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Operational Process and Characteristics of Liquid-Gas Jet Pumps with the Ejected Vapor-Gas Medium

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Abstract

In many industrial processes, the use of a liquid-gas jet pump refers to the ejection of the vapor-gas medium, i.e. a medium containing non-condensable and condensable gases in the liquid jet. Conventional calculation methods are used for jet devices that eject non-condensable gases. However, the presence of steam in the medium ejected makes a significant contribution to the operational process and, consequently, its mathematical description and device specifications. The article deals with the development of physical and mathematical models and determination of properties of liquid-gas jet pumps (LGJP) with an ejected vapor-gas medium. While calculating the performance there were used: Bernoulli equation – for spin-up of the active flow in the nozzle device; water balance equation, heat balance, conservation of momentum – for vapor condensation in the suction chamber; momentum equation and isothermal state equation of liquid-gas mixture – for mixture of media in the mixing chamber; liquid-gas mixture flow equation– for transformation of excess kinetic energy into the potential energy in the diffuser. Extremal characteristics that reflected the potential of the LGJP work were calculated on the basis of the equations. Analysis of specifications was carried out in a non-dimensional coordinates – in terms of the ejection coefficient by dry gas and compression ratio. The calculation of set of extremal characteristics with different ratios of the steam flow to the liquid showed that the presence of steam in the pumped medium degrades performance, i.e. the ejection coefficient is reduced at a constant compression ratio.

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Keywords: non-condensable gas; vapor-gas medium; physical-and-mathematical model; extremal characteristic; potential of jet pump; compression ratio; ejection coefficient by dry gas

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Nomenclature

m_l, m_g, m_v	mass rate of liquid in the *i*-th section, of gas and of vapor
T_{mix}, T_l, T_v	the absolute temperature of the gas-liquid mixture, of liquid and vapor
C_l, C_v	isobaric heat capacity of liquid and vapor
L_k	specific heat of evaporation
p_i	absolute static pressure of the medium in the *i*-th section
ρ_{gi}	density of gas in the *i*-th section
ρ_{mix}	density of the mixture
R_g	the gas constant
T_g	the absolute temperature of the gas
Q_{vg3}	volume flow rate of the saturated gas-vapor mixture in the 3rd section
$\overline{p_i}$	the absolute total pressure in the section 1-1
U_{li}	fluid velocity at *i*-th section
d_{i}	the diameter of the *i*-th section
ζ_{10}, ζ_{34}	coefficient of resistance of the nozzle passage and the mixing chamber
φ	the nozzle velocity ratio
U_{mix4}, U_{g3}	velocity of gas-liquid and gas mixture in sections 4-4, 3-3
τ_{34}	length-averaged wall shear stress
λ_{34}	coefficient of hydraulic friction in the mixing chamber
A_{34}	surface area of the mixing chamber
d_3	diameter of the mixing chamber
k_{vi}	correction factor for the pressure of the saturated liquid vapor in *i*-th section
p_{sv}	pressure of the saturated liquid vapor
ζ_{dif}	coefficient of resistance of the diffuser
α_{2g}	volume coefficient of ejection to dry gas
Q_{2g}	volume flow rate of the gas in the 2nd section
μ_v	mass coefficient of ejection to vapor
ε_{42}, ε_{52}	gas compression ratio
Γ	jet dynamic parameter
c	parameter of resistance
k_t	correction factor for difference of liquid and vapor
B	coefficient, which considers physical properties of flows

1. Introduction

Liquid-gas jet pumps (LGJP) due to their simple design, availability of a variety of assembly options, absence of moving parts, are widely used in engineering [1-3]. In many industrial processes application of LGJPs is associated with ejection of the vapor-gas medium, i.e. a medium containing non-condensable and condensable gases in the liquid jet. For example, in the oil industry it is necessary to pump a mixture of saturated steam and multicomponent gas from the well after the steam-stimulation [4, 5], while in engineering it is required to create a vacuum in steam turbines condensers [6, 7]. Review of the literature on LGJPs [8-12] has shown that the well-known methods of calculation are designed for inkjet devices which eject non-condensable gases. However, the presence of steam in the medium ejected makes a significant contribution to the operational process and, consequently, its mathematical description and device specifications. In this regard the development of physical and mathematical model and determination of properties of liquid-gas jet pumps (LGJP) with vapor-gas medium ejected becomes increasingly relevant.

The aim of the article is to develop liquid-gas jet pump-related theory and determine its properties, including extremum ones, when vapor-gas mixture is ejected.