STUDY OF THE EFFECT OF WATER - STEAM MIXTURE ON SOME METERING DEVICES

A dissertation submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE

BY
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UNDER THE SUPERVISION OF

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Examination Committee

The members of the committee appointed to examine the dissertation of EMIL G. MAWAD find it satisfactory and recommend that it is accepted.

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بسم الله الرحمن الرحيم

MY FAMILY

TO

MY FIANCÈE

STATEMENT

This dissertation is submitted to Ain Shams University for the degree of master in mechanical engineering.

The work included in this thesis was carried out by the author at the laboratory of thermodynamic, Ain Shams University, from 1987 to 1991.

No part of this thesis has been submitted for a degree or a qualification at any other University or institution.

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ABSTRACT

An experimental and a computational investigation on pressure drop of two - phase flow (steam / water) through metering devices (venturis and orifices) was conducted to determine both the mass flow rate and the quality of mixture. The test section was constructed to perform such measurements with a double flash (meter - valve - meter) arrangement venturis and orifices. Pressure drops of downstream meter were affected by the valve, placed inline between the upstream and the downstream meters. Even though the mass flow rates through both meters were the same, the pressure drop across the downstream meter was much higher than the upstream one for the same meters and arrangement.

Experimental investigations showed that the pressure drop in metering devices is strongly dependent on the following parameters,

- droplet size as unstable water droplets will break up in the accelerating steam flow and significantly influence the pressure drop.

- water droplets entrainment from the unstable liquid layer on the wall contributes to the observed pressure drop.

- water droplets thermal non - equilibrium, due to temperature difference between the interior and the surface temperature of these droplets leads to surface evaporation of droplets which

affects the pressure drop.

Experiments were carried out by using steam / water mixtures of different quality. Pressure drop measurements were carried out with different quality mixtures at each meter arrangement.

The numerical model was based on the equation for quasi one dimensional flow with suspended water droplets in the steam and the water layer in the wall. The conservation equations for mass, momentum and energy were solved step wise along the venturi allowing for coupling between phases through the source term concept. The exchange of water droplets in liquid layer, entrainment, water droplet break up and thermal non - equilibrium affect the pressure drop across the venturi.

Pressure drop predicted by the numerical model and affected by taking water droplet break up, entrainment and thermal non - equilibrium effect into consideration, showed good matching with the experimental data.

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NOMENCLATURE

A	cross - sectional area
At	cross - section of the throat area
Ad	droplet projected area
Ag	gas effective area
Atp	two - phase total area
C_D	drag coefficient
Cf	shear stress coefficient
Cp	specific heat with constant pressure
$\bar{D}$	volume median diameter
Dt	throat diameter
D	tube diameter
DH	inlet flow pressure drop
DL	droplet size diameter
G	acceleration of gravity
g	dimensionless constant
h	enthalpy of steam
h	latent heat of vaporization
K	entrainment rate coefficient. flow coefficient. ratio of phase velocities
L	duct perimeter
$\dot{M}$	mass flow rate
$\dot{M}t$	inlet mass flow rate
$\dot{M}l$	pumping water mass flow rate
$\dot{M}s$	steam mass flow rate
$\dot{m}c$	ratio of core flow rate to the total liquid flow rate
m_L	mass of droplet

n number of droplets

P pressure

Pi,P1 inlet pressure

P2 throat pressure

DP pressure drop

DPTP two - phase steam / water pressure drop

DPg steam pressure drop

DPL water pressure drop

DPO inlet orifice pressure drop

DPfo pressure change over orifice when total mixture flow rate flows as liquid

Rec core flow Reynolds number

ReL water flow Reynolds number

R universal gas constant

$\dot{Q}$ volume flow rate

S source term

T temperature

U superficial steam velocity

Vmix steam / water mixture velocity

V,VL water droplet velocity

$\forall$ volume

We Weber number

X quality (ratio of the mass of steam to the total mass of steam / water)

Y compressibility factor

Greek

ρ density of steam / water mixture

ρ_s density of steam

ρ_L density of water

σ surface tension

x step length

λ evaporation coefficient

ϕ correction factor

ϕ_{fo} ratio between two - phase pressure drop to the pressure change over orifice when total mixture flow rate flows as liquid

β throat diameter ratio

μ dynamic viscosity

ν kinematic viscosity

α void fraction

δ film thickness

Subscripts

c core droplet

e entrainment droplet

g gas

H homogenous mixture

i&i control volumes

L liquid

s steam

mom momentum

TP two - phase

1 and 2 are upstream and downstream meters

CHAPTER (1)

INTRODUCTION

Pressure differential devices, such as orifices and venturis, are extensively used in industrial applications to monitor the flow rate of single - phase fluids with reasonable accuracy and cost. Today, there are many alternative devices, but the differential pressure meter family still holds the largest part of applications.

Benedetto Castelli and Evangelista Torricelli laid the foundation for the theory of the head meter in the beginning of the 17th century, with the development of the relative concepts that the volume flow rate of the flow was equal to the velocity times the area and that the discharge through an orifice varies with the square root of the head [1] . Giovanni Poleni, professor of mathematics at Pedue University in the early 18th century, worked on the orifice discharge problem. In 1738 John Bernonulli developed the theorem on which the hydraulic equations for head meter are based.

Pressure differential devices were proposed and developed in the 18th century. On November 12, 1732, Henri Pitot [2] presented his famous paper on the Pitot tube. Several applications of the principle of the Pitot tube were developed during his life. In 1797 Giovanni Battista Venturi [3] published the result of his basic work on the principle of the venturi tube.

In 1887 Clemens Herschel [4], using Venturi's basic work, developed the commercial venturi tube, which was used as the primary element of many of the modern flow meters, and proved it to be a practical and economical means of measuring large volume flow rates of flowing fluids.

Since Clemens Herschel's paper [4], much work has been done on the application of the venturi meter to commercial flow measurements of a single phase flow.

The problem of the measurement of two - phase flow using orifices, venturi meters and other devices is of considerable interest for both research and application. Venturis are used in several applications to monitor the flow rate of two - phase (steam / water) mixtures and has also been used in conjunction with orifices to measure mixture quality [5].

Several arrangements between venturis and orifices, separated by valves, were used to measure the mass flow rate as well as the quality of the two - phase steam / water mass flow rate and quality. The pressure drop across the upstream and the downstream meters was dependent on the droplet size, quality, mass flow rate and meter geometry. But the pressure drop across downstream meter was much higher than that across the upstream one for the same meter type due to the presence of a valve causing water droplets breakup.