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ScienceDirect

Procedia Engineering 157 (2016) 58 – 65

Procedia Engineering

www.elsevier.com/locate/procedia

IX International Conference on Computational Heat and Mass Transfer, ICCHMT2016

Measurement technique of transient fluid temperature in a pipeline

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Abstract

The aim of this paper is to develop a method of determining the heat transfer coefficient on the outer surface of the thermometer used to measure the temperature of a fluid flowing under high pressure. The method is based on the solution to the inverse heat conduction problem. The heat transfer coefficients are determined based on the measurement of the temperature of a cylindrical metal thermometer and the temperature of the wall of a cylindrical pipeline. The temperature sensor is located in the pipeline wall close to the inner surface. The correlations for the Nusselt numbers used to determine heat transfer coefficients on the outer surface of the thermometer and the inner surface of the pipeline contain unknown coefficients which are found using the least squares method. The unknown coefficients are selected so that the sum of the squares of differences between the fluid temperature determined based on the measurement of the temperature of the pipeline wall and the fluid temperature obtained from measurements inside the thermometer, calculated for several dozen set time points, is as small as possible.

Peer-review under responsibility of the organizing committee of ICCHMT2016

Keywords: pipeline; temperature measurement; thermowell; heat transfer coefficient; heat transfer correlations

1. Introduction

Transient flow temperature is one of the most difficult parameters to measure. The greatest difficulty makes insufficient knowledge of the dynamic properties of the thermometer with a complex structure.

Most studies on temperature measurements concentrate on steady-state measurements of the fluid temperature. Only a transient response of the thermometer to step-wise change in fluid temperature is considered to estimate the time constant of the thermometer. Since the thermometer time constant depends strongly on the heat transfer coefficient on the thermometer surface, measurement of the thermometer time constant is usually carried out by air

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Peer-review under responsibility of the organizing committee of ICCHMT2016
doi:10.1016/j.proeng.2016.08.338

and water. In the case of air, the heat transfer coefficient is much less than for water. The dynamic temperature measurement error is usually estimated to abrupt changes in temperature of the fluid.

It is very difficult to measure the transient temperature of steam or flue gases in thermal power stations. Massive housings and low heat transfer coefficients cause the measured temperature to differ significantly from the actual temperature of the fluid [1-4]. Some particularly heavy thermometers have time constants of three minutes or longer, which require about 15 minutes for a single measurement. The problem of dynamic errors in temperature measurements of superheated steam becomes particularly important when superheated steam temperature control systems use injection coolers (spray attemperator). Due to the large inertia of the thermometer, the measurement of the transient temperature of the fluid can be inaccurate, adversely affecting the automatic control of the superheated steam system. A similar problem is encountered in flue gas temperature measurements because the thermometer time constant and time delay are large.

The paper presents a new method for the measurement of transient fluid temperature using a solid cylindrical thermometer and measuring the wall temperature of the pipeline. Identification of the heat transfer coefficient on the outer surface of the thermometer with a new structure is necessary to determine the transient fluid temperature accurately.

Nomenclature

c_{th}, c_w	specific heat of the thermometer and pipe material, J/(kgK)
e_{th}	difference between the fluid temperature and the temperature at the thermometer axis, ºC
e_w	difference between the fluid temperature and the temperature of the pipeline outer surface, ºC
$e_{w,m}$	difference between the fluid temperature and the temperature of the pipeline wall at $r_{w,m}$, ºC
f_{th}, f_w	temperature measured at the thermometer axis and in the pipe wall, ºC
h_{th}, h_w	heat transfer coefficient on the thermometer outer surface and on the pipeline inner surface, W/(m^{2}K)
k_{th}, k_w	thermal conductivity of the thermometer and the pipe material, W/(mK)
L	pipeline length, m
Pr	Prandtl number
$\dot{q}_{in}$	heat flux density, W/m^2
Re_{th}, Re_p	Reynolds number for the thermometer and the pipeline
r	radius, m
r_{in}, r_o	radius of the pipeline inner and outer surface, m
r_{th}	radius of the thermometer outer surface, m
$r_{w,m}$	radius at which the temperature is measured in the pipe wall, ºC
s	pipe wall thickness, m
T_0	initial temperature, ºC
T_{th}, T_w	thermometer and pipe wall temperature, ºC
$T_{f,th}$	fluid temperature obtained using the thermometer, ºC
$T_{f,w}$	fluid temperature determined from the wall temperature measurement, ºC
t	time, s
$x_1,...,x_m$	coefficients
ρ_{th}, ρ_w	density of the thermometer and the pipe material, kg/m^3
Δr_{th}, Δr_w	spatial step in the radial direction for the thermometer and the pipeline, m
θ_f	fluid excess temperature, ºC

2. Mathematical formulation of the problem

The transient temperature of the fluid will be determined based on the measured temperature in the cylinder (thermometer) axis and the measured temperature of the wall (Fig. 1). The measurement point in the wall can be situated inside the wall or on the outer pipeline surface.