Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 116 (2017) 324–333

Energy Procedia

www.elsevier.com/locate/procedia

The 15th International Symposium on District Heating and Cooling

Stratification in hot water pipe-flows

Denis F. Hinz[a]*, Simon Graner[a], Christian Breitsamter[b]

[a]*Kamstrup A/S, Industrivej 28, Stilling, 8660 Skanderborg, Denmark*
[b]*Technische Universität München, Institute of Aerodynamics and Fluid Mechanics, Boltzmannstrasse 15, 85748 Garching, Germany*

Abstract

In district heating and cooling networks, hot or cold fluid is transported in pipe systems over long distances. Heat loss (or gain) from the fluid-carrying pipes to the surrounding is a primary driving mechanism that can lead to various thermal dynamics effects in the fluid. Here, we investigate the thermal dynamics of low-Reynolds number hot water flow in horizontal pipes. In such flows, density differences between hot and cold water generate buoyancy effects. Further, the coupling between heat transfer and momentum transfer along with the temperature-dependent viscosity of water can result in stratified asymmetric flow profiles where fluid is transported with high velocities in the top region of the pipe cross-section and can be almost stagnant in the bottom region. In the flow laboratory at Kamstrup A/S, we carried out experiments to analyze thermally stratified flow profiles with laser-Doppler velocimetry. In this article, we present results for the downstream development of stratified flow profiles for different flow parameters including temperature, pipe diameter, and flow rate (or dimensionless Reynolds number and Rayleigh number, respectively.) Further, we discuss the impact of thermally stratified flow profiles on metering applications in district heating and cooling networks.

Peer-review under responsibility of the Scientific Committee of The 15th International Symposium on District Heating and Cooling.

Keywords: Thermally stratified pipe-flow; Laser-Doppler velocimetry; buoyancy effects

* Corresponding author. Tel.: +45 89931613; fax: +45 89931001.
E-mail address: dfh@kamstrup.com

1876-6102 © 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of the Scientific Committee of The 15th International Symposium on District Heating and Cooling.
10.1016/j.egypro.2017.05.079

1. Introduction

Single-phase thermally stratified flow may appear in horizontal pipes in which two layers of the same liquid with high temperature and density differences flow at low velocities [1]. This stratification is driven through heat transfer between the water, the pipe wall, and the surrounding air. The colder and therefore heavier fluid accumulates at the bottom part of the pipe, while the hotter and lighter fluid occupies the upper part [1]. This phenomenon is driven by buoyancy forces, emerging through a top to bottom temperature gradient in the pipe [2]. Stratification is expected to emerge when the forced-flow has a small Re and the buoyancy forces are relatively high. For large buoyancy forces, which are characterized through high Grashof numbers Gr, effects of forced convection are negligible but for lower Gr forced convection needs to be taken into account. In most practical situations, both phenomena have to be taken into account [3]. In this article, we study experiments to quantify the influence of different water temperatures and pipe diameters on the emergence of stratified flow profiles.

2. Materials and methods

We use a commercial Nd:YAG laser-Doppler velocimetry (LDV) probe from ILA/Optolution with a window chamber that enables full three-dimensional optical access. The probe is mounted on a traversing system for automated displacement in a Cartesian coordinate system (Figure 1 (a) and (b)). We perform all experiments on a verification and calibration test bench in the flow laboratory of Kamstrup A/S using brass pipes of inner diameter D = 15.0 mm (DN15) and D = 25.0 mm (DN25). The pipes are not insulated to provide an experimental setup with maximized heat exchange between the fluid, the pipe, and the environment. The volumetric flow rate Q, the water temperature T, and the pressure p are actively controlled and adjusted within a PID feedback loop.

We perform experiments at various flow rates and temperatures corresponding to different Reynolds numbers Re and Rayleigh numbers Ra. The Reynolds number is defined as

$$\mathrm{Re} = \frac{w_{\mathrm{vol}} D}{\nu}, \tag{1}$$

where $w_{\mathrm{vol}} = Q / A$ is the volumetric velocity and ν is the kinematic viscosity based on the mean temperature

$$T_{\mathrm{mean}} = \frac{T_i + T_o}{2} \tag{2}$$

in the test section with T_i the inlet temperature and T_o the outlet temperature. To assess the downstream development, we perform measurements at cross sections located at z_{ST} = 12.0D, 30.0D, 60.0D, and 110.0D downstream from the inlet (Figure 1 (c)).

3. Results

First, we show results for Re = $1.0 \cdot 10^3$ which corresponds to Q = 0.0392 m^3/h with the DN25 pipe and Q = 0.0235 m^3/h with the DN15 pipe. Figure 2 shows two-dimensional (2D) contour plots of stratified velocity profiles in two different pipe diameters at various distances downstream from the inlet. For the DN15 velocity profiles (Figure 2 (a)–(d)), the stratification increases with increasing downstream distance, as indicated through the red color zone with $w/w_{\mathrm{vol}} \approx 2$. Hence, the asymmetry is highest for z_{ST} = 110.0D whereas all profiles are symmetric along the x-axes. A visual comparison of the DN15 contour plots with the DN25 contour plots shows that the flow is already strongly stratified at 30.0D for DN25. Further downstream at 60.0D and 110.0D, only slight differences in the profiles are visible. This indicates that a fully developed stratified flow emerges at around 30.0D for T = 60°C