Journal of Applied Mechanics

Foreword

Thermal Science and Engineering With Emphasis on Porous Media

This special issue of JAM brings together 16 selected papers from the First Conference on Thermal Engineering held in Beirut on May 31–June 4, 2004. I would like to express my gratitude to the Editor of JAM, Professor McMeeking, for dedicating a special issue of this prestigious journal to selected papers of the inaugural conference on Thermal Engineering.

It has always been the tradition for scientists from the Middle East and the Gulf region, as well as North Africa, to conduct their graduate studies abroad, particularly in North America and Europe. Governments in the region are committed to improving undergraduate education, but until recently it has been the norm not to focus so much on graduate education. Building research capability in institutions of higher learning and attracting highly motivated staff to advance the research agenda were not among the top priorities. But, higher education in this part of the world has started to change thanks to the foresight of the leaders in the region. However, the fact remains that highly-skilled scientists and engineers from the Middle East, the Gulf region, and North Africa sought and are still seeking work abroad in academic and research institutions.

Well-defined venues dedicated to contacts between the academics and researchers in the institutions of higher learning in the region and their counterparts abroad are almost nonexistent. The purpose of starting a biannual international conference to be rotated around the Middle East, Gulf, and North African region countries is to meet this need and provide a well-structured platform to boost research activity and productivity in the region as well as providing a point of contact and networking. Establishing a recurring platform which will serve as a focal point for the gathering of scientists and engineers from the region working abroad, in particular in Europe, North America and other countries of the industrial world, and their colleagues in the countries of the region was deemed essential. Thermal Engineering was selected as an umbrella title for the Conference series because of its encompassing meaning and because this research area is of great importance to the region. Topics related to environment, energy, petroleum and construction are examples of thermal engineering crucial to the economic development and well being of the countries in the region.

Discounting the recent unfortunate events in Lebanon, the country was poised to emerge from its long period of arrested development at the time the decision was made to hold the first Conference on Thermal Engineering in Beirut on May 31–June 4, 2004. Lebanon had come out of a long civil war and the long and arduous process of rebuilding the country had started. Beirut had experienced an explosive growth and rebuilding activity during the last ten years with billions of dollars in investment, and had regained some of its past glory and glitter worthy of its nickname "Paris of the East" of the 1950s and 1960s before the civil war. It was felt that the opportunity to start this exercise in Beirut, to be rotated later to elsewhere, could not be passed up.

The Conference is the brainchild of Professor Ziad Saghir of Ryerson University in Toronto, Canada. Professor Saghir's commitment and tireless efforts, not to mention his organizational skills, lay at the very foundations of the success of the Conference. The encouragement, help, and personal day-to-day involvement of Professor George Nasr from the Lebanese University in Beirut was also crucial and played a major role in this success story. The Conference has been very successful beyond our best expectations. The success of the Conference would not have been achieved without the support of the Lebanese and Canadian governments. The support provided by both governments is gratefully acknowledged. The Lebanese government was enormously supportive of the enterprise and the Canadian Embassy in Beirut was instrumental in making it a success. A large audience of scientists attended the meeting in the beautiful spring weather of Beirut and enjoyed the excellent Lebanese hospitality. The next Conference on Thermal Engineering is scheduled to be held in the United Arab Emirates at Al-Ain on January 3–6, 2006. At the time of this writing all indications are the success of the first Conference on Thermal Engineering will be duplicated and perhaps even eclipsed.

The common theme tying together more than half the contributions in this collection of selected papers is flow in porous medium and in particular thermal issues in porous media. A number of papers in this group are related to issues directly relevant to the oil industry starting with the review article on the Soret effect. Fluid flow through porous media is encountered in many different branches of science and engineering, ranging from agricultural, chemical, civil and petroleum engineering, to food and soil sciences. Scientists, engineers, and politicians recognize the economic importance of enhancing oil recovery techniques, in addition to their growing concerns about pollution and the quality of the water obtained from the ground. Over the past decades, flow through porous media has been extensively studied experimentally and theoretically as it is at the very heart of various industrial processes central to energy production and to environmental issues.

It is only appropriate to open the lineup of the 16 selected papers in this special issue with two pace-setting review articles by well-known experts Jean K. Platten, who reviews the latest in Soret effect research, and Georgy Lebon et al., who summarize thermodynamic theories in use and explore the foundations of a unified extended thermodynamic theory.

The name "Soret effect" is usually attributed to mass separation induced by temperature gradients. The effect was discovered in 1879 by the Swiss scientist Charles Soret who noticed that a salt solution contained in a tube with the two ends at different temperatures did not remain uniform in composition. The salt was more concentrated near the cold end than near the hot end of the tube. Charles Soret concluded that a flux of salt was generated by a temperature gradient resulting, in steady state conditions, in a concentration gradient. Although the German C. Ludwig described the same phenomenon several years before in 1856 in a short communication, the phenomenon bears his name because Soret studied the effect rather in detail and formulated the fundamental equations describing the phenomenon. The Soret effect plays an important role in the operation of solar ponds, biological systems, and the microstructure of the world's oceans. In biological systems mass transport across biological membranes induced by small thermal gradients in living matter is an important factor. One of the challenges in optimizing exploitation of oil reservoirs is a good knowledge of the fluid physics in crude oil reservoirs. Today, the modeling methods are based on pressure-temperature equilibrium diagrams and on gravity segregation of the different components of crude oil. However, improved models which more accurately predict the concentrations of the different components are necessary. The concentration distribution of the different components in hydrocarbon mixtures is mainly driven by phase separation and diffusion, and the Soret effect plays an important role.

The aim of the second review paper by Georgy Lebon, Thomas Desaive, and Pierre Dauby is to convince the reader that the extended irreversible thermodynamics (EIT) theory provides a valuable tool for studying a large variety of macroscopic processes. The underlying principles which hold together the edifice of classical irreversible thermodynamics (CIT) are reviewed and familiar laws such as Fourier's and Fick's are derived from the framework of CIT as well as the Dufour and Soret effects. However, all field equations derived using the framework of CIT are parabolic implying that any disturbance anywhere in the system is felt instantaneously at all other points which is a violation of the fundamental principle of causality. Furthermore CIT is a linear theory which holds only in the vicinity of equilibrium. These shortcomings at the very foundations of CIT prompted the proposition of other formalisms aimed at removing them. Extended irreversible thermodynamics (EIT) provides a unified description of a large body of physical processes and remedies the shortcomings of CIT. The formalism is based on the assumption that fluxes of heat, mass, and momentum are also state variables as well as mass, momentum, and temperature. The open problem in EIT is to develop the evolution equations for the fluxes. The authors accomplish this by neglecting the terms which are second order and higher. The field equations are hyperbolic in EIT thereby removing the objection raised in CIT due to the violation of the causality principle.

The next group of seven papers in this special edition cover issues related to porous media flow and thermal management.

Transport phenomena in heterogeneous porous media are a challenging research topic. Charles-Guobing Jiang, M. Ziad Saghir, and M. Kawaji investigate numerically thermal diffusion phenomena in a laterally heated heterogeneous porous cavity filled with a binary mixture of methane and n-butane. The modeling of the Soret effect in porous media is based on nonequilibrium thermodynamics. The investigation of the Soret effect in a heterogeneous porous medium is important in itself, but the work gains more in significance as the Soret coefficient, the ratio of the thermal diffusion coefficient to molecular diffusion coefficient, is not kept constant but calculated at each point of the computational grid as a function of the temperature, pressure, and the composition of the fluid mixture. The phenomenon of natural convection, induced by two separate sources of buoyancy, through porous media has been recently studied extensively due to its importance in many natural and industrial problems. In double diffusive convection, the solutal field results from the imposition of solutal boundary conditions on the system. In Soret induced convection, solutal gradients are due to the thermal diffusion in a binary mixture, initially homogeneous. In both cases, the dynamics of heat and mass transfer can be very different from those driven by the temperature field alone.

In the next paper A. Bahloul et al. report an extensive analytical and numerical study of natural convection of a binary fluid induced by double diffusivity and Soret effect in a saturated vertical porous annulus. Both cases of buoyancy opposing and helping the motion are addressed. Uniform heat fluxes are applied to the vertical walls while the horizontal walls are impermeable and adiabatic. Solutal gradients are assumed to be induced either by the imposition of constant gradients of concentration on the vertical walls (double diffusive convection) or by the Soret effect.

D. B. Ingham et al. develop new mathematical and numerical techniques to deal with porous materials which undergo several orders of magnitude changes in their Darcy numbers. Flow through a composite channel that has undergone a vertical fracture is considered. The vertical connecting channel is also composed of a composite material. In the case of composite channels with fractures in geological applications order of magnitude changes in the Darcy number result in very large changes in the pressure in the vicinity of the interfaces between these materials, thus posing a challenge for numerical algorithms. Geological configurations involving discontinuities in channel height with sections of the channel composed of several layers of different porous materials occur in oil reservoirs and groundwater flows. The influence of these discontinuities on the fluid flow through regions of different permeability is nothing short of drastic.

Many industrial and environmental problems involve flow in fractured porous media, like oil production, nuclear waste storage, and groundwater pollution. The computation of the full permeability tensor in fractured heterogeneous media as well as other parameters such as the mass exchange coefficient presents a challenge. The paper by Moussa Kfoury et al. addresses the use of homogenization methods to estimate constitutive parameters like permeability and fracture/matrix exchange coefficient at large scale in fractured heterogeneous media. The inspiration for this paper came from the groundbreaking work of Barenblatt, Zheltov, and Kochina, "Basic Concepts in the Theory of Seepage of Homogeneous Liquids in Fissured Rocks" published in 1960 (the first reference in the paper), which blazed the path for several investigations since then along these lines.

Porous media are utilized in many industrial and natural processes as an effective means for the transport and storage of heat energy. Examples include heaters, dryers, cooling units, exchangers, and biological tissue. Most of the studies on packed beds involve the flow of the fluid phase through a fixed solid bed, and a few only deal with moving beds. Experimental investigations of heat transport in moving packed beds are usually difficult to carry out due to limited access to the inside of the packed bed, and to operating conditions that very often are not ideal for experimentation such as high temperature and pressure. Numerical modeling is used as a complementary, and sometimes as the sole, means to gain a better understanding of the phenomena taking place in packed beds and in particular in moving packed beds. Redhouane Henda and Daniel Falcioni study numerically the thermal performance of the preheater, essentially a tube-and-shell heat exchanger in the nickel carbonyl process. After leaving the preheater, the pellets enter a cold-wall reaction zone where coatings of nickel are deposited onto the pellets. Inefficiencies in heat transfer in the preheater greatly affect nickel deposition rate because of sensitivity of the diffusion controlled process to pellet temperature. Both one and two equation volume averaging models may be used to investigate transport phenomena in porous media. Averaging over a representative elementary volume containing both the fluid and solid phases yields the one-equation model, and averaging separately over each of the phases in the same representative volume results in a separate energy equation for each individual phase referred to as the two-equation model. The one-equation model is valid when the temperature difference between the solid and fluid phases is negligible, and is useful for comparison with experimental data as temperature measurements in a packed bed do not distinguish between solid and fluid phase temperatures. The two-equation model is used when thermal exchange between the two phases is not effective, and allows for a better understanding of the interactions between the two phases. The authors show that there is no appreciable difference between the two models under the investigated conditions. Further, they show that adopting a constant temperature at the preheater wall, that is directing the flue gas perpendicular to the preheater tube and decreasing the pellet velocity in the packing bed, improves the thermal efficiency throughout the preheater greatly, and the difference in temperature from pellet to pellet at the preheater outlet is reduced from ~120 °C to ~55 °C.

MHD mixed convection for the buoyancy opposing flow in porous media has not yet been adequately addressed in the literature. Rebhi A. Damseh investigates the MHD-mixed convection heat transfer problem from a vertical surface embedded in a porous media. The effect of transverse magnetic field and radiation heat transfer are examined. Both types of mixed convection heat transfer problem, that is the buoyancy aiding flow and the buoyancy opposing flow, are investigated. In the former case increasing the magnetic field number will decrease the velocity inside the boundary layer, and at the same time the temperature increases; the effect of the magnetic field in this case is to decrease the heat transfer rates. Increasing radiation-conduction parameter will decrease local Nusselt numbers for both buoyancy aiding and opposing flows. The effect of increasing porosity is to increase and decrease the local Nusselt number for the buoyancy aiding and opposing flow, respectively. The effect of increasing magnetic field parameter is found to decrease the local Nusselt number.

Worldwide increase in energy cost and energy consumption requires more effective use of energy. Hence, ways of decreasing energy losses have never been more important. Second law based methods are well suited to analyze the overall energy performance in order to identify optimization criteria. It is well known that heat transfer rates are enhanced when and wherever porous materials are used. Although porous substrates generate a high pressure drop, they remain a good passive technique for heat transfer enhancement. Nadia Allouache and Salah Chikh search for an optimum solution, a compromise between hydrodynamics and thermal performance. A second law analysis based on the evaluation of entropy generation due to both fluid friction and heat transfer is developed and applied to laminar forced convection flow in a double pipe heat exchanger with a porous medium of variable thickness in the annular gap attached to the inner pipe. The minimization of the rate of entropy generation, due to fluid friction and heat transfer, depends on the porous layer thickness, its permeability, the inlet temperature difference between the two fluids, and the effective thermal conductivity of the porous substrate. An increase in the effective thermal conductivity of the porous medium seems to be thermodynamically advantageous. Rather surprisingly, the fully porous annular gap yields the best results in terms of the rate of total entropy generation.

The contribution by Konstantin Kostarev, Antonio Viviani, and Andrew Zuev presents an experimental study of thermo- and soluto-capillary Marangoni convection around a gas bubble in an inhomogeneous fluid with a vertical thermal or surfactant concentration gradient. It is well known that Marangoni convection may be driven by surface tension gradients due either to thermocapillary or soluto-capillary effects. The former has received considerable attention as temperature differences are very common in liquid systems. However, the soluto-capillary convection has not been adequately studied. Bubble migration in a liquid may be caused by either type of Marangoni convection. Convection caused by surface tension gradients due to concentration inhomogeneities, for instance, of dissolved surfactant along the free liquid/gas interface, attracts considerable interest because of its importance in manufacturing technologies. In microgravity when gravity-induced mechanisms of motion are absent or reduced Marangoni convection is the main driving mechanism determining the behavior of gas inclusions in many manufacturing processes. Among these are composite and foamy materials, formation and solidification of alloys, degassing of liquid substances in glasses, ceramics, crystals, and metals. The influence of the adsorbed insoluble surfactant layer at the bubble/drop interface on the thermocapillary convection is well established experimentally in the literature. The surfactant, transported by the convective flow to the trailing pole of the bubble, establishes surfactant concentration-induced Marangoni stresses opposing those caused by the thermal gradient. As a result, the motion driven by thermocapillary forces is slowed down drastically due to the presence of the surfactant. However, the convective motion generated by the external concentration gradient of surfactant dissolved in the surrounding fluid has not been studied. The influence of the diffusive and convective mass transfer mechanisms are determined by the characteristic times of surfactant and heat diffusion. The former are two or three orders of magnitude longer than those of heat diffusion.

The next three contributions address issues related to natural convection. The manufacturing of advanced materials is greatly facilitated in a microgravity environment as buoyancy-induced convection is suppressed or greatly reduced in magnitude. But small vibrations existing on space platforms can totally or substantially alter the fluid behavior under microgravity, thus leading to undesirable semiconductor and protein crystal properties. Thus, there is a need to understand and control the effects of vibrations on fluid systems relevant to material processing aboard space platforms including the g-jitter effects. Many studies have been conducted on fluid-induced vibrations of solid structures. However, the reverse situation of vibration-induced fluid motion, in a closed container full of liquid, has not yet been fully explored. Samer Hassan et al. investigate theoretically and experimentally the effect of small vibrations on the motion of a solid particle suspended in a fluid cell. An inviscid model is developed to predict the vibration-induced motion of the solid particle suspended by a thin wire in the water-filled rectangular cell which vibrates horizontally. The inviscid fluid assumption is valid when the inertial forces are more important than the viscous force, which is equivalent to a very thin boundary layer compared to the particle radius. The validity of this assumption is supported by good agreement between the model predictions and the experimentally measured amplitudes for steel particles in water at different cell vibration amplitudes and frequencies. Both their model and experimental data show the existence of a resonance frequency. At low frequencies the amplitude of the vibratory motion of the particle is linearly proportional to the amplitude of the fluid motion in the cell. At higher cell vibration frequencies well above the resonance frequency, both the model and experiments indicate that the particle amplitude becomes constant and independent of the wire length.

Shari J. Kimmel-Klotzkin and Fadi P. Deek consider a difficult problem—that of computing the time evolution of a rotating turbulent convective flow generated by a buoyancy source of finite size at a relatively high Rayleigh number. The large eddy simulation (LES) with the Smagorinsky subgrid scale model is used. For large-scale geophysical flows, the Coriolis effect due to the rotation of the Earth becomes an important influence in the evolution of the flow. However, the Smagorinsky model is not consistent with a non-inertial reference frame and thus is not the optimal choice for this type of flow. Global oceanic circulation simulations are very important in the study of climatic change. Buoyancy effects due to gravitational forcing can drive large-scale oceanic circulations. Natural phenomena that cause buoyancy driven circulations in the ocean include evaporation, extreme weather conditions such as storms, freezing at the surface, and heating through the ocean floor as a result of megaplumes. Numerical simulations of turbulent convection under the influence of rotation will help understand mixing in oceanic flows. Direct numerical simulation (DNS) techniques can accurately model rotating convective flows and give an “exact” solution to the governing equations but are limited to relatively low Reynolds numbers due to insufficient computational resources, as they may require hundreds of hours of CPU time and tens of millions of grid points even for a flow field bordering on the turbulent regime. By using a large eddy simulation (LES), which involves modeling the small scales and resolving only the large scales, a similar computation could be performed in less than 100 hours of CPU time using a number of grid points less than an order of magnitude smaller. The results demonstrate that LES can be used to qualitatively model large scale rotating flows. The resulting flow structure is in good agreement with the limited available DNS simulations and experimental results. The results also demonstrate that the qualitative behavior of vortices which form under the source depend on the geometry of the flow. An eddy viscosity model is inadequate to accurately model the transition to turbulence between the convective plume and the quiescent ambient fluid, and it is suggested that other types of subgrid modeling should be used in future studies.

Low Prandtl number fluids present a challenge in heat transfer studies. They generate very strong diffusive thermal effects which should be taken into account in numerical modeling. Thus boundary layer approach is not suitable and extended computational domains need to be employed for accurate numerical solutions. The common thread for the next two papers is low Prandtl number fluids.

Mahfoud Djezzar and Michel Daguenet investigate the influence of the slope angle on the natural steady convection in an annulus between two elliptic confocal ducts. A primitive function formulation of the finite volume method is used. The effect of the inclination on the Nusselt number is examined for low Prandtl number fluids and for various Rayleigh numbers. Many cooling and heating devices used in engineering applications such as solar collectors, electronic equipment, certain types of nuclear reactors, and electric transformers can be modeled as vertical parallel plate channels. The focus of most studies in the literature is on air and water as working fluids. However, low Prandtl number fluids employed in the thermal design of core reactors behave differently than air and water. Liquid metals are of great engineering interest due to their unique heat transfer capabilities. In nuclear power plants, if the pump cooling system fails, the hot reactor core would cool off by natural convection with liquid metal as the heat transfer medium. These fluids possess low or very low Prandtl numbers of the order 10^{-2}. They present very strong diffusive thermal effects which should be taken into account in numerical modeling. For this reason the boundary layer approach is not suitable and extended computational domains need to be employed to generate accurate numerical solutions. Antonio Campo, Oronzio Manca, and Biagio Morrone present a numerical investigation of the natural convection of a low Prandtl number fluid in vertical parallel plate channels in the Rayleigh number range 10^3-10^6 and for channel aspect ratios 5, 10, and 15.

Heat and mass transfer from a rotating disk has led to important fluid dynamics studies since von Karman introduced his much celebrated similarity transformation. However, studies with non-Newtonian fluids are relatively few and new. Available literature is restricted to shear rate-dependent viscosity fluids and heat transfer studies have been favored more than mass transfer. Rashaida et al. consider mass transfer from a rotating disk to a Bingham fluid with applications to slurries and suspensions which exhibit yield stresses.

It may be appropriate to close this special edition with another paper related to petroleum management issues. A topic of importance to crude oil transportation as well as other fluids is investigated by Mohand Kessal and Rachid Bennacer who model the effect of dissolved gases on liquid transients in pipelines. In order to improve the reliability and the performance of hydraulic systems it is important to be able to predict the onset and the degree of cavitation during transient flow. Transient cavitation without dissolved gas release is well covered in the literature. But available studies with gas release are not as extensive. A mathematical model which describes homogeneous transient two-phase flow in a pipeline which takes into account gas release is presented. Cavity volume formation, during transients in a homogeneous gas-liquid mixture flow, is modeled and numerically simulated by taking into account the effect of the degassing.

In closing, I would like to express my appreciation to the anonymous reviewers and the authors. Liz Montana, Editorial Assistant of JAM, deserves special thanks.

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