REVIEW

# STATE OF THE ART AND OUTLOOK IN RADIATIVE HEAT-TRANSFER RESEARCH IN METALLURGY FOR 1976-1985

A. S. Nevskii, S. P. Detkov, V. G. Lisienko, and V. P. Trofimov

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A metallurgical oven at some stage involves the use of high temperatures, and in that stage thermal radiation dominates the heat transfer. Many technical advances require higher oven temperatures, and this gives added importance to computational and theoretical methods of analyzing radiative heat transfer. These methods as yet do not meet all engineering requirements, particularly since the error in the calculations increases with the significance of the radiative component.

It is usual for the heat-transfer conditions to represent the limiting stage for a metallurgical process, for which reason heat transfer is accelerated as far as possible subject to the restrictions imposed by product quality and stability in furnace components. However, this is not always so, and in that case it becomes of primary importance to optimize the thermal conditions in order to provide process control. In either case, the object is process acceleration, together with high product quality and economical operation. Maximal acceleration of heat transfer can result in new techniques, one example of this being firing and melting of concentrates in fluidized-bed form.

The aggregates used in ferrous and nonferrous metallurgy are extremely varied; some types of furnaces have large working volumes (heating ovens, blast furnaces, Martens and reflective furnaces, ring ovens, and so on). Radiative heat transfer is dominant in such cases, with the gas acting as the radiation source, the optical density of the gas frequently being high. The significance of convective heat transfer is usually very restricted.

Some metallurgical systems have heat transfer between flowing gases and lumps of material, as in blast furnaces, conveyor systems, and sintering systems. The importance of radiative transfer is much less in such cases. Calculations can then be based on convective heat transfer, with a correction for radiative transfer applied to the heat-transfer coefficient.

Recently, equipment with circulating fuel combustion and fluidized beds has become common, although little is known about heat transfer in them, especially as regards the contribution from radiation.

The raw material itself acts as the fuel during firing in furnaces of cyclone type and in oxygen-flame processing of sulfides; research on these new processes is facilitated to some extent by the analogy with the phenomena in the combustion of powdered fuel.

Special heat-transfer conditions occur in rotating tubular furnaces, which are widely used in ferrous and nonferrous metallurgy, as well as in the production of cement, refractories, and so on.

Many forms of metallurgical plant have many design faults, which often make them expensive to operate; for instance, heating ovens often have large heat leaks through the supporting systems and handling facilities, which in part may result in uneven heating in the metal. Very often, such an oven is operated under suboptimal conditions, which result in considerable excess fuel consumption. It is often found that a newly built plant fails to give its proper output for a prolonged period.

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All-Union Scientific-Research Institute of Metallurgical Heat-Engineering. All-Union Scientific-Research Institute of Nonferrous Metallurgy Energy Sources. Urals Polytechnic Institute. Sverdlovsk. A. N. Lykov Institute of Heat and Mass Transfer, Academy of Sciences of the Belorussian SSR, Minsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 32, No. 1, pp. 161-164, January, 1977. Original article submitted May 26, 1976.

In an open-flame oven, the heat transfer is closely related to the flame structure and the combustion; the exact relationship has not been established in detail.

It is anticipated that the next decade will see further increases in the scale of individual plants and ferrous and nonferrous metallurgy; in particular, this applies to reheating ovens for batch processing, open-hearth furnaces, conveyor-type ovens for sintering concentrates, and the like.

Large design changes are also anticipated in heat-treatment ovens, partly on account of the design of continuous-production lines for rapid heat treatment of thin sheet and certain forms of rolled material. In addition, further developments are expected in the continuous production of steel.

Radiative heat transfer plays a large part in the heat exchangers commonly used in ferrous and nonferrous metallurgy (air heaters for blast furnaces, regenerators, recuperators, etc.).

Radiative transfer, alone or in combination with other forms, is thus very important in many limited aspects of ferrous and nonferrous metallurgy, for which appropriate heat-transfer calculation methods are required. This is necessary not only in the choice of major design parameters for optimum working conditions, but also in economic calculations on the best style of organization and on the standards for fuel consumption. Correct heat-transfer calculations are particularly important in relation to the commissioning of new designs.

During the Ninth Five-Year Plan, various research institutes and technical-college departments performed numerous studies on new or improved methods of heat-transfer calculation for many types of metallurgical furnace; methods have been developed for computing the parameters of sectional and chamber ovens, while researches have also been performed on improved styles of zonal technique for radiation calculation, particularly with allowance for selective emission. Also, methods have been devised for calculating temperature distributions in iron-ore processing in fluidized beds and so on. A method has been formulated for calculating the heat transfer in blast-furnace air heaters, and this has been adopted by design organizations.

Recently, numerous studies have been performed on radiative transfer, alone or in combination with other forms; studies have been performed on selective emission from gases and solids, which have made particular use of advances in applied spectroscopy, while measurements have been made on emission from gases at elevated pressures, which have led to substantial advances in our understanding of radiative heat transfer in dusty media and the factors governing the radiation characteristics of materials such as metals and refractories.

Equations have now been formulated for combined forms of heat transfer that give a reasonably accurate description of the various processes, but solutions have been derived only for very restricted number of cases, and then mainly for laminar flow in the absence of selective emission.

In spite of the above advances, there remain many problems in practical metallurgical heat engineering; existing computational methods have many deficiencies, some of which are due to the crude approximations, while others (as in zonal methods) involve very complex calculations and are difficult to use in engineering design. Also, many of the methods are of purely theoretical origin and have not been thoroughly checked out by experiment under practical working conditions. Methods of that type can be used with reasonable confidence in relative calculations, e.g., in determining the effects of particular parameters on the heat transfer, and therefore they can be used in optimizing operations and in economic calculations, but they are not sufficiently reliable to be used in defining design parameters for new plants to operate under specified conditions, which is a major disadvantage. Also, we have very little knowledge of the effects of combustion processes and aerodynamic phenomena on heat transfer in furnaces. Further, there are no reliable techniques for calculating radiative transfer in the presence of uneven temperature distributions.

Good calculation methods require reliable experimental data on heat transfer in existing systems; unfortunately, even such data have so far been very scanty, partly on account of the major difficulties in data collection and the great range of furnace types. It is often necessary to determine local temperatures in the metal and surroundings in the design of a reliable oven, but methods for the purpose are inadequately developed.

Improved methods for radiative heat-transfer calculation are required in a variety of styles, particularly simplified one-dimensional schemes, such as the zonal and angular methods, or semiempirical methods such as the two-flux approximation, which should be supplemented by research on heat transfer in the fluidized-bed processes now becoming common. Computational methods should be improved to the point where they can be used in engineering design calculations to provide type or standard data. Major advances have already been made in the joint consideration of internal and external heat transfer, but even so it is still usual to discuss the external heat transfer in simplified form. This area should be examined with a view to defining more rigorous solutions and simplifying the computational schemes.

Measurements of heat transfer in industrial systems and pilot plants require reliable instruments for recording temperature, radiation flux, and so on; at the present time, such instruments are frequently designed and built by the researcher himself.

This outline serves to define the following major problems in heat-transfer engineering for metallurgical furnaces.

1. Improved computational methods are required for radiative and mixed forms of heat transfer in such systems, which may be based on simplified one-dimensional schemes, zonal methods, semiempirical techniques, etc.

Methods are also needed to define the effects on the heat transfer from the complicated shape of the working space, selective emission, nonuniform temperature distribution, combustion processes, and aerodynamic effects, all of which are affected by gas circulation, air injection, the level of solid particles in flames, and other such factors.

In addition, improved methods are needed for solving the equations for combined external and internal heat transfer.

2. Engineering design methods are required for major types of plants for various purposes, and such methods should be improved to the point where they can define type or standard designs.

3. More extensive tests are needed on computational methods checked out against actual working systems or major pilot plants.

4. Experimental data should be accumulated on the physicochemical and radiative features of materials, which are essential to calculations on radiative and combined forms of heat transfer in metallurgical plants. In addition, instruments for measuring such quantities should be designed or improved.

5. Research data on radiative and combined forms of heat transfer should be utilized in improving furnace design and optimizing furnace operation.