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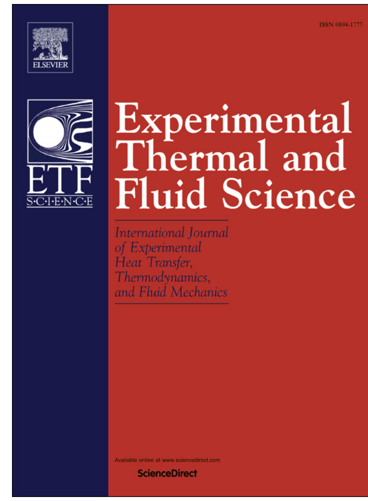

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Experimental study of gas-liquid two-phase flow patterns within centrifugal pumps impellers

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ABSTRACT

This paper aims, through experiments, at determining gas-liquid flow patterns inside a centrifugal pump impeller, as well as to correlate the topological distribution of the phases of pump performance. For this, an experimental facility was built that would allow flow visualization inside the impeller. The construction of the visualization prototype was based on the stage of an Electrical Submersible Pump (ESP) widely used in petroleum industry. High-speed imaging was used as a technique to visualize the flow. The images obtained allowed us to classify the gas-liquid flow into four patterns, which are: Bubble Flow, Agglomerated Bubble Flow, Gas Pocket Flow and Segregated Flow. It was observed that the intensity of pump performance degradation is directly influenced by the flow pattern within the impeller. The occurrence of the Gas Pocket Flow pattern is linked to the intensification of the deterioration of pump performance and the appearance of operating instabilities. When it comes to the Segregated Flow, data has shown that the severity of performance degradation may make the pump incapable of generating pressure. Maps correlating flow pattern and pump performance were set for different operating conditions. These maps showed that the higher the rotational speed, the greater the no-slip gas void fraction where the transition occurred between the phases inside the impeller.

Keywords: centrifugal pump, flow pattern, gas-liquid two-phase flow, performance degradation, flow visualization.

Nomenclature

a	major axis of the spheroid (mm)	t	impeller blade thickness (mm)
b	minor axis of the spheroid (mm)	V_L	liquid phase velocity (m/s)
C_D	drag coefficient (-)	V_G	gas phase velocity (m/s)
d	bubble diameter (m)	α	gas void fraction (-)
d_1	impeller inlet diameter (mm)	β_2	impeller outlet blade angle (˚)
d_e	equivalent diameter (mm)	λ	No-slip gas void fraction (-)
D	impeller diameter (mm)	μ_L	liquid dynamic viscosity (Pa.s)
D_2	impeller outlet diameter (mm)	ρ_L	specific mass of liquid phase (kg/m^3)
F_D	drag force (N)	ρ_{TP}	gas-liquid two-phase specific mass (kg/m^3)
$F_{\nabla P}$	force due to pressure gradient (N)	ϕ_L	flow rate coefficient (-)
g	acceleration of gravity (m^2/s)	ω	rotational speed (rad/s)
h	impeller blade height (mm)	Ψ_L	head coefficient (-)
H_L	single-phase liquid head (m)	Re_ω	rotational Reynolds number (-)
H_{TP}	gas-liquid two-phase head (m)	ΔP_L	pressure increment (kPa)
$P_{in,L}$	single-phase inlet pump pressure (kPa)	ΔP_{TP}	gas-liquid two-phase pressure increment (kPa)
$P_{in,TP}$	two-phase inlet pump pressure (kPa)	$\partial p/\partial s$	pressure gradient along the streamline
$P_{out,L}$	single-phase outlet pump pressure (kPa)		
$P_{out,TP}$	Two-phase outlet pump pressure (kPa)	*abbreviations*	
q_G	volumetric gas flow rate (m^3/h)	ESP	electrical submersible pump
q_L	volumetric liquid flow rate (m^3/h)	IM	image
Re	Reynolds number (-)	VSD	variable speed drive

1. Introduction

The application of centrifugal pumps operating under gas-liquid two-phase flow in nuclear reactor cooling systems and the risk of radioactive fluid leakage motivated initial studies in this field.

Minemura and Murakami [1-2] studied the performance of centrifugal pumps operating under two-phase flow and published the first study correlating flow visualization, data analysis and modeling. This was the first study that linked pump performance to gas-liquid flow pattern inside an impeller.

Patel and Runstadler [3] observed the occurrence of two flow patterns in the impeller channels. In the first pattern, the gas flowed in the form of small bubbles. In the second one, a large stationary bubble was formed in the impeller inlet due to coalescence of smaller bubbles, which resulted in a significant reduction of the pump head from a given flow.

Sekoguchi [4], Kim [5] Sato [6], Andras [7] Poullikkas [8] and Thum [9] also carried out important research on centrifugal pumps operating in the presence of gas related to nuclear power.

Most research carried out in the nuclear industry used large diameter axial pumps, with only one stage and volute. The geometric features of these pumps make it difficult to apply these results in oil industry, where centrifugal pumps are generally radial, with small diameter and multiple stages.

In petroleum industry, the centrifugal pump is the second most popular method of artificial lifting. It is estimated that more than 100,000 wells produce oil using ESPs. When the pressure is less than the oil saturation pressure, the produced fluid is a gas-liquid two-phase mixture. The presence of a compressible phase affects the performance of the centrifugal pump and causes operating instability in the pump system. The physical understanding