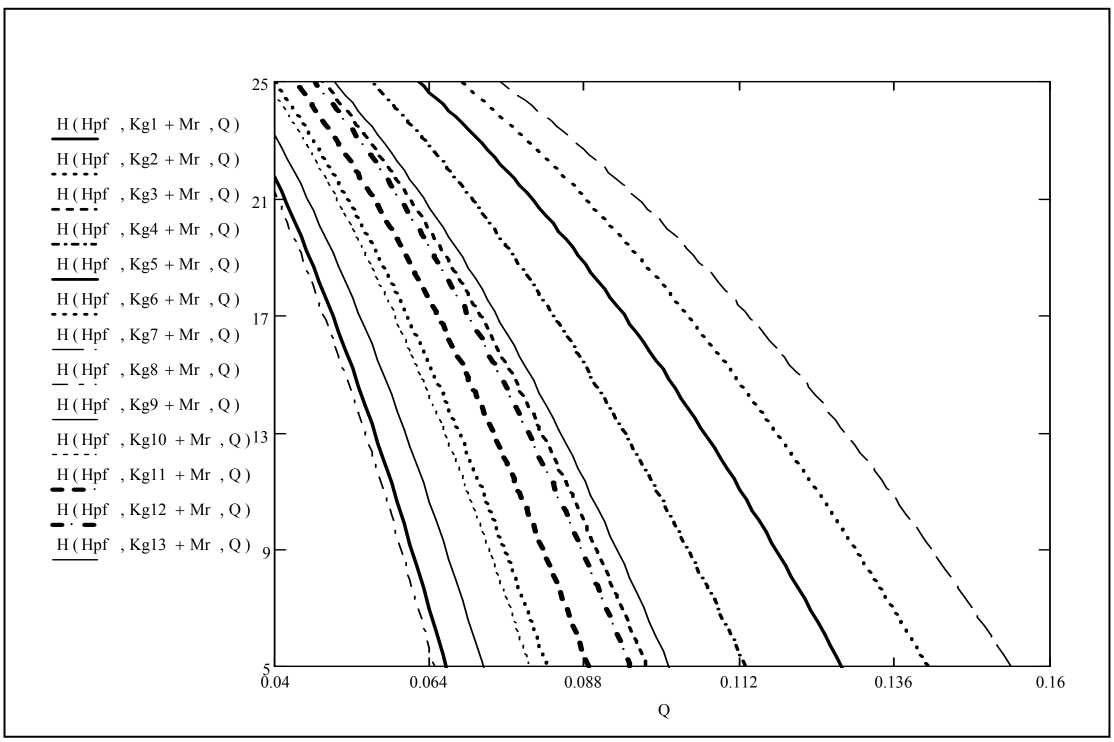


Fig. 15. Head characteristic of the wells battery – the tapping front 1 left, in different configurations having $k = 1, 2, ..., 13$ active wells, exploited between $Z_{imin}$ = 260 mNM and $Z_{imax}$ = 267mNM, on a reservoir having $Z_p$ = 272 mNM.

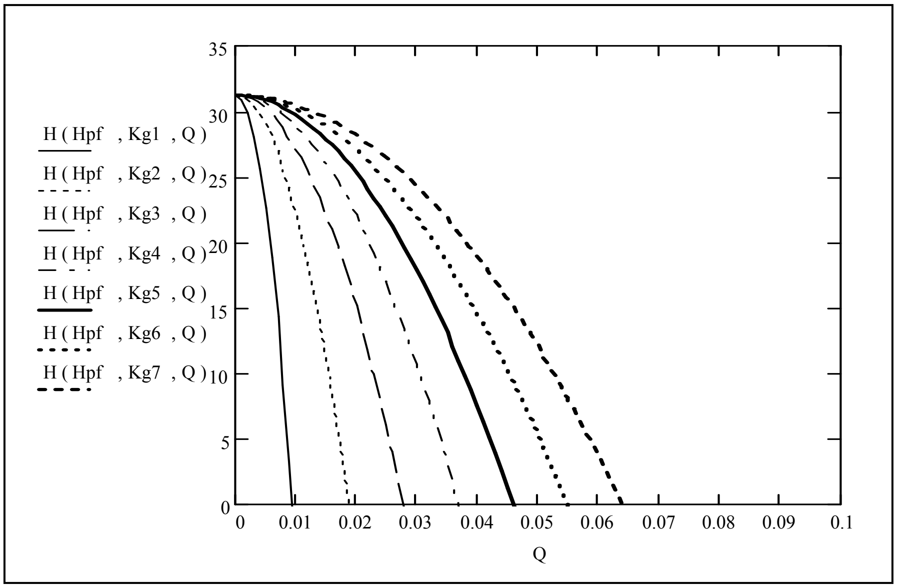


Fig. 16. Head characteristic of the wells battery – the front 1 right ensemble, in different configurations having $k$ = 1, 2, ..., 7active wells, exploited between $Z_{imin}$ = 260 m and $Z_{imax}$ = 267m, on a reservoir having $Z_p$ = 272 m.

TABLE IV
THE HYDRAULIC RESISTANCE MODULES OF THE FRONT 1- LEFT COMPONENTS AND THE PARAMETERS OF THE RESULTING HEAD CHARACTERISTIC OF THE ACTIVE WELLS GROUP

| $j$ Node | $M_{rlat_j}$ | $M_{r_{j-1,j}}$ | $M_{r\zeta ct_j}$ | $\nu_j$ | $K_{gj}$ | $\Sigma M_{rjO}$ | $K_{gO}$ |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 0.98 | 333046.0 | 12850 | 345896 |
| 2 | 910 | 9360 | 2 | 1.95 | 85946.5 | 3490 | 89436 |
| 3 | 725 | 1089 | 14 | 2.92 | 38356.2 | 2401 | 40757 |
| 4 | 505 | 1089 | 25 | 3.86 | 21943.6 | 1312 | 23256 |
| 5 | 300 | 239.6 | 37 | 4.82 | 14084.2 | 1072 | 15157 |
| 6 | 95 | 239.6 | 25 | 5.76 | 9868.4 | 833 | 10701 |
| 7 | -105 | 239.6 | 60 | 6.66 | 7386.0 | 593 | 7979 |
| 8 | -308 | 239.6 | 72 | 7.51 | 5812.0 | 354 | 6166 |
| 9 | -510 | 74.2 | 85 | 8.39 | 4652.4 | 279 | 4932 |
| 10 | -715 | 74.2 | 96 | 9.23 | 3848.2 | 205 | 4053 |
| 11 | -917 | 74.2 | 110 | 10.25 | 3115.2 | 131 | 3246 |
| 12 | -1150 | 74.2 | 128 | 10.92 | 2745.9 | 57 | 2803 |
| 13 | -1400 | 28.6 | 147 | 11.57 | 2445.2 | 28 | 2473 |
| | | | | | 333046.0 | | |

TABLE V
THE HYDRAULIC RESISTANCE MODULES OF THE FRONT 1-RIGHT COMPONENTS AND THE PARAMETERS OF THE RESULTING HEAD CHARACTERISTIC OF THE ACTIVE WELLS GROUP

| $j$ Node | $M_{rlat_j}$ | $M_{r_{j-1,j}}$ | $M_{r\zeta ct_j}$ | $\nu_j$ | $K_{gj}$ | $\Sigma M_{rjO}$ | $K_{gO}$ |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 268 | 0.98 | 333046 | 12496.4 | 345542.4 |
| 2 | 910 | 9360 | 11 | 1.95 | 85947.6 | 3136.4 | 89084.0 |
| 3 | 725 | 1089 | 25 | 2.92 | 38359.8 | 2047.74 | 40407.5 |
| 4 | 505 | 1089 | 37 | 3.86 | 21950.0 | 958.4 | 22908.4 |
| 5 | 300 | 239.6 | 49 | 4.82 | 14093.5 | 718.8 | 14812.3 |
| 6 | 95 | 239.6 | 60 | 5.75 | 9893.7 | 479.2 | 10372.9 |
| 7 | -105 | 239.6 | 75 | 6.65 | 7410.9 | 239.6 | 7650.5 |

TABLE VI
THE EQUIVALENT HYDRAULIC RESISTANCE MODULES OF THE FRONT 1 ENSEMBLE MOTCA- PASCANI IN A COUPLE OF EXPLOITING CONFIGURATIONS WITH 8 ÷ 20 ACTIVE WELLS

| Active wells | | $K^{d}_{gO_m}$ | $K^{s}_{gO_k}$ | Total active wells | $K_{gO}$ |
|---|---|---|---|---|---|
| 1 right | 1 left | | | | |
| 7 | 13 | 7650,5 | 2473,82 | 20 | 1005,36 |
| | 11 | | 3246,64 | 18 | 1190,45 |
| | 9 | | 4932,2 | 16 | 1517,35 |
| | 7 | | 7979,64 | 14 | 1953,12 |
| | 5 | | 15157,04 | 12 | 2614,96 |
| 5 | 13 | 14812.3 | 2473,82 | 18 | 1246,66 |
| | 11 | | 3246,64 | 16 | 1506,19 |
| | 9 | | 4932,2 | 14 | 1983,14 |
| | 7 | | 7979,64 | 12 | 2653,98 |
| | 5 | | 15157,04 | 10 | 3745,80 |
| 3 | 9 | | 4932,2 | 12 | 2708,8 |
| | 7 | | 7979,64 | 10 | 3824,87 |
| | 5 | | 15157,04 | 8 | 5829,59 |

TABLE VII
THE CALCULATION VALUES OF THE EQUIVALENT HYDRAULIC RESISTANCE MODULE IN EXPLOITING CONFIGURATIONS WITH 8 ÷ 20 ACTIVE WELLS

| n | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
|---|---|---|---|---|---|---|---|
| $K_{gO}(n)$ | 5830 | 3790 | 2660 | 1960 | 1510 | 1220 | 1010 |

The head characteristics of the front 1 ensemble can be therefore expressed, for any combination of *n* active wells ($n = k = 8 \div 20$), analytically with the relation and graphically with head curves based on the relation (30), where $H_{pf} = 31{,}22$; $K_{go} = 326370$; $\alpha = 1{,}93562$.

In the case of maximum capacity ($n = 20$) exploitation, reported to the hydrodynamic level of water in the wells, the tapping front provides a catchments discharge $q(20, Z_i)$, under the head in *O: Ho*, with the medium discharge of each well $q(20, Z_i)$, whose values are presented in Table VIII.

Fig. 17 presents the head, the outturn characteristic $\eta$ for collecting front ensemble $H_f$ and the head characteristic of the pipes network $H_R$ for two static head, depending on flow $Q$.

Fig. 18 shows the working and energetic specific features of the submersible pumps, the piezometer lines of collector and wells with pumping, the flow's variation pumped $Q$ and the pump's output $\eta$.

TABLE VIII
THE FUNCTIONAL CHARACTERISTICS OF THE GROUND WATER FRONT 1 ENSEMBLE, PUMPING ON A RESERVOIR HAVING OPERATING WATER LEVEL $Z_P$ = 272 M

| No | $Z_i$ [m] | $Q$ [m$^3$/s] | $H_O$ [m] | $q$ [l/s] |
|---|---|---|---|---|
| 1 | 267 | 0,155 | 7,33 | 7,8 |
| 2 | 260 | 0,133 | 13,71 | 6,7 |

## V. CONCLUSION

By determining the local head loss coefficients at the collector's confluences with multiple lateral communications, based on the semi empirical relations *Levin – Taliev* and on the associate hydraulic resistance modules, analytical expressions can be established quite precise particularized for each studied system, by using Math Cad and Microcal Origin programming system, those analytical expressions facilitate the analysis of the effective working regime of the system, specifying the influence of the hydraulic resistances. The case study of the tapping front Motca – Pascani clearly indicates that – in these specific conditions – the local resistance of the passing through confluence is significantly low, so that it can be neglected, whilst the local hydraulic resistance of the *laterals* at the confluence present significant values that decrease towards the outlet of the collector, and starting from the 6th node they take negative values so a suction effect of the lateral flow by the collector flow is manifesting.

The evolution of the effective values of the head loss coefficients along the collector allows for a more objective reason for its telescoped piping tract.

Due to head loss between the collector's nodes but also because of the variation of local hydraulic resistance at confluences, the pump's head differ from one well to another, therefore the discharge and the efficiency of the electro-pumps and their energy consumption differs.

The determination in working conditions of the effective working regimes of each well can be realized by using an analytical method, elaborated by using a systematically approach of the functioning of the battery of quasi – identical pumping wells, that are exploiting a homogenous aquiferous.

The proposed analysis method is based on the system's mathematical modelling, made easier by the use of the analytic characteristics of its components and the automated data processing system.

The results obtained by applying the proposed method in the case of the tapping front 1 Motca – Pascani, concurs very well with the data obtained through on – site measurements of the mentioned installation.

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