Development of the Method of Preparation of the Boiler and Heating Water by Phase Transfer in a Vortex Flow

A.L. Kartashev, S.D. Vaulin, M.A. Kartasheva, E.V. Safonov

***Abstract*–In this paper, development of the method of preparation of the boiler and heating water by phase transfer in a vortex is considered. Ranque-Hilsch effect in a vortex flow is researched. The devices for realization this effect is presented. Problems of modeling the eddy currents with phase transitions, realizing Ranque-Hilsch effect are described.**

***Index Terms*– vortex flow, Ranque-Hilsch effect, phase transitions, mathematical modeling**.

The water treatment plant for the generation of steam and creating a flow of coolant can be used effects arising from eddy currents, including phase transitions representing the evaporation and condensation of water vapor.

Devices that are implemented vortex motion are called differently: centrifugal cyclone, the cyclone vortex chamber and the vortex, the vortex pipe (Ranque-Hilsch effect) and hydro cyclones, vortex separators, vortex combustor and combustion chambers, etc. [1, 2]. Their common feature is the presence of the working area (typically cylindrical or conical shape) and the vortex flow (generally tangential or axial).

The term "vortex chamber" was introduced in the simulation of atmospheric vortices in the lab. According to the accepted terminology, the vortex chamber – is a device which implements a uniform distribution around the periphery of the medium input chamber and in which a working medium performs a rotary-translational movement.

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In the study of vortex motion and application swirling flows were discovered their unusual features – counter and "recirculation zone" energy separation (Ranque-Hilsch effect). The presence in the flow field considerable centrifugal forces and significantly affects the properties of the eddy currents, causing those flow characteristics, which can be successfully used in the design of the vortex chambers for various purposes.

In the gas dynamics of vortex flows is nontrivial phenomenon known as the Ranque effect (effect Ranka-Hilsch or vortex effect), which consists in the fact that in vortex tubes fairly simple geometry (Fig. 1) is a division of the gas flow into two, one of which – peripheral – has a temperature above the temperature of the source gas and the second – center – correspondingly lower. This effect is all the more strange when you consider that, as in the case of vortex stabilization of gaseous discharges [3], the buoyancy forces would have to lead to a "surfacing" in the center of the vortex hotter gas.

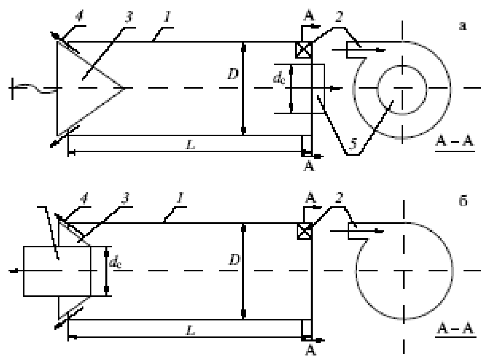

Fig. 1. Schematic diagram of the vortex tubes:
(A) countercurrent type, (b) a ram type
1 – smooth cylindrical tube, 2 – swirl tangential or snail type for compressed gas, 3 – throttle valve (throttle valve), 4 – out of the hot gas through the annular gap 5 – aperture to quit cold gas.

Vortex tubes realizing Ranque-Hilsch effect can be used in the composition of the evaporating section for the simultaneous production of hot water, followed by evaporation to produce steam using vacuum vessel with hot water or water vapor directly into the vortex tube and the cold water used in condensing section for cooling the steam.

For a better understanding of the processes and structure of the flow in the vortex tubes should be, except for the considered planar vortices present features swirling three-dimensional flows in cylindrical channels. Consider a long tube (Fig. 2) near the closed end which is located swirler – a gas distribution device that provides spin when entering the gas pipe.

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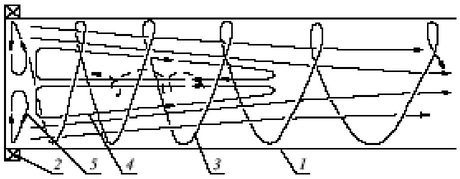

Fig. 2. Typical pattern of flow in a pipe near a tangential or snail vortex
1 – smooth cylindrical tube with a closed end, 2 – swirler,
3 – peripheral vortex flow, 4 – central zone of inverse currents,
5 – circulation flow.

An important feature of the vortex flow is the presence of phase transitions, in detail these processes are considered in paper [4]. For water treatment systems that use as a working medium water characterized by the processes of evaporation and condensation of water vapor occurring during the movement of the medium in the vortex tube.

In operation of all types of vortex power converters there is a common characteristic of all the vortex devices property consisting in that, when creating a vortex flow of gas or liquid therein is intensive heat and mass transfer processes that change the physical characteristics of the fluid and its status. At the same time the energy impact on the working environment at the expense of the various methods of organization and management of the vortex flow.

The vortex gas flow liquid and two-phase heterogeneous environments is accompanied by various physical effects, among which are the most important: the heating and cooling of the working medium, the formation of two-phase liquid-gas environments, accompanied by cavitation, dispersion, and spray fluid. Understanding the nature of the processes occurring in the vortex flow of gaseous, liquid and two-phase liquid-gas vortex flow allows purposefully lead the development of the vortex energy converters and processing equipment using them, which opens up opportunities for improving the quality of devices using eddy currents.

Hot water at a pressure of 2-5 atmospheres and a temperature of 90-100 °C in the vortex tube leads to the fact that the flow of hot water begins intensive evaporation (boiling) to form a large amount of steam, which will flow out of the "hot" end of the vortex tube. Because of the "cold" end of the vortex tube will expire chilled water. A feature of work processes in the vortex tube in this case is the presence of a multiphase fluid, greatly complicates the dynamic processes in the vortex tube, whose behavior requires a fairly complex and lengthy investigations.

The use of steam as a source of the working environment, on the contrary, causes condensation of steam in the "cold" end of the vortex tube (in some cases, the formation of the solid phase – ice, greatly complicates the work of the vortex tube because of infringement of the design mode).

In addition, in order vortex tube can be supplied and vapor-liquid mixture. Thus, depending on the parameters of the vapor-liquid mixture, and the geometric characteristics of the vortex tubes may be implemented by various modes of energy separation streams. For the simulation of such flows is necessary to use models and methods of mechanics of heterogeneous media [5, 6].

Currently vortex tubes which realizing the effect of Rank-Hilsch used for different purposes. As an example, the following technical means.

Refrigeration and heating installation on the basis of the vortex tube. The principle of operation is based on the vortex tube vortex effect. Essence of vortex effect is to reduce the temperature in the central layers of the swirling gas flow (free vortex) and raising the temperature of the peripheral layers. With appropriate design of the device (Fig. 3), the gas vortex can be separated into two streams, with reduced and increased temperatures.

Technical capabilities. Working medium pressure gas Inlet pressure 0.5 ata ... 100. The minimum temperature of the cold flow - 90 °C. The maximum temperature of the hot stream to + 300 °C. Efficiency 40 ... 60%.

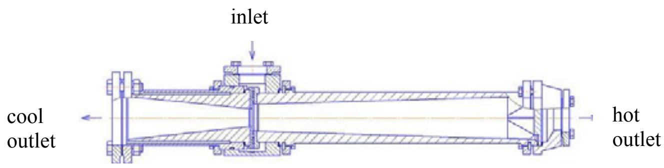

Fig. 3. Construction of the vortex tube.

Vortex flows, including implemented in vortex tubes using Ranque-Hilsch effect, applied in a number of industrial devices and assemblies [7]. The book discussed a study of energy separation in intensive swirling flow when the flow channels on the axially symmetric vortex tubes. Analyzed existing models Ranque-Hilsch effect and given the improved method for calculating the characteristics of vortex tubes. Techniques of analysis and design of vortex devices. Described based on vortex tube vortex burner igniters, plasma torches, their design and method of calculation. Figures 4–5 are the different options for commercially produced vortex tubes.

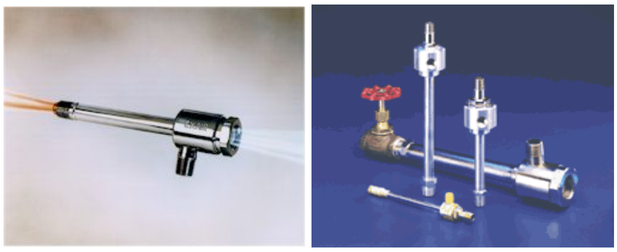

Fig. 4. Typical view of commercially available vortex tubes.

Fig. 5. Commercially available vortex tube cooling.

Development evaporator section based on the eddy current Ranque-Hilsch effect. For the developed multifunctional water treatment plant as an evaporator section of the vortex tube can be used. Thus operation of this section of the evaporator can be in two modes.

The first mode. The vortex tube under a pressure of 3 ... 4 kgf/cm^2 is supplied hot water with a temperature of 70 ... 80 °C. On the "hot" withdrawal from the vortex tube is obtained with water at 90 ... 100 °C. Further, this water enters the vacuum chamber, at reduced pressure where it

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comes intensive boiling and vapor is formed, after the separator (acting as a cleaning vapor) enters the condenser mounting section. Chilled water from the "cold" outlet of the vortex tube flows into the condenser section and serves as a cooler for condensate.

The second mode. The vortex tube under pressure 4 ... 5 kgf/cm^2 is supplied superheated water at a temperature of 110 ... 120 °C. When you receive a water vortex tube in the separation process takes its boiling streams and "hot" output is a pair (the pair will be "clean", free of impurities, which is likely to allow dispense with the separator), the evaporator section with an additional evacuated. On "cold" output is the water that can be used in the condenser section as a coolant. If the water temperature at the "cold" output is too high, then it can be used in the heat exchanger when heating the raw water supplied to the evaporator section. These modes have a fundamental difference, due to the fact that in the first mode in the evaporator section is water, and the second mode – vapor liquid two-phase medium.

Offered to develop evaporator design provides similar performance demineralized water is not at the expense of the adiabatic multiple stages of boiling water in the evaporator, and due to intensified thermal mass transfer processes in the eddy currents in the field of centrifugal forces. It is assumed to reach the desired rate of generation of steam in a smaller volume.

Furthermore, the use of a vortex effect in the evaporator section splits supplied via water line into two circuits: steam generating circuit for generating and distillate loop circulating water serving as a cooling agent with a temperature sufficient to cool the steam and the distillate. Last significantly affect the weight and dimensions of the condenser section.

Summary: examined existing physical principles and technological solutions in the field of phase transitions in the vortex. Variants of using a vortex tube, realizing Ranque-Hilsch effect for the energy division of fluid flow in the evaporator section as a multifunctional water treatment plant.

Problems of modeling the eddy currents with phase transitions, realizing Ranque-Hilsch effect. Research Ranque-Hilsch effect should not be considered complete. It requires still conducting both theoretical and research experimental to give it the status of a theory confirmed experimentally. As theoretical problems to the fore appear need to build a more rigorous physical model of energy separation in a vortex flow taking into account such factors as:

– kinetics of movement and exchange of micro volumes of kinetic energy;
– real, depending on the initial conditions, the distribution of micro volumes largest forward speed;
– entry into the central part of the flow of the turbulent boundary layer structures;
– the dependence of the translational velocity of gas exiting from the pipe radius.

Considerable approximation to reality models considered possible, taking into account the three-dimensionality of the main flow. Progress in this area can probably be caused by the use of numerical modeling at least for laminar flow. Compressibility environment and energy separation may be the next step.

As one of the important applications of vortex tubes is the separation of gas condensate or evaporation, for meaningful improvement of appropriate equipment required to enter in the model account kinetics of the condensation, separation and evaporation of the droplets.

The proposed theory, apparently, may give rise to a new round of inventive activity, the main achievements which are likely to be in the way of increasing heterogeneity of the velocity of the incoming flow, and further improvement of poorly studied direct-flow vortex tubes with depressed reverse vortex.

It is important extensive research back-vortex flows with the purpose of their use in energy, chemical and process equipment for the isolation environment and the chamber walls from exposure to the reaction zone.

The study of the above problems and to help in solving the problems that are discussed in this project, first of all it is the following model problem:

– study the effectiveness of energy separation flow at the outlet of the vortex tube, working in hot (superheated) water;
– the study of operating modes of the vortex tube in the presence of vapor-liquid medium;
– determination of optimum operating conditions based on the evaporating section of the vortex tube as a part of multifunctional water treatment plant;
– experimental studies modes evaporator section based on the vortex tube;
– research designs evaporator section based on the vortex tube.

For the answer to these questions should be developed mathematical model describing all the different processes in the vortex tube, realizing the Ranque-Hilsch effect. Developed modeling tasks vortex flows with phase transitions, realizing the Ranque-Hilsch effect.

The developed tasks include:

– the development of a mathematical model describing the diversity of processes in the vortex tube, realizing the Ranque-Hilsch effect;
– the approaches to numerical modeling of processes in the vortex pipe.

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