TR 77 FC

DEVELOPMENT OF AN EXPERIMENTAL METHODOLOGY IN ORDER TO ESTIMATE INSTANTANEOUS HEAT TRANSFER COEFFICIENT IN THE ENTRANCE REGION OF AN INTERMITTENT GAS FLOW

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The application of new standards of pollutant gas emission restrictions has forced the motor-car industry to improve their catalytic exhaust system. In order to reduce the noxious gas emission, the exhaust gas temperature must be maintained into a specific range. Therefore, it becomes necessary to well-know the interaction between gas and inner wall along the whole exhaust system (from combustion chamber to monolith). Such local information can be obtained from numerical simulations computed on fluid mechanic solvers which take into account heat transfers between gas flow and solid wall. Due to the complex geometry of exhaust manifolds and the intermittent feature of the gas flow, the viability of numerical results is not guaranteed.
The aim of the present study is to design an experimental device representing a basic exhaust pipe with a simple cylindrical geometry and to develop an experimental methodology in order to estimate a heat transfer coefficient describing the interaction between pipe wall and intermittent gas flow. The prime objective of this experimental approach is to better understand the solid-fluid interaction in the case of an intermittent compressible flow. Thereafter, the numerical simulation of this experiment carried on several software makes it possible to choose among the latter, the one which describes the best the studied exhaust system.

THE THEORETICAL MODEL: MEASUREMENT PRINCIPLE OF HEAT TRANSFER COEFFICIENT

In the exhaust pipe, the compressible gas flow is modelled by a set of equation which is available for a thermally and hydrodynamically developing flow. The model describes an axisymmetric domain. It takes into account the coupled physical mechanisms: the thermal one due to the conduction in the solid part and the dynamical one due to convection in the compressible gas flow inside the tube.
In the solid, we consider both axial and radial conduction due to presence of thermal singularities at the inlet and at the outlet of the tube [1]. The boundary conditions of the inner and the outer surface of the tube will be conditions of the third kind.
The gas flow will be modelled with one-dimension Navier-Stockes equation for a compressible fluid in which shear stress is neglected. So, the governing equations of the gas flow are reduced to the one-dimension Euler equations: heat transfer appears via a heat source term on right hand side of the energy equation. In order to solve this system, we assumed that the gas is a perfect one. Boundary conditions are chosen in order to have a well-posed problem [2]. Therefore, temperature, density and velocity are imposed at the inlet of the tube whereas pressure is imposed at the outlet.
The theoretical model is computed using an upwind scheme for the gas flow equation and an ADI method for heat transfer equation in the tube. We assumed that all thermophysical

properties are isotropic and homogeneous and that the cylinder's ones depend only on the temperature field.

EXPERIMENTAL DEVICE

The experimental device has been designed and constructed in order to re-create the intermittent gas flow of an exhaust system. Note that it's really important to control all inlet conditions of the gas flow in the exhaust pipe in order to be able to estimate their influence on heat transfers on the inner tube interface. Therefore the gas flow has been realised with a pressure tank equipped with a valve dragged by a camshaft. The volume of the tank was calculated in order to have negligible variations of pressure during experimental process. It was also insulated to have a constant entry temperature for the gas flow. The exhaust system is just a metallic hollow cylinder. For such kind of exhaust pipe, one is able to write and numerically solve the set of governing equations in the gas flow and in the cylinder.
The thermal excitation in exhaust pipe is only generated by the hot intermittent gas flow. One will control the inlet conditions such as pressure, temperature and flow rate in order to estimate their thermal effects on temperature field of the cylinder. In a first time, only periodic steady state will be of interest.
Both heat flux sensor and gas temperature probe have been implanted in several suitable selected places of the exhaust pipe. In order to estimate the heat flux which is assumed to be one-dimensional, the temperature of the solid is measured, with fine thermocouples, in two points located along a radial direction in the tube. In the same section, the mixed-temperature of the gas flow is measured on the axis of the tube with a two thermocouple probe.

EXPERIMENTAL PROCESS AND FIRST RESULTS

Since heat transfer coefficient is defined by the equation *(1)*, it can be determined if, locally, superficial instantaneous heat flux and both wall and gas temperatures are known:

$$h = \frac{\phi}{(T_{gas} - T_{wall})} \qquad \textbf{\textit{(1)}}$$

The knowledge of the thermophysical properties of the tube allows determining both instantaneous heat flux transferred between the tube and the gas flow and instantaneous wall temperature via an inverse method [3].

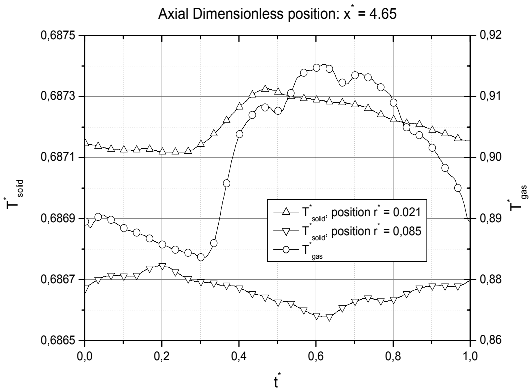

Figure 1 : dimensionless recordings

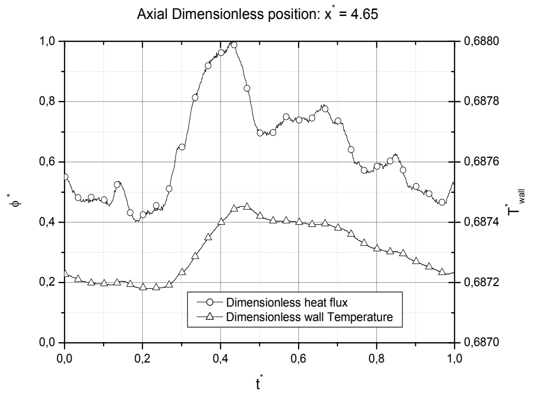

Figure 2 : dimensionless estimated heat flux and wall temperature

First results are just presented here in dimensionless form. Figure 1 shows an example of temperature recordings and Figure 2, the heat flux and the wall temperature estimations.

Figure 3 presents the heat transfer coefficient calculated from equation *(1)* and averaged over several periods.

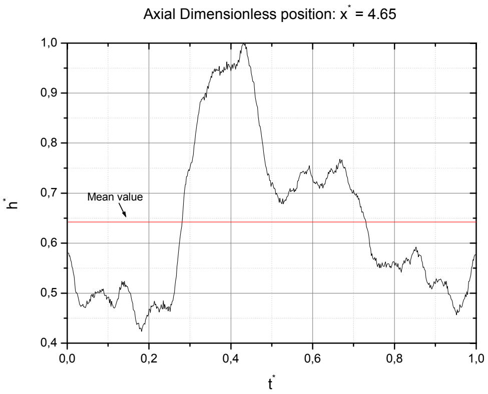

Figure 3 : dimensionless heat transfer coefficient

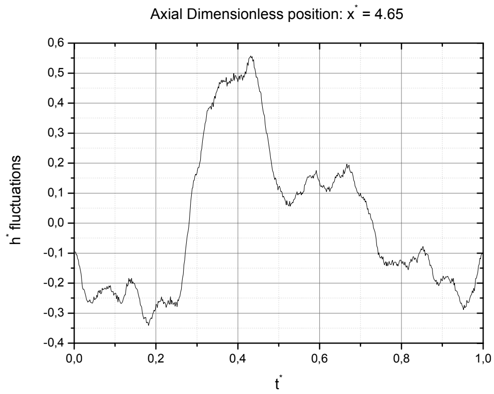

Figure 4 : dimensionless heat transfer coefficient fluctuations

One can see on these figures that all the system features are periodic and that their period is the same as the inlet velocity one. The Figure 3 shows that the crenellated shape of the inlet velocity doesn't lead to a similar shape for the heat transfer coefficient. Moreover, this coefficient doesn't vanish when the inlet flow vanishes. The heat transfer coefficient can be split into a mean value and a fluctuation value. The heat transfer fluctuations which are presented in Figure 4 take values from 30 per cent below to 50 per cent above the mean value. This implies a noticeable thermal penetration depth. Therefore, one can not neglect the influence of these fluctuations on thermal wear of the exhaust pipe.

CONCLUSION

We presented an original experimental approach to study the solid – fluid interaction in the case of an intermittent gas flow. The experimental device is designed and constructed to re-create the main features of the compressible flow in engines.

The direct model describing the coupled problem is solved by an ADI method in the solid and an upwind method in the fluid. The estimation of the heat transfer coefficient is carried out by a well known inverse technique.

This first experiments show that it is possible to estimate the instantaneous heat flux coefficient with a flux sensor and a gas temperature probe. These results will help us to better understand how the intermittent features of the gas flow affect the heat transfer coefficient. Up to now, our study has been carried out with a discontinue estimation of the heat transfer coefficient but an original inverse method will be developed in order to determine this coefficient as a continuous function of time and axial position

Note that the basic geometry of the developed exhaust pipe allows focusing on basic physical phenomenon whereas a complex geometry doesn't permit it. Moreover, such experiments present the advantage to be comparable to other authors' data whereas experiments carried out on an engine won't.