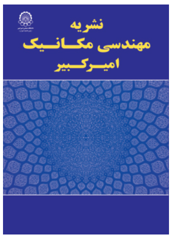

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Simulation of Heat Transfer in Shutdown Time of Engine by Conjugate Heat Transfer

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ABSTRACT: At the time of engine shutdown, the most probability of boiling exists. The reason is that in a few seconds after stopping of revolution of water pump, the temperature of coolant that is in direct contact with the cylinder head, increases; and if the temperature rising is not considered in design, it can causes film boiling in water jacket of engine. In time of the engine shut down, the cylinder is in contact with piston, and if the cylinder temperature does not drop rapidly, it will cause serious damage to the engine. Also, decreasing in heat transfer from hot gases of combustion chamber to coolant due to stopping the revolution of coolant causes the damage in gasket. Therefore, this damage can be prevented by obtaining distribution of the block temperature during silencing. In this paper, coupled heat-transfer simulation of cooling jacket, block and cylinder head after the engine shut down is carried out with AVL-Fire software. Results of pressure and heat transfer coefficient, heat flux in water jacket and temperature distribution in block and cylinder head are achieved. Finally, effect of engine shutdown is investigated.

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1- Introduction

Increasing temperature in hot spots in the engine, such as exhaust valves and piston head, causes burning phenomena in these areas. If the heat transfer in the combustion chamber wall is not performed well, the temperature in areas such as the exhaust valve and the piston head increases sharply, which can provide the ground of the knock phenomenon. Generally, cooling in the engine is carried out in order to keep the engine's temperature in a certain range, so that the performance of the engine parts is not affected and the oil does not lose its lubrication properties.

Boo [1] used a single-phase boiling model to simulate sub-cooled boiling in a water passage. They first validated the proposed model with Robinson's and Zeitoun's experimental results [2, 3]. Chang et al. [4] performed the current simulation to correct cylinder gaskets. They enumerated the communication channels between block and cylinder head and changed their diameters in three stages. Dong et al. [5] investigated four boiling models in a horizontal duct of T-section under the conditions of the operation of the cooling system of the internal combustion engines, and then used the two existing models, which had a good fit with the experimental data, to simulate boiling in water passage. Mohammadi et al. [6-7] compared the results of boiling heat transfer coefficient with a single-phase boiling model and two-phase boiling model in the vehicle diesel engine water-jacket. They used Fluent software along with the User Defined Function (UDF) for boiling modeling and used the results of Kang [8] to validate the models.

In the present work, we study the effect of engine shutdown and subsequent phenomena on the temperature distribution of block and cylinder head and possible boiling due to stopping fluid movement due to engine and water pump shutdown. In the first ten seconds, the engine works in critical conditions (maximum and complete load), then the engine suddenly turns off and all conditions (heat transfer coefficient and fluid temperature) change. Therefore, contrary to previous research, the present study is a simulation of an unsteady problem.

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2- Methodology

The mass conservation equation for incompressible flow in unsteady state:

$$\nabla . V = 0 \quad (1)$$

The momentum conservation equation for incompressible flow:

$$\frac{DV}{Dt} = \rho g - \nabla P + \mu \nabla^2 V \quad (2)$$

The energy conservation equation for incompressible flow in low velocities:

$$\rho c_v \frac{DT}{Dt} = k \nabla^2 T \quad (3)$$

The Foster-Zoober equation is used to calculate the heat transfer coefficient of pool boiling. It is possible to correct the nucleate boiling heat transfer coefficient with a correction coefficient S due to the flow availability. Two models are proposed for calculating the correction coefficient S: Chen model and BDL model. The total heat flux is also obtained by Eq. (4):

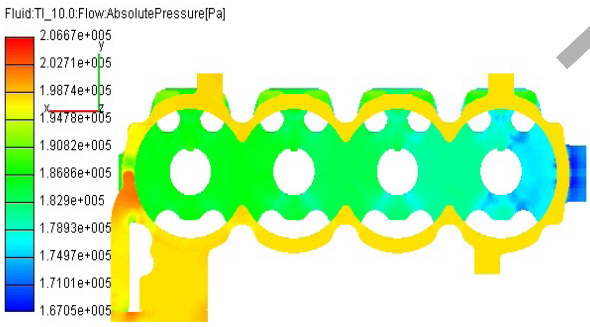
$$q_{total} = \varphi h_{mac} (T_w - T_\infty) + S h_{mic} (T_w - T_{sat}) \quad (4)$$

3- Results and Discussion

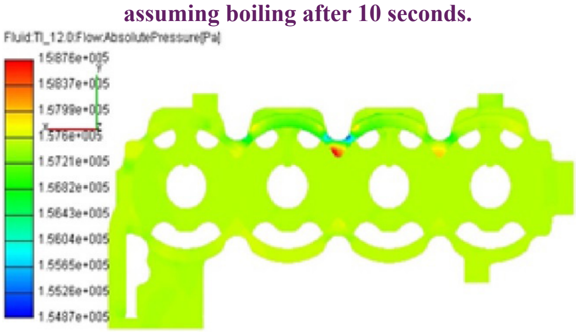
In the present study, solving solid and fluid heat transfer was used as coupling. In the process of solving the simultaneous solid and liquid heat transfer, the water-jacket and the solid body part of the engine (block and cylinder head) are individually meshed and simulated, and in each step the information of the boundary conditions of heat transfer between the boundary of fluid and solid is exchanged. This action continues until the convergence and non-change in the boundary conditions of the two solutions are stabilized. The heat transfer coefficient is obtained by the wall function. The purpose of this study is to simulate the block and cylinder with the water-jacket, considering the boiling effect in the transient state using the Chen model, and the distribution of temperature and heat transfer coefficient in the block, cylinder head, and fluid passage are determined.

Since pressure variations have a direct effect on boiling, it is necessary to check the changes in pressure after engine shutdown. In Fig. 1, fluid pressure is observed in 12 seconds. For up to 10 seconds, engine is working simulated and the pressure distribution is similar to that of the working engine steady solution. The pressure difference tends to zero in the various areas of passage post-shutdown. As shown in the Fig. 1, with passing time, the internal pressure of the system approaches to the atmospheric pressure, which reduces its boiling temperature. Hence, possibility of boiling can increase by shutting down the engine followed by the water pump shutting off.

In Fig. 2, the maximum temperature of the fluid in terms of time in the cylinder head is shown between the two candles. The temperature rises sharply from engine shutdown time, and after 10 seconds the fluid temperature increases to 94°C and there is no trace of boiling phenomena in the passage. But after 10 seconds of the engine shut down, the fluid temperature



Pressure distribution in water-jacket in cylinder head, assuming boiling after 10 seconds.



Pressure distribution in water-jacket in cylinder head, assuming boiling after 12 seconds.

Fig. 1. Contour of pressure distribution in fluid, in 12 seconds.

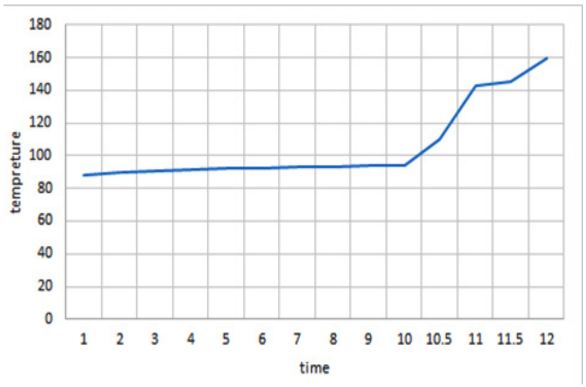


Fig. 2. Temperature versus time.

rises to 160°C and the film boiling phenomenon occurs (Fig. 2). Since the heat transfer coefficient increased from its critical value, the solution was automatically discontinued by the software.

4- Conclusions

In this research, unsteady heat transfer in blocks, cylinders, and water-jacket using AVL FIRE software, together with an intermediate code for simultaneously solving heat transfer in solid and fluid, was carried out for the distribution of temperature and fluid behavior after engine shutdown. For the assumption of boiling, single-phase models have been used because of their low computational time over the two-phase solution of boiling equations. After simulation, the results are as follows:

In the working conditions of the engine, the two methods of Chen and BDL obtained the same results with a 5% error. But with Chen's method, more precision was obtained at engine working velocities.

For a period of 10 seconds, engine is working simulated and the pressure distribution is similar to the steady solution of the engine. Over time, the pressure inside the system approaches the atmospheric pressure, which reduces its boiling temperature. Hence, boiling can increase by turning off the engine and then shutting off the water pump.

Boiling does not occur up to 10 seconds and the amount of boiling heat transfer is zero. When the engine is shut down and the pump is stopped, it starts boiling. The boiling heat flux increases substantially in fraction of a second.

In the boiling test, it was observed that after 2.3 seconds after engine shutdown, the temperature of the fluid inside the passage reached 160°C and the boiling entered the film region.

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