RESEARCH STATEMENT

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My research is primarily concerned on analytical and computational modeling of various problems arising in the dynamics of different fluids (Newtonian, non-Newtonian power-law type, polar, micropolar, viscoelastic, particulate suspensions and nanofluids) with heat and/or mass transfer with a particular focus on multiphase flows, flow and transport in porous media in the presence of various effects such as MHD, chemical reaction, radiation, heat generation or absorption, and Soret and Dufour effects. This type of research has applications in a wide range of problems that arise in science and engineering. I am mostly interested in fundamental nanofluid problems which typically find applications in geophysical and microfluidic contexts. One of the most interesting issues in understanding the transport properties of particulate suspensions is capturing the interactions between the suspended particles and the fluid. I employ and modify numerical methods to solve complex systems of partial differential equations and favor finding analytical solutions to simplified problems whenever possible. I entertain collaborations with researchers from different countries working in mechanical and chemical engineering and applied mathematics departments and I greatly benefit from these interactions, both as a source of interesting problems and as a way to keep in touch with different applications and solution methods. I believe that the inter-disciplinary bridging of mathematical tools holds the key to improve our understanding of transport processes. The main areas of my research are very briefly described below.

1- Heat Transfer Enhancement Using Nanofluids:

A nanofluid is a base fluid with suspended metallic nanoparticles. Because traditional fluids used for heat transfer applications such as water, mineral oils and ethylene glycol have a rather low thermal conductivity, nanofluids with relatively higher thermal conductivities have attracted enormous interest from researchers due to their potential in enhancement of heat transfer with little or no penalty in pressure drop. I have been studying, in collaboration with other researchers, heat transfer enhancement using various models of nanofluids in enclosures and other geometries. In [1,2], we have obtained non-similar solutions for natural convective boundary layer flow over a sphere embedded in a porous medium saturated with a nanofluid. In [3], we have studied the effect of nanofluid variable properties on natural convection in enclosures filled with an Cuo-Eg-Water nanofluid. In [4], we have studied MHD free convection flow of a nanofluid past a vertical plate in the presence of heat generation or absorption effects. In [5], we presented the laminar MHD mixed convection flow of a nanofluid along a stretching permeable surface in the presence of heat generation or absorption effects. In [6], we have also presented the mixed convection flow in a lid-driven inclined square enclosure filled with a nanofluid.

2- Forced and Free Convective Flows of Particulate Suspensions:

Buoyancy-induced flow and heat transfer has attracted the interest of many investigators over the past two decades. This interest stems from the possible applications of these studies in many industries. Examples of processes in these industries include geothermal reservoirs, petroleum reservoirs, chemical reactors, energy storage systems and many others. In spite of the high possibility of particulate entrainment into such flows, there has been no significant work in the open literature done on free convection flow and heat transfer for a dusty fluid. Analysis and study of free convection of a particulate suspension over surfaces or in enclosures requires the consideration of two-phase flow models. The two main modeling approaches for a particulate suspension available in the literature are the continuum approach in which both phases are treated as interacting continua and the Lagrangian approach in which only the fluid phase is treated as a continuum and the particle phase is governed by the kinetic theory. The equations governing a two-phase fluid-particle system are rather complex to preclude analytical solutions except in very idealized special cases. In [7], I studied transient flow of a particulate suspension in circular pipes and presented analytical solutions. In [8], I have also investigated analytically and numerically flow of a hydromagnetic suspension in channels due to an oscillating pressure gradient. In [9] My former student and I have considered the problem of steady natural convection hydromagnetic flow of a particulate suspension through an infinitely long channel in the presence of heat generation or absorption effects under the isoflux–isothermal condition. In addition, I have contributed a series of papers (some in collaboration with others) in the area of multiphase fluid-particle flow with or without heat transfer see, for instance, [10-26].

3- Fluid Flow in Porous Media:

Flow through porous media has been considered a pioneering research work in the area of fluid transport since the beginning of this century. It also has gained extensive attention in recent years. This is due to the applicability of this research area in contemporary technology. The applications include geothermal engineering, building thermal insulation, chemical catalytic reactors, packed cryogenic micro-sphere insulation, petroleum reservoirs, direct contact heat exchangers, coal combustors, nuclear waste repositories, transport through granular media and heat pipe technology. The term of porous medium is used for solid fissured rocks from underground formations that contain natural gas, oil or water. It is also used for ceramics, fibrous aggregates, filter paper, sand filters, a loaf of beard, and for other solids which contain holes. The holes may fill with a gas or a liquid. Thus, in general a porous medium consists of apportion of space occupied by heterogeneous or multiphase matter. The solid phase is usually the solid matrix and that space within the porous medium which is not part of the solid matrix is referred to as the void space or pore space. The solid phase should be distributed through the porous medium in such a way that it is present inside any representative elementary. I have contributed a series of papers in collaboration with others on various aspects of flow through porous media, see [27-54].

4- Heat and Mass Transfer:

Many transport processes occurring both in nature and in various industries involve fluid flows with combined heat and mass transfer. Such flows are driven by multiple buoyancy effects arising from density variations caused by the variations in temperature as well as species concentration. Also, there has been increased interest in studying buoyancy-induced flow by simultaneous heat and mass transfer from different geometries embedded in porous media. This interest stems from many engineering and geophysical applications such as geothermal reservoirs, drying of porous solids, thermal insulation, enhanced oil recovery, packed bed catalytic reactors, cooling of nuclear reactors, and underground energy transport. I have worked in collaboration with others on modeling heat and mass transfer processes in various geometries and in the presence of various physical effects, see [55-75].

5- Non-Newtonian Fluids:

A number of important practical fluids such as molten plastic, food stuff, polymers, slurries, etc., are non-Newtonian fluids in their flow characteristics. Due to the growing use of these non-Newtonian substances in various manufacturing and processing industries, considerable efforts have been directed towards understanding their friction and heat transfer characteristics. Many of the inelastic non-Newtonian fluids encountered in chemical engineering processes and bio-chemical industries are known to follow the empirical Ostwald–de Waele model, or the so-called power-law viscosity model in which the shear stress varies according to a power function of the strain rate. However, because such fluids have more complicated equations that relate the shear stress to the velocity field than Newtonian fluids have, additional factors must be considered in examining various fluid mechanics and heat transfer phenomena. On other hand, Micropolar fluids are fluids of microstructure. They represent fluids consisting of rigid, randomly oriented or spherical particles suspended in a viscous medium, where the deformation of fluids particles is ignored (e.g. polymeric suspensions, animal blood, liquid crystals). In order to describe accurately the behavior of such fluids, the geometry and intrinsic motion of individual material particles have been taken into account, and the angular velocity field of rotation of particles and the conservation of the angular momentum are added in the theory of micropolar fluids. In this case, many classical concepts such as the symmetry of the stress tensor or absence of couple stresses are no longer existed. Owing to its relatively mathematical simplicity, the micropolar fluids model has been widely used in lubrication to investigate the polymer solutions in which the Newtonian lubricant is blended with small amount of long-chained additives. Moreover, The study of visco-elastic fluids has become of increasing importance in the last few years. This is mainly due to their many applications in petroleum drilling, manufacturing of foods and paper and many other similar activities. The boundary layer concept for such fluids is special importance owing to its application to many engineering problems, among which we cite the possibility of reducing frictional drag on the hulls of ships and submarines. I have worked contributed a series of papers in collaboration with others, see [76-107].

6- Magnetohydrodynamics:

The study of magnetohydrodynamic (MHD) flow of electrically-conducting fluids is of considerable interest in modern metallurgical and metal-working processes. There has been a great interest in the study of magnetohydrodynamic flow and heat transfer in any medium due to the effect of a magnetic field on the boundary-layer flow control and on the performance of many systems using electrically-conducting fluids. This type of flow has attracted the interest of many researchers due to its application in many engineering problems such as MHD generators, plasma studies, nuclear reactors, crystal growth, and geothermal energy extractions. By the application of a magnetic field, hydromagnetic techniques are used for the purification of molten metals from non-metallic inclusions. Therefore, modeling of MHD problems is very useful to polymer technology and metallurgy. I have worked, individually and in collaboration with others, on various problems involving MHD effects, see [108-156].

7- Natural Convection Gas Transport In Porous Media:

Natural convection is the study of heat transport processes by fluid motion carrying energy with it as a result of the temperature difference between the fluid and the solid. Convection heat transfer consists of two main mechanisms due to both diffusion (random molecular motion) and bulk motion of the fluid. Convection heat transfer can be classified according to the nature for the flow as forced convection and free convection. Forced convection investigates the heat transfer between a moving fluid and a solid surface. The fluid flow is caused by an external means such as a fan, a pump, or atmospheric winds. Thus, the flow has a non-zero streaming motion in the far field away from the solid surface. There are various types of forced convection such as duct flows and bodies immersed in a uniform stream. In contrast, a free convection flow field is a self-sustained flow driven by the presence of a temperature difference, which is opposed to forced convection where external means are used to cause the flow. Natural convection fluid motion is due solely to buoyancy force caused by the density differences as a result of the temperature difference. This force is a strong function of the temperature difference between the solid and the fluid. As such, the buoyancy force will induce a flow current due to the gravitational field and the variation in the density field. Convection above a hot surface occurs because hot air expands, becomes less dense, and rises. In general, natural convection heat transfer is usually smaller compared to a forced convection heat transfer. Natural convection can be divided in two main branches namely external and internal natural convection. External natural convection may occur along different geometries such as free convection along vertical walls, inclined walls, and horizontal walls. In addition, natural convection may take place around horizontal and vertical cylinders as well as around spheres. Natural convection may take place around other immersed bodies such as cubes and spheroids. In [157], I analyzed free convection flow of an electrically conducting fluid along a vertical plate embedded in a thermally stratified porous medium in the presence of a uniform normal magnetic field. In my study [158], I considered non-Darcian effects, Hartmann and Hall effects of magnetohydrodynamics, as well as thermal stratification effects. In [159], I developed a mathematical model governing free convection boundary-layer flow over an isothermal inclined plate embedded in a thermally stratified porous medium in the presence of a non-uniform transverse magnetic field. In [160], I studied numerically the problem of unsteady, laminar, two-dimensional hydromagnetic natural convection heat transfer in an inclined square enclosure filled with a fluid-saturated porous medium in the presence of a transverse magnetic field and fluid heat generation effects. In [161], I formulated and solved the problem of coupled heat and mass transfer by natural convection from a vertical, semi-infinite flat plate embedded in an air saturated porous medium in the presence of an external magnetic field and internal heat generation or absorption. In addition, I have contributed a series of papers in collaboration with others in [162-177].

8- Filtration Modeling:

Mathematical modeling of granular filtration of particulate suspensions through the porous medium of a filter is an integral part of constructing a prediction model of any water purification system or commercial system for separating multiphase materials. In general, the composition of the particulate suspension varies over time during the operation of such systems. The versatility of granular filtration is evident from its scope of application as well as from the manner in which it is carried out. Either liquid or gas fluid streams can be treated. Besides water or air, systems which may be treated by granular filtration include such diverse substances as flue gas, combustion products, molten metal, petrochemical feed stocks, polymers, alcoholic, or nonalcoholic beverages. Granular filtration is referred to as hydrosol filtration or aerosol filtration depending on whether liquid or gas suspension is respectively involved. The basic principle of granular filtration remains the same regardless of the system being treated, the medium used, or the manner in which filtration is conducted. The suspension is made to pass through a medium composed of granular substances or medium under pressure or gravity. As the suspension flows through the medium, some of the particles present in the suspension, because of the various forces acting on them, move toward and become deposited on the surface of the granules of which the medium is composed. The extent of deposition throughout the medium, in general, cannot be made uniform; however, the entire medium is intended to be used for particle collection. I have worked on a unique multiphase filtration model which is based on first principles and is inclusive of well known filtration theories. As a result, I have published some papers dealing with various aspects of deep bed filtration, see [178-191].

Future Work:

By combining numerical simulations and analytical methods, my research attempts to paint as complete a picture as possible of boundary-layer and confined flows arising in the context of single and multiphase fluids in the presence of many physical effects. In the coming years, I wish to continue working on the same areas of interest mentioned above with some focus on modeling fundamental flows such as those prevalent in interfacial flows of suspensions and particle interaction. At the same time, I plan to keep interacting with researchers in neighboring fields to ensure that my work remains ultimately driven by actual applications.

Research Awards:

- Awarded **Khawarizimi International Award in Engineering**, Tehran, Iran, 2012.
- Awarded **Most Outstanding Reviewer Award** for International Journal for Numerical Methods in Heat and Fluid Flow, Literati Network Awards for Excellence, 2012.
- Awarded **Highly Commended Award Winner**, Emerald Literati Network Awards for Excellence, 2012. Winning Paper in International Journal for Numerical Methods in Heat and Fluid Flow, Volume 21, pp. 418-433, 2011.
- Awarded **Khalifa Award for Outstanding University Professor in Scientific Research at the Arab World Level**,Khalifa Education Awards, Abu Dhabi, UAE, 2011.
- Awarded **Senior Scientist Award**, American Filtration and Separation Society, 2007.
- Awarded **Outstanding Research Award in Basic and Applied Sciences**, University Level, Kuwait University, 2001.
- Awarded **Outstanding Research Award**, College of Engineering and Petroleum Level, Kuwait University, 2001.
- Awarded **Young Arab Researcher Award in Engineering Sciences**, Abdul-Hamid Shoman Foundation, Amman, Jordan, 1998.
- Awarded **Achievement Award for Engineering & Technology**, Fleetguard,Inc.,1993.

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