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The method of discrete-continuous research for hydraulic calculations of circular distribution network lines with uniform gridiron selection

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Abstract: Taking into account the main power factors and laminar flow of compressible and incompressible media have developed a method of hydraulic calculation of the exact circular pipe with one node approach and the limited number of the travel selection.

Keywords: The Law Kirhgofa, The Recirculating Network, "Jam", The Node Cart, The Node Of The Selection, The Hydraulics

1. Introduction

Ring network of pipelines is notable that nature selects the optimum mode of flow in it. However, the specialist who builds and operates a network should take into account the needs of consumers, the minimum values of the pressure at the nodes connecting consumers necessary capital expenditures, operating costs and other features of the life of the object. Difficult task with multiple connection nodes registered users - nodes selection of hot and cold water, natural gas and other end products. To solve these problems in [1], an approach equidistant nodes with the same intensity of selection criteria. Similar approach, but in a distributed throughout the length of the selection, known as a uniform approach track selection, used in [2,3]. Continuing these studies, the following method is proposed accurate hydraulic calculations loopback pipeline network to supply a single node and the limited number of nodes in the selection among the state of the laminar flow.

2. Basic Concepts and Assumptions

If the entrance area (x=0), the mass flow rate of the medium, then the intensity of uniform track selection$m=q/L$ (q– second overall selection of the site with the length L) system solution of monomer-quasi equations of momentum and mass conservation.

$$\frac{dp}{\rho}+g\frac{dy}{dx}+\frac{\lambda|w|w}{2D}dx=0,\ M=\rho wF=M_0-mx \qquad (1)$$

comparing potential energy of unique mass unit:

$$P(x)=\begin{cases} p(x) \ \ \textit{for compressible environment}; \\ p(x)+\rho wy(x)\ (x) \ \ \textit{for incompressible environment}; \end{cases}$$

then

$$P_B-P_E=\frac{8\pi\nu}{F^2}\left(M_0-\frac{q}{2}\right)L\ . \qquad (2)$$

Here p,ρ,w,M - the average static pressure, density, velocity and mass flow of the medium at x; D,F,λ - internal diameter, free area and the resistance coefficient; g - acceleration of gravity - the height of the slope leveling pipe axis y(x) on the horizon; $\lambda=64/\mathrm{Re}$ - the formula Stokes drag coefficient; Re - Reynolds criterion - the kinematic viscosity of the transported medium - the value of the potential energy of the unit mass of the medium at the beginning and end of the section.

When transporting compressible medium its density obeys a real gas law $\rho = p/(ZRT)$ (hereZ,R,T - compressibility, temperature, gas constant gas). By virtue of its smallness in the force of gravity to ignore P(x). For incompressible fluid taken $\rho = const$.

3. Formulation of the Problem

Consider the loop pipeline with one node for supplying medium and N sites with travel selection with different intensity.

Common selections of the sites are $q_1, q_2, q_3, ..., q_{N-1}, q_N$; the lengths of $l_1, l_2, l_{3,...,} l_{N-1}, l_N$, cross-sectional areas $F_1, F_2, F_3, ..., F_{N-1}, F_N$. To isolate the pressure and the height of the pipe axis leveling the nodes use indexes from 0 to N. The index 0 to N correspond to the same section - site gas supply. The intensity of the supply M_0 and the pressure $-p_0$.

Need to find a flow and pressure of the medium in the nodes of the ring, with the smallest coordinate of the reduced potential energy of the transported medium and appropriate at this point to the static pressure.

4. Method of Solving the Problem

Let that in the section $x_* = \theta l_K$ $(0 \le \theta < 1)$ from the beginning of the K section counterclockwise reached the lowest value for the ring potential ofgiven energy where the flow direction changes.

The first section of the ring counter-clockwise input the flow rate isM_1. With the passage of the 1st section of it is reduced to, the passage of the 2nd section - for another, while passing the third area - another ..., passing K-1st section - for another. The K section and it is reduced by θq_K and the cross section $x_* = \theta l_K$ becomes zero (see figure). Therefore, the relationship between unknown M_1 and θ has the following form

$$M_1 = q_1 + q_2 + q_3 + ... + q_{K-1} + \theta q_K. \qquad (3)$$

Therefore, the formula for the differential given the potential energy of the medium on the elementary sections with movements counterclockwise written as

$$P_{i-1} - P_i = \begin{cases} \dfrac{8\pi\nu\theta l_i}{F_i^2}\left(-\dfrac{q_i}{2} + \sum\limits_{j=i}^{K-1} q_j + \theta q_K\right) & for \quad i = 1,2,...,K-1 \\ \dfrac{8\pi\nu\theta l_i}{F_i^2}\dfrac{\theta q_i}{2} \quad for \quad i = K,\ P_i = P_*. \end{cases} \qquad (4)$$

To get rid of the intermediate values of the reduced potential energy of the medium, adding the formula (4) on the allowed values for i, go to the total potential energy of the drop shown in the network counterclockwise

$$P_0 - P_* = 8\pi\nu \sum_{i=1}^{K-1} q_i \left(\sum_{j=1}^{i} \frac{l_j}{F_j^2} - \frac{l_i}{2F_i^2} \right) +$$

$$+ 8\pi\nu\theta q_K \left(\sum_{j=1}^{L-1} \frac{l_j}{F_j^2} + \frac{\theta l_K}{2F_K^2} \right) \qquad (5)$$

In this equation, two unknowns p_*, θ.

We proceed similarly for the elementary sections, in which the motion of the medium occurs in the clockwise direction:

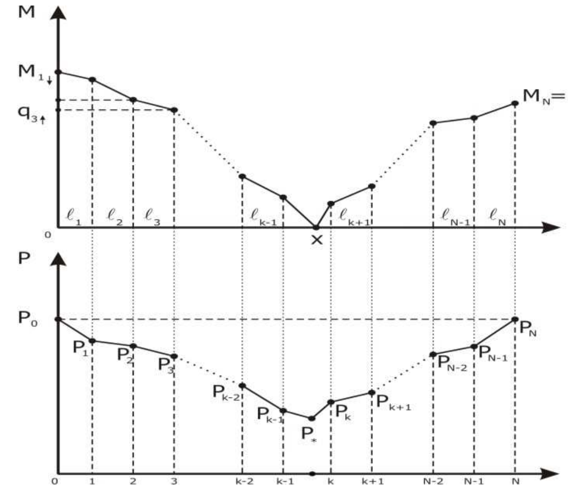

Fig 1. *Schematic representation of changes in the mass flow rate of travel and the reduced potential energy of the transported medium in a circular pipe with transportation selection with different intensities at elementary sections*

$$P_i - P_{i-1} = \begin{cases} \dfrac{8\pi\nu(1-\theta)l_i}{F_i^2}\dfrac{(1-\theta)q_i}{2} \quad for \quad i = K, P_{i-1} = P_*; \\ \dfrac{8\pi\nu l_i}{F_i^2}\left((1-\theta)q_K + \sum\limits_{j=K+1}^{i} q_j - \dfrac{q_i}{2}\right) \quad for \quad i = 1, K+2, ..., N-1, N. \end{cases} \qquad (6)$$

Here also will reduce the number of unknowns, for which we calculate the total potential energy of the drop shown in the network environment in the clockwise direction from the inlet section to a section $x_* = \theta l_K$

$$P_N - P_* = 8\pi\nu(1-\theta) q_k \left(\frac{(1-\theta) l_K}{2F_K^2} + \sum_{j=K+1}^{N} \frac{l_j}{F_j^2} \right) +$$

$$+ 8\pi\nu \sum_{i=K+1}^{N} q_i \left(-\frac{l_i}{2F_i^2} + \sum_{j=1}^{N} \frac{l_j}{F_j^2} \right). \qquad (7)$$

This equation contains the same unknowns as (5). Given the $P_0 = P_N$ left-hand side of (5) and (7) will be mutually equal. Equating the right parts and discarding the constant factors $8\pi\nu$, we obtain

$$\sum_{i=1}^{K-1} q_i\left(\sum_{j=1}^{i}\frac{l_j}{F_j^2}-\frac{l_i}{2F_i^2}\right)+\theta q_K\left(\sum_{j=1}^{K-1}\frac{l_j}{F_j^2}+\frac{\theta l_K}{2F_K^2}\right)=$$

$$=(1-\theta)q_K\left(\frac{(1-\theta)l_K}{2F_K^2}+\sum_{j=K+1}^{N}\frac{l_j}{F_j^2}\right)+$$

$$+\sum_{i=K+1}^{N} q_i\left(-\frac{l_i}{2F_i^2}+\sum_{i=K+1}^{N}\frac{l_j}{F_j^2}\right).$$

The left side of the equation with unknown collect terms (terms drop out of the equation):

$$\theta q_K\sum_{i=1}^{N}\frac{l_i}{F_i^2}=\sum_{i=K}^{N} q_i\left(-\frac{l_i}{2F_i^2}+\sum_{j=1}^{N}\frac{l_j}{F_j^2}\right)-$$

$$-\sum_{i=1}^{K-1} q_i\left(\sum_{j=1}^{i}\frac{l_j}{F_j^2}-\frac{l_i}{2F_i^2}\right).$$

Hence we find the solution

$$\theta=\frac{\sum_{i=K}^{N} q_i\left(-\frac{l_i}{2F_i^2}+\sum_{j=1}^{N}\frac{l_j}{F_j^2}\right)-\sum_{i=1}^{K-1} q_i\left(\sum_{j=1}^{i}\frac{l_j}{F_j^2}-\frac{l_i}{2F_i^2}\right)}{q_K\sum_{j=1}^{N}\frac{l_j}{F_j^2}}. \quad (8)$$

To determine the number of the section to the lowest potential energy given medium in a ring pipeline, consider the schematic representation of the changes in the mass flow rate and reduced the potential energy of the medium in the pipeline (see figure).

Suppose that the section with the lowest environment potential energy here coincided with a knot K-1 (i.e., in (5) and (7)). In this case, the absolute value of change in the potential energy of the medium on the K section will be equal to

$$\frac{8\pi\nu}{F_K^2}\frac{M_{K-1}+M_K}{2}l_K.$$

In this case condition $p_0-p_*=p_N-p_*$ is performed. Therefore, to determine the number of the section with the lower section of the reduced potential energy of the medium into the ring to check the difference

$\varphi_K=(p_0-p_*)_K-(p_N-p_*)_K,$,

where $(p_0-p_*)_K, (p_N-p_*)_K$ obtained when $\theta=0$.

If the value K is to take less than the actual, it is expected $\varphi_K>0$; if the value of K is to take more real, it is expected $\varphi_K<0$. This statement is substantiated by the fact that, as the flow in a certain direction in this area given the potential energy of the fall protection will be intense, and vice versa.

A similar argument arises for the case when the section x_* was within the K elementary section (i.e. $0<\theta<1$). In this case, the conditions $\varphi_{K-1}>0$ and $\varphi_K<0$. It is easy to verify that $j=1,2,3,...,K-2$ when also the case $\varphi_j>0$, and if $j=K+1,K+2,...,N-1,N$ appropriate inequality $\varphi_j<0$.

On the basis of these judgments is defined elementary section K with the lowest potential energy environment here in the ring. And value θ is determined by the formula (8). For a known value θ can determine the mass flow rate of the nodes from the (3) counter-clockwise, and starting $M_N=M_0-M_1$, in a clockwise direction. And the pressure in the nodes of the ring and the smallest value of the pressure in the annulus is found by difference given the potential energy of the medium (4) and (6).

5. Discussion of the Method

At certain parts of the elementary ring may not track gas extraction. For these areas should take $q_i=0$.

Using different cross-sectional areas F_j for different areas, we have created the conditions for the application of the method in optimizing the diameter and thickness of the pipe from the point of view of reducing capital expenditures and operating costs.

Solving the problem, in fact, we localized place x_* and define the value of the least static pressure p_* in the ring. The value p_* can be bounded from below: to provide the smallest possible value of the pressure at the nodes of the consumer connection. In these cases, one can re-apply to the algorithm with the new values p_0.

The formulas are not difficult to take into account of local resistance network section.

The name of this method reflects the search for a number K (discrete unknown) of the site and search section $x_*=\theta l_K$ (continuous unknown) on the K section with the lowest potential energy of a unit mass of the transported medium in the ring. It is similar to the method of [4,5] and, in contrast to the methods of [6], provides an exact solution of the problem.

The method can be generalized to the cases of two or more nodes in the supply of medium ring line.

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