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CALCULATION OF GEOMETRIC DIMENSIONS AND HYDRODYNAMIC CHARACTERISTICS OF VENTURI PIPES OF A SELF-DRAINING SOLAR CIRCUIT

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ABSTRACT

This research paper provides an increase in the energy efficiency and reliability of self-draining solar plants by optimizing their hydrodimatic operating modes.

Based on this goal, the objectives of the study were to analyze the existing methods of protecting solar collectors of water heating and hot water supply systems from freezing and to identify the most promising methods. Also, the identification of the regularities of the hydrodynamics of a self-draining solar circuit.

KEYWORDS: Hydrodynamic Characteristics, Geometric Dimensions, Venturipipe, Self-Draining, Solar Circuit & Solar Heating Systems

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Original Article

INTRODUCTION

At present, due to the rise in prices for traditional energy sources, attention is again beginning to increase the use of solar energy. At the same time, the new interest in heating systems is very relevant in the light of the Decree of the President of the Republic of Uzbekistan "On measures for the further development of alternative energy sources".

Involvement in the energy balance of the Republic of Uzbekistan of non-traditional types of energy, primarily solar energy, is of significant scientific and practical interest. The use of ecologically clean solar energy supplied to the republic of the Central Asian region practically all year round: it is especially important for heat supply, as the most realistic and technically prepared area of practical use of solar energy.

Research on the use of solar energy is receiving much attention in Uzbekistan. The use of solar energy will be able to ensure the economy of fuel resources for the national economy of our country.

Solar heating systems for buildings are among the devices where the use of solar energy can be most effective. However, these systems have not yet received proper distribution in the republic. The expansion of the use of solar energy for heating buildings is constrained, mainly due to the relatively high specific investment in solar systems compared to conventional systems. The reason for this is the traditional approach to the development and creation of solar heating systems, which does not provide for the use of self-regulation processes to simplify and increase the reliability of heating systems under conditions of non-stationary solar radiation.

Water heating systems are widely used in practice when using traditional energy sources. They are easy to operate, meet sanitary and hygienic requirements, and can be easily connected to heating networks.

One of the reasons hindering the widespread use of solar water heating systems is the problem of freezing solar collectors at night, as well as in the daytime with cloudy weather. Self-draining systems are used to increase the reliability of solar plants. When the solar circulation pump is turned off, the coolant from the solar collector is drained into a special tank below or in an increased capacity heating coil of the storage tank. The disadvantage of such systems is the increased power consumption for the circulation of the coolant. Therefore, increasing the energy efficiency and reliability of self-draining solar plants is an urgent task.

METHODS OF RESEARCH

The main element of solar water heating systems is a solar collector (SC), which is used to convert solar energy into thermal energy removed from the collector by a coolant - water. The solar collector operates in conditions of uneven intake of solar radiation, which can lead to its breakdown at negative outdoor temperatures due to freezing of water in it at night.

The problem of freezing of solar collectors in winter can be solved in several ways.

The simplest solution is to stop using the solar heating system throughout the winter and drain the water from the collector. The amount of heat that will not be received during the period from mid-October to mid-March, according to [3], corresponds to 20% of the total annual energy production. This solution is acceptable for solar systems with seasonal hot water supply.

To assess the influence of the Venturi pipe location on the hydrodynamic characteristics of a self-draining solar circuit, let us consider the distribution of the total pressure and its components in it, using for this the relations arising from the Bernoulli equation.

Several layouts of a self-draining solar circuit with a Venturi pipe are possible: with the location of the pipe in the discharge or suction zone of the pump, and also with the use of two tanks - an expansion and a drain.

The diagram of the total and hydrostatic pressures in dynamic mode in a self-draining solar circuit with one expansion vessel and a Venturi pipe installed in the discharge zone and in the pump suction zone is shown in Figure 1.

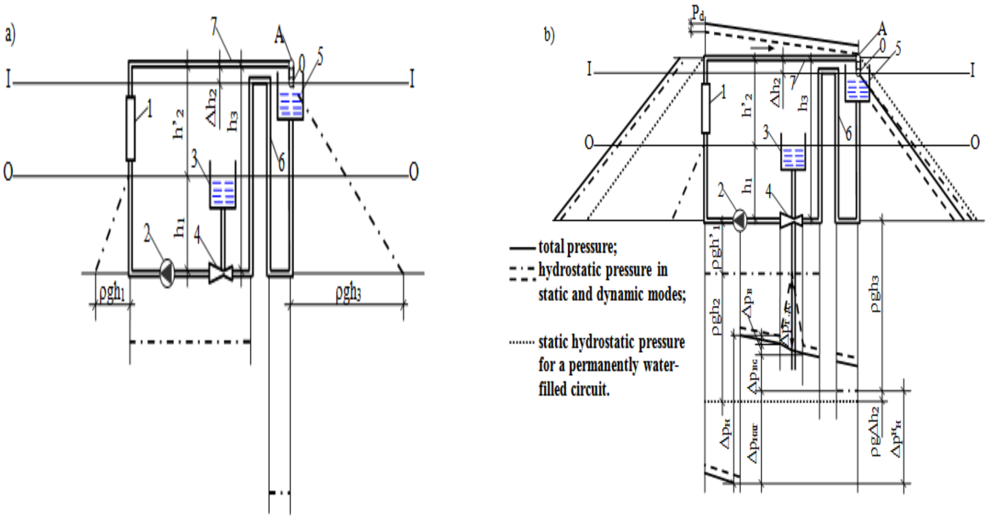

Figure 1: Pressure Distribution in a Self-Draining Solar Circuit with Venturi and Two Tanks.a - when the Pump is Inactive; b - with the Action of the Pump.
1 - Solar Receiver; 2 - pump; 3 - Drainage Tank; 4 - Venturi Pipe;
5 - Expansion Tank; 6, 7 - Loops on the Return and Supply Pipelines.

The issue of pressure losses in the restriction devices, directly related to the problem under consideration, has been comprehensively investigated only for standard diaphragms, nozzles and Venturi nozzles used in measuring the flow rates of liquids, gases and steam.

The dependence of the pressure loss of P_n standard orifice devices on the relative area $m = F_d / F_D = d^2 / D^2$ in fractions of the pressure drop ΔP is shown in Figure 2.

It can be seen from the graph that for the same value of m in the Venturi nozzle, the pressure loss is much less than in the diaphragm and nozzle. They are the smallest in a long Venturi nozzle with a taper angle (6-8 times less than in the diaphragm).

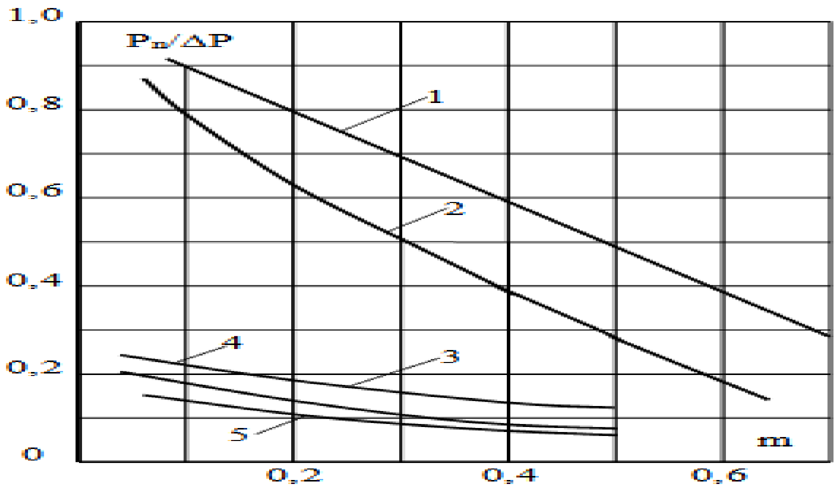

Figure 2: Pressure Loss in a Standard Orifice
1 - Diaphragm; 2 - Nozzle; 3 - Short Venturi Nozzle (a¬¬d=any Value)
4 – Long Venturi Nozzle (ad=14-150); 5 – Long Venturi Nozzle (ad=5-70).

A standard Venturi nozzle (Figure 3., A) can be used without graduation to measure the flow rate of media in pipelines with a diameter.

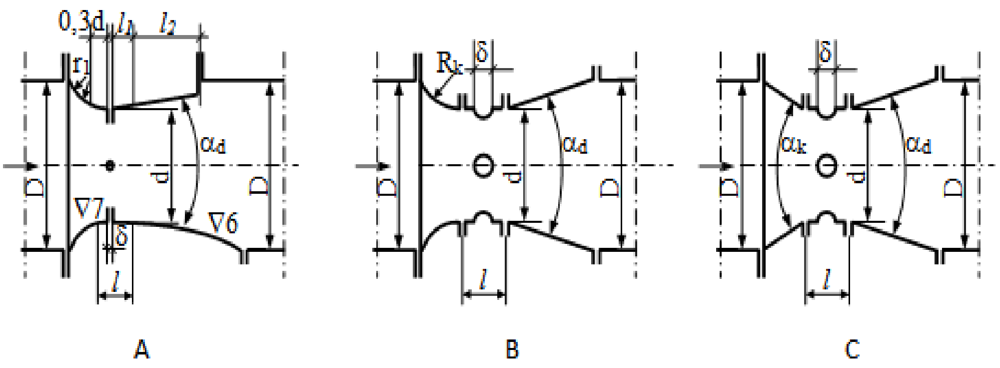

Figure 3: Variety of Venturi Tube Shapes
a - Standard Venturi Nozzle (short and Long); b - Confuser-Diffuser Transition with a Rectilinear Diffuser and a Confuser along the Radius; c - Confuser-Diffuser Transition with a Rectilinear Diffuser and a Confuser.

While observing 50 mm the condition 0.05$\leq m \leq$ 0.6. In this case, the length should be ℓ_1 within the limits $0{,}2d \leq \ell_1 \leq 0{,}4d$, the number of side holes should be at least four with a diameter $\delta\leq$0.13 d(but not less than 3 mm), the inner surface should have a high processing purity (6-7 grade of purity).

Solar heating is usually characterized by low flow rates of the coolant, as a result of which, for a small-sized orifice used in a solar circuit, some of the listed requirements are unacceptable, especially a high cleanliness of the inner surface treatment. In addition, to improve the intensity of water suction and improve manufacturability, the diameter of the side holes δand the shape of the confuser of the device should be changed accordingly (Figure 3, b, c). Therefore, it is not possible to use the hydrodynamic characteristics of a standard nozzle Inside when calculating a small-size restriction device for a solar circuit, without their corresponding refinements.

Calculation of the hydraulic resistance of a Venturi pipe with its known geometric dimensions is a difficult task. The mechanism of action of the resistance forces is so complex that until now it has not been possible to find an exact method for calculating the resistance coefficient ζ ;in technical calculations, most often it is necessary to use the values of the resistance coefficients given in the literature in the form of average figures or in the form of tables of experimental data for various combinations of the geometric dimensions of the transition. The only possible calculation method for ζ Venturi tube in such a case is to experimentally determine the required data with the subsequent generalization of the results in a criterial form.

Let us derive the criterion equation for the pressure loss in the Venturi pipe using the method of dimensional analysis.

The pressure loss in the venturi can be represented as a power function of the following independent variables:

$$P_n = \varphi(W^a, \rho^b, \mu^c, d^d, D^e, \delta^f, \ell^K). \qquad (1)$$

Let us express the dimensions of the variables of dependence (1) in the system of three quantities MLT: M-mass, L-length, T-time, tab. 1.

Table 1: Title and Dimensions of Dependency Variables

Variabletitle	Designation	FormulaDimensions
Pressureloss	P_n	$L^{-1}MT^{-2}$
Flowrate	W	LT^{-1}
Density	ρ	ML^{-3}
Dynamicviscositycoefficient	μ	$ML^{-1}T^{-1}$
Neckdiameter	d	L
Pipelinediameter	D	L
Sideholesdiameter	δ	L
Insertionlength	ℓ	L

Let us substitute independence (1) instead of symbols of variables of their dimension:

$$(L^{-1}MT^{-2}) = \varphi\left[(LT^{-1})^{a},(ML^{-3})^{b},(ML^{-1}T^{-1})^{c},L^{d},L^{e},L^{f},L^{K}\right]. \qquad (2)$$

For this equation to be homogeneous with respect to dimensions, the following relationships between exponents must be satisfied:

$$\text{for}\ \left.\begin{aligned} M&:1 = b + c \\ L&:-1 = a - 3b - c + d + \ell + f + K \\ T&:-2 = -a - c \end{aligned}\right\}. \qquad (3)$$

Let us simplify relations (3) and express them in terms of *a*,*b*,*d*:

$$\left.\begin{aligned} a &= 2 - c \\ b &= 1 - c \\ d &= -c - e - f - K \end{aligned}\right\} \qquad (4)$$

Taking into account relations (4), dependences (1) will take the form:

$$P_n = \varphi(W^{2-c},\rho^{1-c},\mu^{c},d^{-c-e-f-K},D^{e},\delta^{f},\ell^{K}). \qquad (5)$$

Combining terms with the same exponents, we get a dependence of five dimensionless complexes:

$$\frac{P_n}{\rho W^2} = \varphi\left[\left(\frac{\rho W d}{\mu}\right)^{-c};\left(\frac{D}{d}\right)^{e};\left(\frac{\delta}{d}\right)^{f};\left(\frac{\ell}{d}\right)^{K}\right] \qquad (6)$$

Dimensionless complexes of dependence (6) are the well-known Euler and Reynolds criteria. Taking this into account, dependence (7) can be represented in the form of a criterion equation:

$$Eu = \varphi\left[\mathrm{Re}^{-c},\left(\frac{D}{d}\right)^{e},\left(\frac{\delta}{d}\right)^{f},\left(\frac{\ell}{d}\right)^{K}\right]. \qquad (7)$$

The resulting equation corresponds to the " π -theorem", since the number of dimensionless complexes is equal to the number of variables essential for the process, minus the primary quantities, i.e.5 = 8 - 3.

For the problem under consideration, the greatest practical interest is the dependence of the drag coefficient on the number *Re* and the geometric dimensions of the Venturi pipe. Considering that, $\zeta = 2Eu$ equation (7) can be rewritten as:

$$\zeta = \varphi_1 \left[\mathrm{Re}^{-c}, \left(\frac{D}{d}\right)^{e}, \left(\frac{\delta}{d}\right)^{f}, \left(\frac{\ell}{d}\right)^{K} \right] \tag{8}$$

The criterion equation (8) can serve as the primary basis for obtaining empirical dependencies for calculation ζ.

RESULTS

CONCLUSIONS

Improving the reliability and efficiency of self-draining water systems of solar heat supply can be achieved by connecting the drain tank with circulation pipelines through the narrowed section of the Venturi pipe.

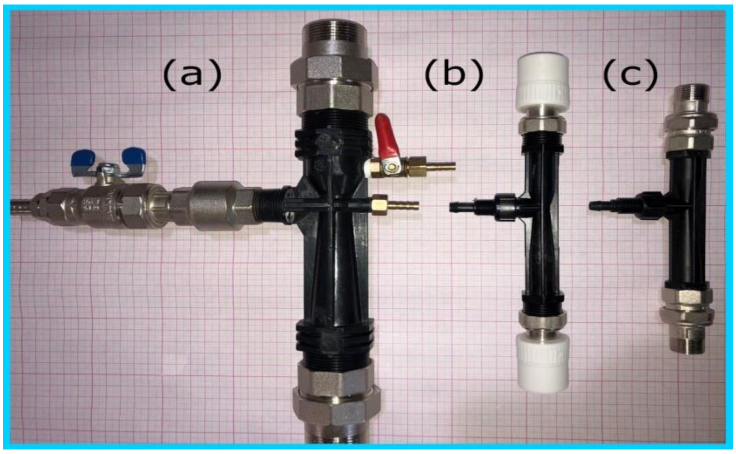

Figure 4: Use Venturi Pipe for Efficiency of Self-Draining Water Systems.

The use of the AE allows, in comparison with the usual self-draining solar circuit of the siphon drain back type, to reduce the power consumption for the circulation of the coolant to 65-80% by eliminating the loss of hydrostatic pressure ρgH associated with the rupture of the jet due to cavitation.Several layouts of a self-draining solar circuit with a Venturi pipe are possible: with the location of the pipe in the discharge or suction zone of the pump, as well as using two tanks - an expansion and a drain. The most economical is the location of the Venturi pipe in the pump suction zone, when, all other things being equal, it is required to develop a lower hydrodynamic pressure in the throat of the transition and a lower initial pressure to close the circuit.

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