The numerical modeling and the infrared thermography applied to the detection of fluids nature in pipes

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Abstract
The development of numerical methods has made the numerical simulation an important tool in industry and in research fields. In this paper, we present numerical simulations intended to show the ability of the non-destructive thermal control method in detecting the nature of fluid flowing in a given pipe. We examined two kinds of pipe, steel and PVC containing each three different liquids: water, thermal oil, and ethanol. We considered incompressible liquids in laminar flow in steady state. The obtained results, in form of thermographical images and spatial distribution of temperature on the pipe surface are interesting and they show that temperature responses can inform us about the nature of fluid flowing inside the inspected pipe. The modeling was carried out using a calculation software based on the finite element method.

Keywords: pipe, numerical methods, finite element method, non-destructive thermal control, temperature response.

1 Introduction

Industry and research institutions need qualified Scientists of high level, able to take on projects of physical phenomena modeling, mathematical aspects of control models and ensure problem-solving in an industrial or a research perspective.
Pipeline transport is a mode of transport of gaseous, liquid, solid or multiphase achieved by means of pipes generally forming a network [1][2]. This is a mode has become very popular and preferred transporting mode especially for long distances. The used materials are typically the PVC or steel pipe and the choice depends on the nature and the state of the products to be transported.

In this work we perform simulations, based on finite element method [3], of two types of pipes that are among the most used in transporting industry to detect fluids they carry. The method consist in applying to the external surface of these pipes a stream of constant heat and will analyzing their steady thermal responses in the case of laminar flow. We consider the case of incompressible fluids with different thermal properties such as water, thermal oil and ethanol. The obtained results show the ability of the non-destructive thermal control method in detecting the nature of fluid flowing in a pipe.

2 Description of the adopted model

We considered two pipes commonly used in industrial networks. A metal pipe represented by a steel pipe, and an other in plastic in PVC, whose geometrical characteristics are described in the table below [4].
Table 1. The geometrical characteristics of the two pipes used in this study

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Pipe 1 (Steel)</th>
<th>Pipe 2 (PVC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube length</td>
<td>1000 mm</td>
<td>1000 mm</td>
</tr>
<tr>
<td>Inside diameter</td>
<td>80 mm</td>
<td>100 mm</td>
</tr>
<tr>
<td>Thickness</td>
<td>3 mm</td>
<td>7 mm</td>
</tr>
</tbody>
</table>

V: The liquid flow rate.
L: The length of the pipes.
P: Pressure of liquid at output pipe

Figure 1. Geometry of the studied structure

2.1 Mathematical Model

In the model we studied two modes of heat exchange: Exchange of heat by conduction in the metal part of the pipe and heat exchange by convection between the inner surface of the pipe and the considered fluid that completely filled pipe. The thermal response of the inspected pipe is raised in the form of the surface temperature. The determination of the spatial distribution of this surface temperature of pipe is obtained by solving the following equation of Heat [5].

\[ \begin{equation}
T = \frac{1}{\lambda \rho c} \left( \frac{\partial^2 T}{\partial x^2} \right) + \frac{Q}{\lambda} + \frac{V}{\rho c} \left( T - T_0 \right)
\end{equation} \]

Where

\begin{itemize}
\item T the temperature of the pipe surface (° K)
\item \( \lambda \) is the thermal conductivity ( W / ( mK ) )
\item \( c \) is the specific heat ( J / ( kg.K ) ) and \( \rho \) is the density (kg/m³).
\end{itemize}

The initial temperature of the pipe is assumed: \( T_0 = 293 \, ^\circ \text{K} \). The external faces of the pipes are exposed to a constant density \( Q = 50 \, \text{W/m}^2 \); the internal are convective heat exchange with fluids that are at an initial temperature of \( T_0 = 293 \, ^\circ \text{K} \), as we considered that the liquid flow at low velocity \( V = 0.013 \, [\text{m/s}] \) and the outlet pressure is zero.

The pipe surface temperature distribution is determined by a calculation based on the finite element method software. The adopted mesh structure is compound of tetrahedral mesh elements (Figure 2).
2.2 Simulation Results

thermophysical characteristics of the pipes and fluid flowing there through used in the simulations are shown in Tables 2 and 3 [5].

Table 2. Pipe thermophysical characteristics

<table>
<thead>
<tr>
<th>thermophysical characteristics</th>
<th>Steel pipe</th>
<th>PVC pipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal conductivity $k$ (W/m.K)</td>
<td>44.5</td>
<td>0.589</td>
</tr>
<tr>
<td>Density $\rho$ (kg/m$^3$)</td>
<td>7850</td>
<td>999.054</td>
</tr>
<tr>
<td>the specific heat $C$ (J/kg.K)</td>
<td>475</td>
<td>4180</td>
</tr>
</tbody>
</table>

Table 3. Liquid thermophysical characteristics

<table>
<thead>
<tr>
<th>thermophysical characteristics</th>
<th>Water</th>
<th>thermal oil</th>
<th>Ethanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal conductivity $k$ (W/m.K)</td>
<td>0.6</td>
<td>0.1891</td>
<td>0.169</td>
</tr>
<tr>
<td>Density $\rho$ (kg/m$^3$)</td>
<td>1000</td>
<td>886.2</td>
<td>798</td>
</tr>
<tr>
<td>the specific heat $C$ (J/kg.K)</td>
<td>4200</td>
<td>1907</td>
<td>2460</td>
</tr>
<tr>
<td>Dynamic viscosity (Pa.S)</td>
<td>0.001</td>
<td>0.0105</td>
<td>0.00120</td>
</tr>
</tbody>
</table>

2.2.1 Effect of the liquid nature flowing in a the steel pipe

To illustrate the ability of the infrared thermography in detecting the fluid nature flowing in the pipes we considered in this study three types of liquid: water, ethanol and thermal oil. In Figure 3 are represented the surface temperature distribution obtained from the three fluids flowing in a steel pipe.
Figure 3. The surface temperature distribution of a steel pipe containing (a) water, (b) the thermal oil, and (c) ethanol.

In Figure 4 are represented the spatial surface temperature variations according to oy axis of the considered pipe (in the direction of flow).

Figure 4. Spatial surface temperature variations of a steel pipe containing (a) water, (b) the thermal oil, and (c) ethanol.

The results shows that the pipe surface temperature varies slightly versus the thermophysical properties of the liquid it contains.

2.2.2 Effect of the liquid nature flowing in a PVC pipe

In Figure 5, are plotted the distribution of the surface temperature of the three considered above liquid flowing through a PVC pipe.

Figure 5. Surface temperature distribution in the case of a PVC pipe containing (a) water, (b) the thermal oil, and (c) ethanol.
To show the ability of infrared thermography in the control of industrial pipes and in particular the detection of the type of fluid flowing therethrough; we plotted (Figure 6) the temperature variation along the tube.

The curves show that the temperature values of the pipe surface temperature depend on the thermophysical properties of the considered liquid. By establishing calibration curves between fluid flowing in the pipe and the surface temperature one can recognize the fluid nature. In figure 7 and 8 are respectively plotted the spatial temperature variation along steel pipe and of the PVC one containing: water, thermal oil and ethanol.
We note that for each considered pipe the thermal response varies according to the liquid flowing therethrough; and accordingly the response of a pipe that contains water is different from that which contains the thermal oil or ethanol. The precedent results are observed independent of the pipe nature, steel or PVC.

3 Conclusion

A numerical model based on the finite element method has been implemented for the thermal response study of a pipe according to the nature of the liquid that contains. The goal of this model is to demonstrate the ability of the infrared thermography in detecting the nature of the fluid flowing in a given pipe, of steel or plastics in this study, material commonly used in the industry.
Numerical simulations have shown that the surface temperature distribution of a pipe changes with the nature of the liquid contained therein. The exploitation of these results shows the possibility of using thermographic measurements in the recognition of circulating fluids in pipes in service which is a great contribution to the industry.

References


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