TYPE Editorial
PUBLISHED 09 May 2023
DOI 10.3389/fther.2023.1203906

OPEN ACCESS

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RECEIVED 11 April 2023
ACCEPTED 18 April 2023
PUBLISHED 09 May 2023

CITATION
Dombrovsky LA (2023), Editorial: Editor's challenge in heat transfer mechanisms and applications: 2022.
Front. Front. Therm. Eng. 3:1203906.
doi: 10.3389/fther.2023.1203906

Editorial: Editor's challenge in heat transfer mechanisms and applications: 2022

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KEYWORDS

combined heat transfer, computational modeling, sophysticated approaches, thermal radiation, heat conduction, phase shanges, thermal destruction

Editorial on the Research Topic
Editor's challenge in heat transfer mechanisms and applications: 2022

In the study of many heat transfer processes, it is necessary to consider the interaction of heat conduction, natural or forced convection, and heat transfer by thermal radiation. The greatest difficulties in the computational modeling of combined heat transfer are related to time-consuming calculations of radiative transfer in absorbing and scattering media. Such media are, for example, gases or liquids with suspended particles, as well as dispersed materials and solids with microcracks or bubbles. Natural objects of study include the Earth's atmosphere and ocean, snow and ice, powders or dust, ordinary sand, and even biological tissues with optically heterogeneous living cells. In thermal engineering, these are combustion products containing soot and fly ash particles, porous ceramics and heat-shielding materials, particles in thermochemical reactors, and melt droplets from a possible severe nuclear reactor accident.

Thermal radiation has a wide spectral range in which the optical properties of substances and materials are usually substantially dependent on the radiation wavelength. Therefore, in order to calculate the contribution of thermal radiation to heat transfer, radiative transfer calculations must be carried out for a large set of different wavelengths. In the numerical solution of transient heat transfer problems, such calculations, carried out at each time step, are the main factor influencing the computation time. It is also important that the numerical solution of the integrodifferential radiative transfer equation (RTE) regarding the radiation intensity, which is dependent not only on the coordinates but also on the direction, is a very complex procedure (Coelho, 2014). This means that the use of simple but sufficiently accurate models of radiative transfer in scattering media is absolutely essential for solving many problems of combined heat transfer.

Fortunately, heat transfer problems (unlike optical diagnostics problems) have a number of physical features that allow simpler mathematical models. Note that we are usually dealing with multiple scattering of radiation in a medium when the angular distribution of the radiation in a single scattering is irrelevant. In this case, the so-called transport approximation can be used (Dombrovsky, 2012); the integral term in RTE is missing and the scattering anisotropy is taken into account by a transport scattering coefficient. The high accuracy of the transport approximation has been confirmed for diverse problems (Dombrovsky, 2010; Dombrovsky, 2019).

A further simplification of the mathematical formulation of the problem is due to the fact that in heat transfer problems, it is important to know only the spectral radiative flux and the divergence of the integral radiative flux in the volume of the medium, whereas the angular distribution of the radiation intensity is often irrelevant. Therefore, it is usually sufficient to use simple differential models such as P_1 approximation or the two-flux method (Wilson et al., 2012; Dombrovsky et al., 2019; Dombrovsky).

In some problems, e.g., for calculations of the directed flame radiation, the second solution step is required where the field of the radiation energy density in the medium volume is integrated by a ray-tracing procedure. However, the P_1 approximation is sufficient to take into account the thermal radiation in calculations of the radiative heat transfer within the flame (Dombrovsky et al., 2018).

Another group of problems, which can cause difficulties, relates to heat transfer in materials with phase transitions or volumetric thermal destruction as well as surface ablation of materials under intense thermal loads.

During the melting or solidification of materials of complex chemical composition, the so-called mushy zone, bounded by solidus and liquidus isotherms, is formed between the solid and molten material. In this zone, the structure of the medium changes from a porous solid matrix with inclusions of melt to a liquid medium with suspended solid particles. When modeling thermal processes in the mushy zone, not only changes in local mean values of density, heat capacity, and thermal conductivity should be taken into account but also the distributed latent heat of the phase transition. The latter is easiest to do without introducing a heat source or sink into the energy equation but by using an equivalent increase in the heat capacity of the medium in a given temperature range. The same technique also works well for problems without a mushy zone when there is a narrow phase transition front. In this case, the latent heat of melting is spread out over a small temperature interval whose width is chosen based on the grid intervals and time integration step (Dombrovsky et al., 2015).

During intensive thermal destruction of thermal protection materials such as phenolic carbons used in rocket technology, the gaseous products of destruction pass through the porous char layer. The energy equation for this process contains not only the heat absorbed during the destruction but also a convective component. For a successful and technically simple solution to the problem, it is recommended to consider alternating processes of heat conduction and gas filtration at each time step. Mathematically, such a solution looks like the splitting of the operator in the right-hand part of the transient energy equation. This procedure is convenient also because the resulting computer code contains separate modules for particular simple problems. Algorithms of this type can also be recommended for the calculation of the pyrolysis of organic materials, which is widely used in engineering.

A similar idea can also be used to calculate the ablation of materials under very high heat flux (as in the case of the re-entry of spacecraft into dense layers of the atmosphere). The gradual reduction in material layer thickness as a result of ablation can be considered as a set of small steps with the removal of one and more layers of the calculation grid. Such an algorithm of moving surface accounting does not require revision of the computational domain discretization and undesirable temperature field interpolation, leading to an increase in computational error.

The length of this editorial does not allow us to discuss some other creative approaches to the computational modeling of heat transfer processes. However, I hope that the examples discussed will be of interest to young researchers working in our research field.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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