International Journal of Thermal Sciences 50 (2011) 1215–1222

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

journal homepage: www.elsevier.com/locate/ijts

Transient heating of a semitransparent spherical body immersed into a gas with inhomogeneous temperature distribution

S.S. Sazhin [a,*], I.G. Gusev [a], P.A. Krutitskii [b], M.R. Heikal [a]

[a] Sir Harry Ricardo Laboratories, Centre for Automotive Engineering, School of Computing, Engineering and Mathematics, Faculty of Science and Engineering, University of Brighton, Brighton BN2 4GJ, UK

[b] Keldysh Institute for Applied Mathematics, Department 4, Miusskaya Sq. 4, Moscow 125047, Russia

ARTICLE INFO

Article history:
Received 7 October 2010
Received in revised form
5 January 2011
Accepted 14 February 2011
Available online 1 April 2011

Keywords:
Heating
Spherical body
Heat conduction
Diesel engines

ABSTRACT

The transient heat conduction equation, describing heating of a body immersed into gas with inhomogeneous temperature distribution, is solved analytically, assuming that at a certain distance from the body gas temperature remains constant. This problem is a generalisation of the problem solved earlier where gas, into which the body is immersed, was assumed to be initially homogeneous. This solution is applied to the case when the distribution of gas temperature is chosen such that heat flux in gas initially does not depend on the distance from the body surface in the region close to this surface. The solution is applied to modelling body heating in conditions close to those observed in Diesel engines. It is pointed out that inhomogeneous gas temperature distribution leads to slowing down of body heating compared with the case when the body is immersed into a homogeneous gas. In a long time limit, the distribution of temperature in the body and gas does not depend on the initial distribution of gas temperature. In the case of a body immersed into an inhomogeneous gas, for large times the correction to the Newton law is shown to be essentially the same as predicted by the model, based on the assumption that gas is initially homogeneous. For short times, this correction approaches finite values, well below those predicted by the model, based on the assumption that gas is initially homogeneous. For large gas domains these values are close to 1. These results essentially confirm the earlier finding that ignoring these corrections is expected to lead to unacceptably large errors in computations.

1. Introduction

The problem of modelling droplet or solid body heating/cooling and evaporation has been discussed in numerous papers (e.g. [1,2]) and the results have been summarised in a number of reviews and monographs, including [3–6] (see [7–9] for the most recent developments in this area). In computational fluid dynamics (CFD) codes, a simplified model of these processes is usually used, which is based on the assumption that gas in computational cells is always homogeneous and the gas temperature in the immediate vicinity of the droplet surface is the same as in the rest of the cell [5,6]. The droplet heating in this case is described based on the Newton's law with gas ambient temperature assumed equal to gas temperature in any point of the cell. The validity of this approach has been investigated in [10], where the effects of a sudden immersion of a body into a homogeneous gas have been studied. In the model, described in [10], gas temperature was fixed at a certain distance from the surface of the body and equal to the ambient temperature, while gas temperature near the body was allowed to change with time alongside the temperature inside the body. As follows from the analysis of [10], noticeable deviations from the predictions of the conventional Newton's law, used in CFD codes, were observed. At the initial stage, the body was heated up (or cooled down) much quicker than predicted by the Newton's law, while at the final stages the body heating/cooling followed the Newton's law, but with the values of the heat transfer coefficient smaller or larger than predicted by the conventional model, depending on the thickness of the region where gas temperature was allowed to change.

One of the main limitations of the model described in [10] is that it was based on the assumption that initially gas temperature was homogeneous in the whole domain. This imposes a serious limitation for practical applications of this model in a realistic environment when the ambient temperature can vary with time.

The main objective of this paper is to generalise the model described in [10] to the case when the initial gas temperature is not

* Corresponding author. Tel.: +44 1273 642 677; fax: +44 1273 642 301.
E-mail address: S.Sazhin@brighton.ac.uk (S.S. Sazhin).

1290-0729/$ – see front matter
doi:10.1016/j.ijthermalsci.2011.02.012