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Analysis of thermal mixing in circle shaped body inserted inclined channel

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ABSTRACT

In this study, thermal mixing (*TM*) phenomena in a rectangle channel with adiabatic circle shaped body are investigated experimentally. Two parallel jets in different temperatures are located in the channel which has a circular exit hole to supply continuity of mass. Experiments are carried out for different inclination angle (0°, 30°, 60° and 90°) of the channel. Also, effects of ratio of flow rate, jets diameters, and temperature difference between hot and cold jets were analyzed. A circle shaped passive element with low thermal conductivity is located into channel to control thermal mixing. Thermal mixing index is calculated from measured temperatures. Experimental results showed that thermal mixing of fluid is effected from geometric parameters, drastically. It is found that *TM* is function of the temperature difference of inlet jets.

1. Introduction

Homogenous mixing of fluids in different temperature is commonly encountered subject in many fields of industry and engineering applications such as nuclear engineering, mechanical engineering and environmental science. Temperature fluctuations occur in the mixing region of cold and hot fluid. These fluctuations may cause fatigue with high cycles and subsequently cracks in surrounding surfaces. For instance, in 1992, extensive cracking was found in a control rod guide tube that had been removed from the core of the UK Prototype Fast Reactor (PFR). High-cycle thermal fatigue was found to be the cause of the cracks in the connecting pipe and the middle-stage heat exchange shell at the Tsuruga-2 PWR (Japan) in 1999. These industrial cases revealed that controlling of thermal mixing in industrial systems is a challenging subject that needs to be solved. Using jets to increase mixing efficiency is one common method that is used recently.

The three-dimensional flow and mixing characteristics of multiple and multi-confined turbulent round opposing jets in a novel in-liner mixer are examined numerically using the standard k–ε turbulence model by Wang and Mujumdar [1]. In their study, they indicated that multiple opposing jets can achieve better mixing than single opposing jets. Wang et al. [2], made a numerical investigation to examine mixing efficiency of opposing jets in a confined channel using CFD code FLUENT. Some new design approaches to improve mixing effectiveness under laminar conditions in two-dimensional configurations were studied for different operating conditions and geometric configurations. Dissimilar inlet momenta with equal/unequal slot width, addition of baffles in the exit channel, effect of baffle height and multiple baffles are the parameters which used in the study. Also pressure loss due to the baffles was examined. Consequently, it is found that dissimilar inlet momenta and unequal slot width could significantly improve the mixing effectiveness; this improvement depended strongly on the operating conditions and geometric configurations. Addition of baffles in the exit channel enhances mixing effectiveness. The pressure loss was found to depend strongly on the mixer geometry and operating conditions. In their numerical work Wang et al. [3] studied the mixing characteristics and flow field of two-dimensional laminar confined opposing streams using air and water as the working fluids. The study carried out for temperature-dependent fluid properties for various temperature differences of the opposing jets, different operating conditions and different geometries. Numerical results show that the effects of temperature-dependent fluid properties on the mixing characteristics are dependent strongly on the magnitude of temperature difference, flow conditions and geometric configurations. Chang et al. [4] made a numerical analyzes to investigate the thermal mixing efficiency in Y-shaped channel. They solved two dimensional incompressible,

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Nomenclature

d	diameter (mm)
$\dot{m}$	flow rate (kg/s)
MI	mixing index
n	number of jet
PE	passive element
S_t	standard deviation of fluid temperature
t	time (s)
T	temperature of fluid (°C)
TM	thermal mixing
W_{MI}	uncertainty of mixing index
ΔT	temperature difference between hot and cold fluid (°C)
ϕ	inclination angle of the channel (°)

Subscript

h	hot flow
c	cold flow
avg	average

steady state equations using Lattice Boltzmann method. They inserted different types of passive element to improve thermal mixing efficiency. It is demonstrated that the enhanced mixing efficiency is result of an increased intersection angle between the velocity vector and the temperature gradient within the channel. Durve et al. [5] studied a numerical model to understand physics of thermal mixing phenomena based on some former fundamental studies. In the study they investigate the capabilities of various temperature fluctuation models to predict the temperature fluctuation intensities in a triple jet flow. The model which developed was in good agreement with former studies and predicts the mean velocity and temperature field with considerable accuracy. Durve et al. [6] studied hydrodynamic characteristics of flow field of single, two parallel and three parallel jet flows, numerically. In the study, effects of jet spacing, merge-combine point of jets and velocity ratio on flow field were investigated. Also flow field of single jet, two jet and three jet cases were compared with each other. Based on the results, it is found that the merge point of the jet flow is influenced from spacing between the jets and the jet exit conditions such as turbulent intensity. Also velocity ratio of jets plays important role on the location of merge and combining point of the jets. Naik-Nimbalkar et al. [7] made an experimental study and numerical investigation of thermal mixing on single/twin jets in cross flow. Experiments were carried out for different velocity ratios and 15 °C temperature difference between main pipe and jets fluid. Based on findings, prediction of mean temperature, magnitude of the temperature fluctuations, characteristic frequencies of temperature fluctuations, attenuation of the temperature fluctuations in the boundary layer near the pipe wall, effect of multiple jets entering in the cross flow and effect of space between twin jets was investigated. Consequently, authors assert that numerical predictions are in good agreement with experimental measurements. Jung and Yoo [8], carried out Large Eddy Simulations (LES) of the triple jet flow for two different sub-grid scale models. The sub-grid scale models used were Smagorinsky–Lilly model and the k–l model. The simulations were aimed to investigate the effect of inlet thermal intensities (T_{rms}/T) on thermal mixing. The predictions were validated by comparing with the available experimental data. It was concluded that LES predicted faster decay of mean temperature along the axis of the

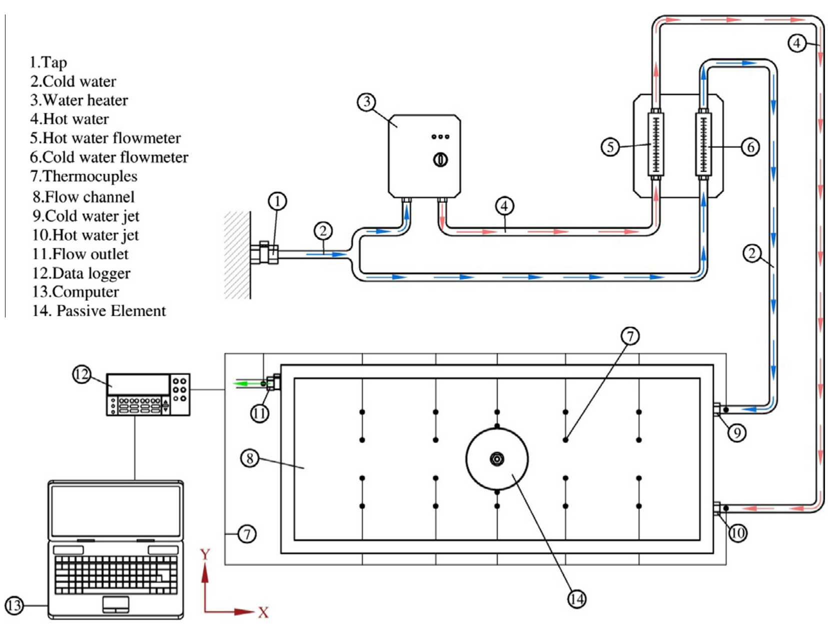

Fig. 1. Diagram of experimental Set-Up.