



Thermal mixing in a T-junction: Novel CFD-grade measurements of the fluctuating temperature in the solid wall

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ABSTRACT

This article reports new experiments performed with the purpose of generating novel data of the fluctuating temperature inside the solid in the mixing region between hot and cold water in a T-junction. This data has been measured using a novel sensor (coefh) developed at the Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA) in Cadarache, France. These experiments are performed within the framework of the MOTHER project. The main objective of the MOTHER project is to validate various CFD approaches (such as LES, Hybrid i.e. RANS/LES and RANS) for transient heat transfer in a T-junction configuration including the pipe wall. Hence, the performed experiments have focused on accurately measuring and documenting the boundary conditions to be able to have a well-defined database for CFD validation. The tests are performed for two different Reynolds numbers 40000 and 60000 and for two different T-junction geometries; a sharp corner and a round corner.

1. Introduction

Thermal fatigue is a degradation mechanism which occurs in a wide range of industrial applications. One such application is the primary piping system of a nuclear power plant, where the mixing of flows with different temperature can lead to thermal fatigue. The consequences of thermal fatigue can be serious and can cause sufficient structural damage for a power plant to require a complete shut-down. Therefore, it is highly relevant in the context of aging and the life time management of a nuclear power plant. In the last decade, several efforts have been made for the assessment of thermal fatigue (Brailard et al., 2006; Chapuliot et al., 2005; Coste et al., 2008; Fontes et al., 2009; Kamide et al., 2009; Smith et al., 2013). The generic configuration that is mostly considered is the T-junction, where the mixing of two separate hot and cold streams occur immediately downstream of the T-junction. This transient turbulent mixing results in high temperature fluctuations next to and inside the pipe walls. The first step is, however, to be able to predict the temperature fluctuations in the fluid close to the wall. In this regard, an extensive amount of research work has been performed in relation to the application of CFD for the assessment of thermal fatigue in the T-junction (Gillis et al., 2013; Howard and Pasutto, 2009; Jayaraju et al., 2010; Kuhn et al., 2010; Nakamura et al., 2009; Westin

et al., 2008).

In the recent past, an attempt was made to evaluate the accuracy in the CFD predictions such thermal fluctuations in the form of the OECD CFD Benchmark for the Vattenfall T-junction configuration (Smith et al., 2013). The considered configuration was based on adiabatic walls. As an outcome of the benchmarking exercise, one of the recommendations was the need for more insights into the heat transfer phenomenon from the fluid flow to the wall. This recommendation was the main motivation behind the MOTHER project, with the purpose of generating novel data of the fluctuating temperature in the solid wall for the validation of CFD calculations.

The main objective of the **MOTHER** project (**Modelling T-junction HEat TransfeR**) is to validate various CFD approaches (such as LES, Hybrid (RANS/LES) and RANS) for transient heat transfer in a T-junction configuration including the wall with new experimental data. These CFD calculations have to take into account the effect of the wall and the heat transfer. The mean and fluctuating fields of the velocity and the temperature (fluid and wall) are also evaluated. The effects of the mixing tee geometry (a round and a sharp corner) as well as Reynolds numbers (Re) are investigated at Re = 40000 and Re = 60000. The FATHERINO facility at CEA in Cadarache is used as the test facility. This facility is specifically designed to study the

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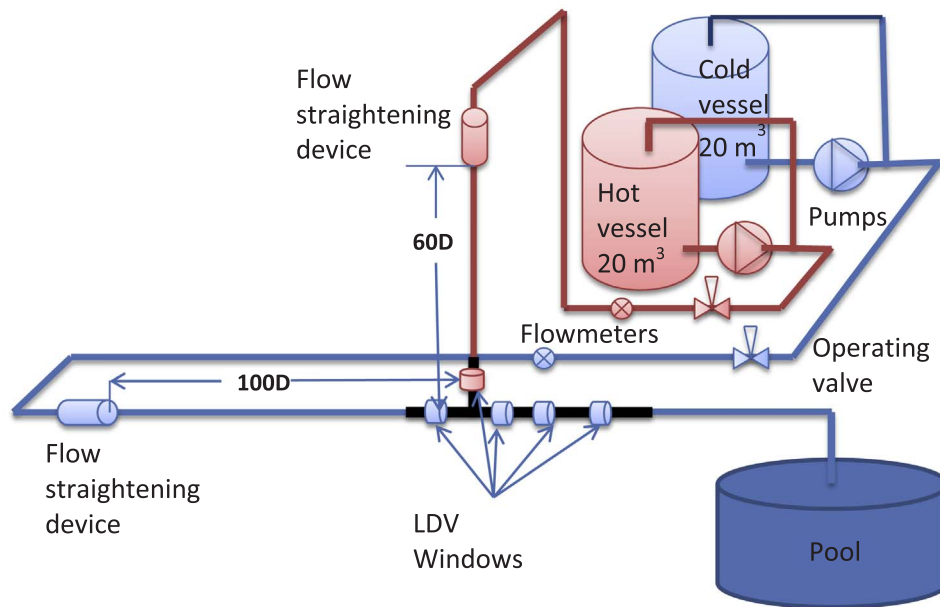


Fig. 1. The FATHERINO facility – overall view with the long straight pipes.

thermal loads for mixing in T-junction geometries. The instrumentation includes Laser Doppler Velocimetry (LDV) and thermocouples for the measurement of temperature. The advanced “coefh” sensor is used for the latter. The description of the FATHERINO test facility is given in Section 2. Details of the measurement techniques and the boundary conditions are given in Section 3. In Section 4, the results in the mixing region are reported. This is followed by the conclusions in Section 5.

2. The FATHERINO experimental setup

The experimental setup is composed of an equal T-junction (54 mm × 54 mm in diameter D) connected to two straight upstream pipes, i.e. a direct and a perpendicular branch, as shown in Fig. 1. The straight direct branch carries the cold water and is 100 D long, whereas, the straight perpendicular branch is 60 D long and carries the hot water. These pipes are composed of successive sections of PVC (polyvinyl chloride material) and stainless steel close to the T-junction and the whole system is connected by the flanges (Fig. 1).

Two independent pumps are installed to supply the flows to the T-junction. In addition, two operating valves (controlled by the flow meters) are used to keep the flow rates constant during the decreasing water level in the respective vessels. The capacity of each vessel is 20 m^3 , which is sufficient in order to perform a test during several hours with the current flow rates.

In order to reduce the effects of the pipe bends, two flow straightening devices are installed before the straight pipes. These devices consist of cylinders with several long drilled parallel holes followed by three fine grids in order to generate evenly distributed velocity profiles with homogeneous turbulence.

2.1. The mock-ups

2.1.1. The stainless steel 304L mock-ups

Two internal geometries are investigated, one sharp corner and one round corner, as shown in Fig. 2. The common dimensions for the 304L mock-ups are a nominal internal diameter of 54 mm with a thickness of 9.53 mm. The diameter of the 304L mock-ups has been controlled and it has been found to be between 53.80 mm < $\varnothing$ < 53.97 mm. The internal radius, R , of the roundness of the intersection between the two pipes is less than 1 mm for the sharp corner (i.e. can be assumed to be perfectly sharp in CFD) and $R = 18$ mm for the round corner.

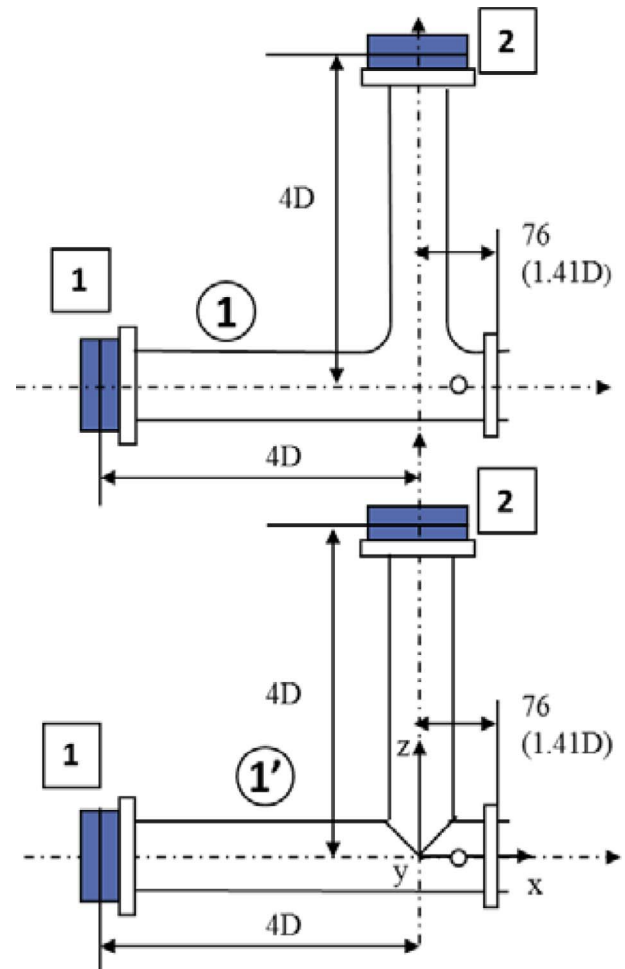


Fig. 2. The sharp and the round corner geometries.

The surface roughness has been measured (of the order of 1–10 μm) and it can be concluded that it is safe to assume hydraulically smooth pipes in the CFD considering the values of the skin friction in the tests. The stainless steel is used for the mock-ups is 304L with the following

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