Understanding fluid dynamics has been one of the major advances of applied mathematics, physics and engineering over the last hundred years. The analysis of the behaviour of fluids is based on the fundamental laws of mechanics which relate continuity of mass and energy with force and momentum together with the familiar solid mechanics properties. Heat transfer is the movement of energy due to a temperature difference. There are three physical mechanisms or modes of heat transfer, viz, conduction, convection and radiation. Heat normally flows from an area of higher temperature to a region of lower temperature. Heat can be made to flow from a cooler area to a hotter area. But this is not a spontaneous phenomena as work must be done on the system. Commonly found examples of this are refrigerators and heat pumps.

Convection occurs when heat is transferred due to diffusion and bulk motion, most commonly between a fixed surface and a moving fluid. Convection can be further subdivided into free convection, forced convection and mixed convection. For free convection, the flow of the fluid is induced by buoyancy forces, whereas in forced convection the fluid flow is due to external force such as a fan, blower, or pump. An example of free convection is the heating of water in a vessel containing a heater. At the oven door surface, heat is diffused into the air. The increased temperature of the air causes it to expand. As it expands, it has a lower density than the cooler surrounding air causing it to rise. As the air moves up, heat is transported away from the oven door. An example of forced convection can be found under the hood with the car radiator. Air is forced by a fan over the fins of the radiator which has been heated by the engine coolant. Heat is diffused into the air as it comes into contact with the surface of the radiator, and is then transported away by the bulk motion of the air flow. A combined effect of natural and forced convection is called mixed convection.

Natural convection in enclosures plays a vital role for the transport of heat energy in many engineering applications and naturally occurring processes. As a continuation
of the pioneering works of Benard (1900), Rayleigh (1916), Jeffreys (1926) and Pellow and Southwell (1940) problems have been solved and satisfactory results have been obtained through theoretical, experimental and numerical investigations. Batchelor (1954) seems to be the first to investigate natural convection in a rectangular fluid filled cavity. He was mainly interested in thermal insulations which such cavities can provide and studied the heat transfer characteristics for the case of small Rayleigh number limit and showed that the mode of heat transfer is primarily by conduction. The research works of Eckert and Carlson (1961) and Elder (1965) published in early sixties focused mainly on the measurement of flow pattern and temperature field for free convective flow in a rectangular cavity with temperature difference maintained across the side walls. Many studies on natural convection in enclosures was well documented by Gill (1966), Davis (1968), Davis (1983), Lage and Bejan (1993) and Dalal and Das (2005).

The problem of lid-driven flows in cavities has been a major topic for research due to its fundamental nature and owing to the wide spectrum of engineering applications that are associated with it. Examples of such applications can be traced in oil extraction, thermal management of electronic cooling and improvement of performance of heat exchangers. Lot of work has been done in this area by Ghia et al. (1982), Hansen and Kelmanson (1994), Botella and Peyret (1998), Albensoeder et al. (2001) and Patil et al. (2006).

In most of the naturally or artificially constructed solids, the space occupied by these are not completely filled with matter; almost in every body there are empty interspaces which are called pores. The material consisting of a solid matrix with interconnected voids is considered as a porous medium. In a natural porous medium the distribution of pores with respect to shape and size is irregular (for example cloths, sponges). The human skin viewed under microscope shows a large number of pores in it. This type of naturally occurring porous materials and the flow through then have initiated studies on the flow through porous medium.

Mixed convection flow and heat transfer in cavities with or without porous medium
is of interest in science and engineering. Its applications include nuclear reactors, lakes and reservoirs, solar collectors and crystal growth. Moreover the flow and heat transfer in a shear driven cavity arises in industrial processes such as food processing and float glass production. These types of problems have been studied by Koseff and Street (1984), Iwatsu et al. (1993), Prasad and Koseff (1996), Al-Amiri (2000), Khanafer and Chamkha (1999) and Oztop and Dagtekin (2004). Gebhart (1971) separated mixed convection problem further into fluid flow and heat transfer processes pertaining to external flow or internal flow and has provided a review of some of the common geometries. Most of the experimental and numerical investigations on mixed convection processes reported during the last three decades are related to external flow system, especially for a general horizontal fluid layer heated from below. On the other hand internal or confined flows are of great interest to designers of alternative energy systems like solar ponds, solar storage devices, etc.

Magnetohydrodynamics is a branch of continuum mechanics which deals with the motion of an electrically conducting fluid in the presence of a magnetic field. The motion of conducting material across the magnetic lines of force creates potential differences which in general cause electric currents to flow. The magnetic fields associated with these currents modify the magnetic field which creates them. On the other hand, the flow of electric current across a magnetic field associated with a body force, called Lorentz force influences the fluid flow. Some of the features of magnetohydrodynamics are apparent when any ordinary electrically conducting fluid such as mercury or liquid sodium moves in a magnetic field and they are significant in extremely high temperature gases. All materials become ionized at sufficiently high temperature forming a gas composed of individual ions and electrons. In the absence of magnetic field a high ionized gas behaves in most respect like a classical gas, but this behaviour is modified in a striking manner when magnetic field is applied.

Magnetohydrodynamic convection flow of an electrically conducting fluid in different porous geometries is of considerable interest to the technical field due to its frequent occurrences in industrial, technological and geothermal applications. Also, it has applications in nuclear engineering in connection with reactor cooling. These
types of problems have been studied by Oreper and Szekely (1983), Garandet et al. (1992), Rudraiah et al. (1995), Chamkha (1997), Chamkha (2002) and Robillard et al. (2006).

Improvements to make heat transfer equipment more energy efficient would need to focus on miniaturization on the one hand and an astronomical increase in heat flux on the other. Heat transfer fluids such as water, mineral oil and ethylene glycol play a vital role in many industrial processes. The poor heat transfer properties of these fluids compared to most solids is a primary obstacle to the high compactness and effectiveness of heat exchangers. The essential initiative is to seek the solid particles having thermal conductivities several hundreds of times higher than those of conventional fluids. An innovative idea is to suspend ultrafine solid particles in the fluid for improving the thermal conductivity of a fluid. Many types of particles, such as metallic, non-metallic and polymeric, can be added into fluids to form slurries. However, the usual slurries, with suspended particles in the order of millimeters or even micrometers may cause some severe problems. The abrasive action of the particles cause the clogging of flow channels, erosion of pipelines and their momentum transfers into an increase in pressure drop in practical applications. Furthermore, they often suffer from instability and rheological problems. In particular, the particles tend to settle rapidly. Thus, although the slurries give better thermal conductivities, they are not practically applicable.

Nanofluids are engineered colloidal suspensions of nanoparticles (1-100 nm) in a base fluid. Common base fluids include water and organic liquids. Nanoparticles are typically made up of chemically stable metals, metal oxides or carbon in various forms. The size of the nanoparticles impart some unique characteristics to these fluids, including greatly enhanced energy, momentum, mass transfer, as well as reduced tendency for sedimentation and erosion of the containing surfaces. Nanofluids are being investigated for numerous applications, including cooling, manufacturing chemical and pharmaceutical processes, medical treatments, etc.

The earliest observations of thermal conductivity enhancement in liquid disper-
ions of submicronic solid particles (nanoparticles) are reported by Masuda et al. (1993). The term "nanofluid" was first proposed by Choi (1995) to indicate engineered colloids composed of nanoparticles dispersed in a base fluid. The thermal conductivity of nanofluid is much higher than that of the convectional heat transfer fluids reported by Khanafer et al. (2003), Kim et al. (2004), Maiga et al. (2004) and Tiwari and Das (2007).

A brief review of literature dealing with mixed convection flow in enclosures is outlined below.

Torrance et al. (1972) numerically investigated both thermally stable and unstable shear-driven flows in cavities with depthwise aspect ratios of 0.5, 1 and 2. These simulations were performed for fixed values of $Re = 100$ and $Pr = 1$, with the three cavity walls at a constant temperature different from the temperature of the top driving lid. Their results indicated that the Richardson number is a governing parameter of the problem. They particularly concluded that the flow pattern in the cavity is influenced by the buoyancy if the absolute value of the Richardson number is greater than unity. Iwatsu et al. (1993) studied numerically mixed convection heat transfer in a driven cavity with a stable vertical temperature gradient. Their results showed that the flow features are similar to those of a conventional driven cavity of a non-stratified fluid for small values of the Richardson number. Also, they found that when the Richardson number is very high, much of the middle and bottom portions of the cavity interior are stagnant.

Iwatsu et al. (1992a) studied numerically the flow of a viscous thermally-stratified fluid in a square container. The flow was driven by the top lid of the container, which executes torsional oscillations. Their results exhibited occurrence of resonance phenomena when the top lid oscillated for particular values of frequency. When the imposed frequency of the oscillating lid was close to these values, the fluid motion was amplified and the heat transfer across the system boundaries was enhanced. Their numerical results were qualitatively consistent with a fundamental physical argument. Iwatsu et al. (1992b) studied the flow of a viscous fluid in a two-dimensional square
cavity. The flows was driven by the top sliding wall, which executed sinusoidal oscillations.

Mansour and Viskanta (1994) studied both experimentally and theoretically mixed convection heat transfer in a shallow cavity with a moving bottom wall. They analyzed the problem theoretically for two- and three-dimensional laminar flows and low Reynolds number k-ε turbulence model. Their comparison of the numerical predictions with experimental data revealed a reasonably good agreement. They found that the turbulence intensity under natural convection conditions can be controlled when shear flow is introduced, depending on the location in the cavity and the value of the Richardson number \((R_i)\).

Al-Amiri et al. (2007) have investigated steady mixed convection in a square lid-driven cavity under the combined buoyancy effect of thermal and mass diffusion. The transport equations were solved numerically using the Galerkin weighted residual method. The average Nusselt and Sherwood numbers were obtained at the bottom wall for some values of the parameters considered in their investigation. Their results demonstrated the range where high heat and mass transfer rates can be attained for a given Richardson number.

Mahapatra et al. (2006) studied numerically mixed convection in a two-sided lid-driven differentially heated square enclosure with radiation in the presence of a participating medium. They considered the outcome of the interaction of forced convection induced by the moving vertical hot and cold walls with the natural convection induced due to the differentially heated enclosure. They considered two different orientations of the wall movement to simulate opposing and aiding mixed convection phenomenon and studied its interaction with radiation.

Recently, Shraif (2007) has studied the laminar mixed convective heat transfer in a two-dimensional shallow rectangular cavity of aspect ratio 10 with hot moving lid on top and cooled from bottom. He found that the rate of increase of the average Nusselt number with a cavity inclination is mild for forced convection while it is much steeper for natural convection. Also he found that the local Nusselt number at the
heated moving lid starts at a high value and decreases rapidly and monotonically to a small value towards the right side. The local Nusselt number at the cold wall exhibits oscillatory behaviour near the right side due to the presence of separation bubble at the cold surface in that location.

Arpaci and Larsen (1984) have presented an analytical treatment of the mixed convection heat transfer in tall cavities, which had one vertical side moving, vertical boundaries at different temperatures and horizontal boundaries adiabatic. They showed that in this particular case, the forced and buoyancy-driven parts of the problem can be solved separately and combined to obtain the general mixed convection problem. Aydin (1999) conducted numerical investigation of the transport mechanism of laminar combined convection in a shear and buoyancy driven cavity. His results were obtained for different values of the mixed convection parameter, $Gr/Re^2$ in the range 0.01 to 100 at $Re = 100$. He found that the increasing value of $Gr/Re^2$ defines three different heat transport regimes, the forced convection, the mixed convection and the natural convection. Similar trend of results was obtained by Oztop and Dagtekin (2004).

Kuhlmann et al. (1997) performed experimental and theoretical investigations of the two- and three-dimensional flows which are induced when the two facing sides of the cavity move with constant velocities in opposite directions to each other. Their results indicated that the existence of non-unique two-dimensional steady flows depend upon the cavity aspect ratio and the Reynolds number, which is determined by the wall velocities. At low Reynolds number, the flow consisted of separate co-rotating vortices adjacent to each of the moving walls. Blohm and Kuhlmann (2002) studied experimentally incompressible fluid flow in a rectangular container driven by two facing side walls which move steadily in anti-parallel for Reynolds numbers up to 1200. The moving sidewalls were realized by two rotating cylinders of large radii tightly closing the cavity. They found that beyond a first threshold robust, steady, three-dimensional cells bifurcate supercritically out of the basic flow state. When both side walls moved with same velocity (symmetrical driving) the oscillatory instability was found to be tricritical.
Mixed convection heat transfer in a two-dimensional rectangular cavity with constant heat flux from partially heated bottom wall, while the isothermal sidewalls are moving in the vertical direction was studied numerically by Guo and Sharif (2004). They considered several different values of the heat source length, the aspect ratio of the cavity, as well as symmetric and asymmetric placement of the heat source. For asymmetric placement of the heat source, it was observed that the maximum temperature decreases and the average Nusselt number increases as the source is moved more and more towards the sidewall. This is desirable since more effective cooling process is achieved. Also they concluded for thin rectangular cavities, that the heat transfer process improves rapidly as the aspect ratio approaches one whereas the improvement is not significant when the cavities are taller.

Transient convective motion and heat transfer in a three-dimensional square cavity driven by combined temperature gradient and imposed lid shear were analyzed by Mohamad and Viskanta (1991). The cavity was filled with a low Prandtl fluid and the vertical walls were maintained at different but constant temperatures. The horizontal connecting walls were adiabatic. The upper wall was moving and either aided or opposed the buoyancy-driven motion. They reported studies for $Pr = 0.005$, $Gr = 10^7$ and a range of Reynolds numbers for both aiding and opposing flow situations. Mohamad and Viskanta (1995) performed three-dimensional numerical simulations of fluid flow and heat transfer in a lid-driven cavity filled with a stably stratified fluid to study the effect of a sliding lid on the flow and thermal structures in a shallow cavity. They found that the rate of heat transfer increases as $Ri$ decreases or the Reynolds number increases.

Alleborn et al. (1999) studied heat and mass transfer in a three-dimensional two-sided lid-driven shallow cavity having an aspect ratio of 5, which had both moving bottom hot wall and top cooled wall, and two others adiabatic. They determined the effect of Reynolds number and concentration in cavities at different angles that is, with horizontal and vertical orientation of the cavity, by using vorticity-stream function approach. They found that cavity length and velocity were parameters affecting the mass transfer and established two turning points and flow configurations in which
heat and mass transfer were minimized. Also they found that for a vertical cavity, there are two turning points and flow configurations with minimal heat and mass transfer, and for a horizontal cavity heated from below a Hopf bifurcation indicating inception of oscillatory flow regimes.

Experimental and numerical studies have been performed to investigate the combined effects of lid movement and buoyancy on flow and heat transfer characteristics for the mixed convection inside a lid-driven arc-shaped cavity by Chen and Cheng (2004). In their experiments, steady-state temperature data were measured by T-type thermocouples and the flow field was visualized by using kerosene smoke. Flow pattern, friction factor and Nusselt numbers were investigated in wide ranges of independent parameters (Reynolds number and Grashof number).

Horne and O'Sullivan (1974) studied the stability of natural convective flow in a porous medium heated both uniformly and non-uniformly from below. Their results showed that in certain cases of the uniformly heated problem, there exists, two distinct possible modes of flow, one of which is fluctuating and the other being steady. However in the non-uniformly heated case the boundary conditions forced the solution into a unique mode of flow which is regularly oscillating when there is considerable non-uniformity in the heat input at the lower boundary, provided that the Rayleigh number is sufficiently large. Also they found that the natural convective regime of flow through porous medium is greatly influenced both by the presence of vertical boundaries and by the types of boundary conditions employed.

Vafai and Tien (1981) have analyzed the effects of a solid boundary and the inertial forces on flow and heat transfer in porous media. Their results showed that the effect of boundary on heat transfer can be quite important and is more pronounced for the thermal boundary layer with a thickness less than or of the same order as that of the momentum boundary layer and this was expected to happen at high Prandtl numbers and large pressure differences. Lauriat and Prasad (1989) have examined the relative importance of inertial and viscous forces on natural convection in porous media via the Darcy-Brinkman-Forchheimer solutions for a differentially heated vertical cavity.
Their numerical results indicated that a porous medium can transport more energy than a saturated fluid, if the porous matrix is highly permeable and the thermal conductivity of solid particles is greater than that of the fluid.

Kaneko et al. (1974) conducted an experimental investigation of natural convection in liquid saturated confined porous medium and found that the mode and intensity of convective motions are affected by the angle of inclination of the medium and certain properties of the saturated fluid. They found that the physical properties of the system, in particular the thermal conductivity of the dispersed solid phase, the viscosity and the coefficient of thermal expansion of the fluid phase to influence the mode and intensity of convective currents. Also they found that the maximum number of convective cells occur at an angle of 10° from the horizontal. With further increase in the angle of inclination, the multicellular motion was transformed to a unicellular pattern.

Tashtoush (2000) established a new analytical solution for the effect of viscous dissipation on mixed convection flow and heat transfer about an isothermal vertical wall embedded in Darcy and non-Darcy porous media with uniform free stream velocity. He found from the Nusselt number results that viscous dissipation lowers the heat transfer rate in both Darcy and Forchheimer flow regimes for aiding as well as opposing flows. Jue (2001) analyzed Benard convection in a rectangular enclosure filled with fluid saturated porous medium. He used a general Darcy-Brinkman-Forchheimer model to account for the flow in a porous medium. His results showed that the strength of Benard convection and heat transfer rate become weaker due to the existence of more flow restrictions in the porous medium. The heat transfer rate in a low porosity medium such as \( \epsilon = 0.4 \) can be larger than that of the high porosity medium with \( \epsilon = 0.6 \), in the case of \( Ra = 5 \times 10^6, Da = 10^{-4} \) due to different flow patterns.

Hossain and Rees (2003) performed numerical investigation of natural convection flow of a viscous incompressible fluid in a rectangular porous cavity heated from below with cold sidewalls. They focused on how the flow and heat transfer are affected by
variations in the cavity aspect ratio, the Grashof number and the Darcy number.
Their results showed that the flow becomes weaker as the Darcy number decreases
from the pure fluid limit towards the Darcy flow limit. In addition the number of
cells which formed within the cavity is always even due to the symmetry imposed by
the cold sidewalls.

The problem of natural convection flow in a cavity filled with water saturated
porous medium near its maximum density and subjected to thermal non-equilibrium
condition has been investigated numerically by Saeid (2007). The natural convection
flow in the horizontally heated rectangular cavity was assumed to be two-dimensional.
He presented variations of the average Nusselt number with the Rayleigh number for
different values of the heat transfer coefficient parameter $H$ and the thermal con­
ductivity parameter $K_r$. Also he found that by increasing $H$ and $K_r$ the shape of
the isotherms of the solid phase appears to be similar to those of water due to the
enhancement of the thermal communications between the two phases.

Mixed convection in a lid-driven porous cavity has recently received considerable
attention because of numerous applications in engineering and industry. The laminar
transport processes in a lid-driven square cavity filled with a water-saturated porous
medium was studied numerically by Al-Amiri (2000). He analyzed the characteristics
of the flow and temperature fields in the porous cavity under stable thermal stratifica­
tion with emphasis on the influence of the quadratic inertial effects. Oztop (2006) has
analyzed mixed convection heat transfer and fluid flow in a partially heated porous
lid-driven enclosure. He found that the location center of the heater is the most effec­
tive parameter on mixed convection flow and temperature field and the highest heat
transfer is obtained when the heater is located on the left vertical wall.

Oreper and Szekely (1983) studied numerically the transient development of the
fluid flow and temperature distribution in a rectangular cavity in the presence of an
imposed magnetic field. They found that the imposition of the external magnetic field
on buoyancy driven circulation system modifies both the velocity and the temperature
field, provided the magnetic field is large enough. Garandet et al. (1992) proposed
an analytical solution to the equations of magnetohydrodynamics that can be used to model the effect of a transverse magnetic field on buoyancy driven convection in a two-dimensional cavity. Their results show that in the high Hartmann number limit, the velocity gradient in the core is a constant outside of the two Hartmann layers at the vicinity of the walls normal to the magnetic field.

Natural convection of an electrically conducting fluid in a rectangular enclosure in the presence of a magnetic field was studied numerically by Rudraiah et al. (1995). They indicated that the average Nusselt number decreases with an increase in the Hartmann number and the Nusselt number approaches unity for a strong magnetic field. This shows that the convection in the enclosure is suppressed due to the introduction of the magnetic field. Alchaar et al. (1995) studied numerically the effect of a transverse magnetic field on the buoyancy-driven convection in a shallow rectangular cavity for a wide range of Rayleigh number and Hartmann number by varying the Prandtl number from 0.005 to 1, for different aspect ratios, where the vertical walls are differentially heated and the horizontal walls are thermally insulated with an upper free surface. They showed that the convective modes inside the cavity strongly depend on both the strength and orientation of the magnetic field and that the horizontally applied magnetic field is the most effective one in suppressing convective currents.

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 was developed by Chamkha (1997). He found that the presence of the non-uniform applied transverse magnetic field caused both the skin-friction coefficient and the local Nusselt number along the plate length to increase while the presence of the inertial effects due to porous medium caused these properties to decrease.

Kandaswamy and Kumar (1999) investigated numerically the effect of magnetic field on the natural convection of water near its density maximum. They reported that the average heat transfer rate depends nonlinearly on the temperature gradient
and that the effect of the magnetic field on the natural convection is to inhibit the heat transfer rate. Saravanan and Kandaswamy (2000) have studied the convection in a low Prandtl number fluid driven by the combined mechanism of buoyancy and surface tension in the presence of a uniform vertical magnetic field. The fluid was contained in a square cavity with the upper surface open and isothermal vertical walls. The thermal conductivity of the fluid was assumed to vary linearly with temperature. It was shown that the heat transfer across the cavity from the hot wall to the cold wall becomes poor for a decrease in thermal conductivity in the presence of magnetic field.

Kharicha et al. (2004) studied numerically the laminar magnetohydrodynamic flow, driven by a rotating disk at the top of a cylindrical cavity filled with a liquid metal. They investigated the effects of the magnetic field on the fluid and wall electrical conductivities and the wall thickness. Their results showed that for fixed values of the Hartmann and Reynolds numbers, the velocity distribution depends strongly on the conductance ratio k, in spite of the fact that, the Hartmann layer thickness and side layer thickness do not vary with k.

In recent years, there has been considerable interest in studying the influence of magnetic field on the flow through porous cavity. The magnetohydrodynamic laminar flow between two parallel porous disks for large suction Reynolds number and arbitrary Hartmann number was examined by Rudraiah and Chandrasekhara (1969). The equations of motion were solved using the singular perturbation technique and the expressions for the velocity, pressure and stress distributions were obtained. They observed that both radial and axial velocity profiles are flattened under the combined effect of suction and the imposed magnetic field, even for small Hartmann number.

Bian et al. (1996) conducted a numerical investigation on the effect of an electromagnetic field on free convection in an inclined rectangular porous enclosure saturated with an electrically conducting fluid. They considered the enclosure with the long side walls heated isothermally while the short ends thermally insulated and a uniform magnetic field applied normal to the heated walls. They found that the transition
from a single to a multi cellular convection pattern is considerably affected by the imposition of magnetic field.

Tasnim et al. (2002) studied analytically the first and second laws of thermodynamic characteristics of flow and heat transfer inside a vertical channel made up of two parallel plates embedded in a porous medium and under the action of a transverse magnetic field. Their results indicated that the inverse Darcy number has insignificant effect on entropy generation while average entropy generation rate shows linear variation with group parameter. Hassanien and Allah (2002) studied analytically the unsteady two dimensional free-convection and mass-transfer flow of a viscous, incompressible and electrically conducting fluid through a porous medium with variable permeability in the presence of a transverse magnetic field. They found that when the magnetic parameter increase, the velocity decreases.

Recently, Aziz (2007) has studied hydromagnetic heat and mass transfer by natural convection from a vertical cylinder embedded in a thermally stratified porous medium. The surface of the cylinder was assumed to be permeable to allow possible fluid blowing or suction. He presented numerical results for the skin friction factor, the local Nusselt number and the local Sherwood number for various parametric conditions.

The use of nano sized particles to enhance heat transfer was first studied by a research group at the Argonne National Laboratory around a decade ago. Choi (1995) was probably the first one who called the fluids with particles of nanometer dimensions as 'nanofluids'.

Xuan et al. (2000) examined the transport properties of nanofluid and the thermal dispersion effect with two different approaches, the conventional approach and the modified approach. In the first approach the existing heat transfer coefficient correlations for the pure fluid were directly extended to the nanofluid, by substituting the thermal properties of nanofluid for those of pure fluid. In the second approach the thermal dispersion, which takes place due to the random movement of particle was considered. This thermal dispersion flattened the temperature distribution and
made the temperature gradient between the fluid and the wall steeper, increasing the heat transfer rate between the fluid and the wall.

Xuan and Li (2000) discussed four possible reasons for the improved effective thermal conductivity of nanofluids: the increased surface area due to suspended nanoparticles, the increased thermal conductivity of the fluid, the interaction and collision among particles, the intensified mixing fluctuation and turbulence of the fluid and the dispersion of nanoparticles. Eastman et al. (2001) used pure copper (Cu) nanoparticles of less than 10 nm size and achieved 40% increase in thermal conductivity for only 0.3% volume fraction of the solid dispersed in ethylene glycol. They indicated that the increased ratio of surface to volume with decreasing size should be an important factor. Also, they showed that the additive acid stabilizes the suspension and thus increases the effective thermal conductivity.

Putra et al. (2003) presented their experimental observations on natural convection of aluminium oxide ($Al_2O_3$)-water and copper oxide (CuO)-water nanofluids inside a horizontal cylinder heated from one end and cooled from the other. Unlike the results of forced convection, they found a systematic and definite deterioration of the natural convective heat transfer, which is dependent on the particle density, concentration, and the aspect ratio of the cylinder. The deterioration increased with particle concentration and was more significant for CuO nanofluids.

Heat transfer characteristics of copper nanofluids with and without acoustic cavitation have been investigated experimentally by Zhou (2004). The effects of such factors as acoustical parameters, nanofluid concentration and fluid subcooling on heat transfer enhancement around a heated horizontal copper tube were discussed in detail. Their results indicated that the copper nanoparticles and acoustic cavitation have profound and significant influence on heat transport in the fluid. The addition of copper nanoparticles did not change the dependence of heat transfer on acoustic cavitation and fluid subcooling.

Santra et al. (2004) investigated numerically laminar natural convection in a nanofluid filled square cavity. They considered the left wall as an isothermal heat
source and the right wall as an isothermal heat sink, while top and bottom walls being insulated. They observed that the heat transfer augmentation is possible using nanofluid in comparison to conventional fluids. Also, the rate of heat transfer increases with the increase in solid volume fraction of the nanofluid.

Khaled and Vafai (2005) investigated the effect of thermal dispersion on heat transfer enhancement of nanofluids. Their results showed that the presence of the dispersive elements in the core region did not affect the heat transfer rate. However, the corresponding dispersive elements resulted in 21% improvement of Nusselt number for a uniform tube supplied by a fixed heat flux when compared to the uniform distribution of the dispersive elements. These results provided a possible explanation for the increased thermal conductivity of nanofluids which may be determined partially by the dispersive properties.

Xuan et al. (2005) observed that the random motion of nanoparticles tends to flatten the temperature distribution profile near the boundary wall. Due to the irregular fluctuation of suspended nanoparticles, the Nusselt number variation fluctuated along the main flow direction. Their results indicated that the distribution and volume fraction of the nanoparticles are important factors in determining the temperature distribution and heat transfer improvement of nanofluids.

Buongiorno (2006) developed a two-component four-equation nonhomogeneous equilibrium model for mass, momentum, and heat transport in nanofluids. He proposed reason for the abnormal heat transfer coefficient increases: the nanofluid properties may vary significantly within the boundary layer because of the effect of the temperature gradient and thermophoresis. For a heated fluid, these effects can result in a significant decrease of viscosity within the boundary layer, thus leading to heat transfer enhancement.

Wang et al. (2006) investigated numerically free convective heat transfer characteristics of a two-dimensional cavity flow over a range Grashof numbers and solid volume fractions for various nanofluids. Their results showed that suspended nanoparticles increased significantly the heat transfer rate at all Grashof numbers. For water-$\gamma Al_2O_3$
The increase in the average heat transfer coefficient was approximately 30% for 10 vol% nanoparticles. The maximum increase in heat transfer performance of 80% was obtained for 10 vol% Cu nanoparticles dispersed in water. Furthermore, the average heat transfer coefficient was seen to increase up to 100% for the nanofluid consisting of oil containing 1 vol% carbon nanotubes. Furthermore, the presence of nanoparticles in the base fluid is found to alter the structure of the fluid flow for horizontal orientation of the heated wall.

Maiga et al. (2006) studied the hydrodynamic and thermal behaviors of a turbulent flow of nanofluids, which are composed of saturated water and Al2O3 nanoparticles at various concentrations, flowing inside a tube subjected to a uniform wall heat flux boundary condition. This study has provided an interesting insight into the thermal behaviors of nanofluid in the context of a confined tube flow. Their numerical results showed that the inclusion of nanoparticles into the base fluid has produced an augmentation of the heat transfer coefficient, which has been found to increase appreciably with an increase of particles volume concentration. Also they found that such beneficial effects appear to be more pronounced for flows with moderate to high Reynolds number.

Assael et al. (2006) investigated experimentally the thermal conductivity of nanofluids using the transient hot-wire method. They observed that the addition of nanoparticles results in an increase of the thermal conductivity. Also they discussed existing methods for the prediction and correlation of the thermal conductivity increase. Li and Peterson (2006) conducted an experimental investigation to examine the effects of variations in the temperature and volume fraction on the steady-state effective thermal conductivity of two different nanoparticle suspensions. Copper and aluminum oxide nanoparticles with area weighted diameters of 29 and 36 nm, respectively, were blended with distilled water at 2%, 4%, 6%, and 10% volume fractions and the resulting suspensions were evaluated at temperatures ranging from 27.5 to 34.7°C. Their results indicated that the nanoparticle material, diameter, volume fraction, and bulk temperature all have significant impact on the effective thermal conductivity of these suspensions.
Prakash and Giannelis (2007) calculated thermal conductivity of alumina nanofluids (with water and ethylene glycol as base fluids) using temperature as well as concentration dependent viscosity. In their model, the interfacial resistance effects were incorporated through a phenomenological parameter. The micro-convection of the alumina nanoparticle was included through Reynolds and Prandtl numbers. They found that the thermal conductivity is more sensitive to Reynolds number than Prandtl number. As a result, there was a net enhancement in thermal conductivity as temperature was increased.

The laminar flow forced convection heat transfer of $Al_2O_3$/water nanofluid inside a circular tube with constant wall temperature was investigated experimentally by Heris et al. (2007). They obtained the Nusselt numbers of nanofluids for different nanoparticles concentrations as well as various Peclet and Reynolds numbers. They found that heat transfer coefficient increases by increasing the concentration of nanoparticles in the nanofluid. The increase in heat transfer coefficient due to the presence of nanoparticles was much higher than the prediction of single phase heat transfer correlation used with nanofluid properties.

An attempt is made in this thesis to study the mixed convection in a lid-driven cavity filled with a fluid saturated porous medium or nanofluids. This problem is considered for various physical conditions such as magnetic field, moving walls and aspect ratio. The second Chapter describes the formulation, boundary conditions and numerical method used to solve the problem. Six different problems are analyzed. The results and discussion are presented in Chapters 3-8. Overall conclusions arrived at each chapter are summarized in Chapter 9.