Chapter (1)

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The information about the mechanical properties of solutions and melts is very important for the processing of these materials in almost all branches of industries . The last half of the present century has seen an immense development of highly sophisticated theories which describe the non-linear (non-Newtonian) behaviors of such types of materials . Some of these theories are based on microscopic models [1,2] , where special types of statistics , termed conformation statistics [3] , are employed in order to determine the macroscopic mechanical properties . Other theories are based on phenomenological equations of state [4] . In the present work , the constitutive equation based on the retarded motion approximation up to the fluid of grade two is used .

Within the frame of non-linear theories of constitutive equation , whether macroscopic or microscopic , these properties are designated by a set of parameters known as material constants . The fluid of grade two is characterized by three parameters;namely the coefficient of viscosity , μ , and the two elastic constants α_1 and α_2 which are related to the two normal stress differences $(S_{11} - S_{22})$ and $(S_{11} - S_{33})$. The determination of these material parameters is done using proper devices , known as rheometers and the branch which is concerned with such measurements is termed rheometry .

In general , the rheometer is based on the solution of a specific boundary value problem which allow a number of experimental measurements sufficient to determine a specific set of material parameters. The conventional rheometers based on the realization of either steady or periodic viscometric flow are not capable to determine the non-Newtonian properties of fluids . For this reason , one of the major purposes of rheology is to investigate further types of flow other than viscometric flow, which allows the determination of some of the non-Newtonian properties of fluids .

It is worthy to mention that about 30 years ago [5] the force and the torque acting on a sphere which undergoes simultaneous rotational and translational creeping motion in a fluid delivers nearly complete characterization of an incompressible fluid , at least up to third order . However , the practical realization of a corresponding device has never been carried out .

Many authors study the axial symmetric flow of an incompressible viscous fluid between two concentric rotating spheres , both analytically and numerically [6-10] .The only coefficient which can be determined in this case is the coefficient of viscosity μ .Wimmer et al [11] study this problem experimentally and they show how the flow field takes place in the two cases ; namely , when one of the two spheres is rotating while the other is being at rest and in the other case in which both of the two spheres are rotating .

About 25 years ago Walters et al [12] designed special device consisting of two eccentric cylinders where both cylinders are rotated with the same angular velocity . With this device it was possible to determine in the first approximation both components of the complex viscosity .

Another rheometer , termed eccentric cylinder rheometer [13,14] , is constructed on the basis of a fluid rotating in the annular region between two eccentric cylinders . Besides simplicity of the construction , this rheometer allows reliable measurements for the elastic constant α_1 .

The present work deals with another boundary value problem which promises to create a successful rheometer . The steady state isochoric flow of a fluid of grade two moving in the annular region between two eccentric spheres is investigated and the velocity field up to second-order is computed . The construction of the rheometer based on these calculations is designed and the viscosity μ and the combined second-order material coefficient ; i.e. the first normal stress difference coefficient$(\alpha_2 + 2\alpha_1)$, are determined using this rheometer .

A large number of theoretical and experimental works is done on the viscous flow between two eccentric spheres . Jeffery [15] , Stimson and Jeffery [16] solved the stationary rotational viscous flow in the so called axisymmetrical case , where the rotation takes place about the common diameter of the two spheres . These authors employed the bispherical system of coordinates which appears to be the most appropriate one . Noteworthy , is that this system can be used in the case when the two spheres are external to each other , as well as the case of one sphere enclosing the other . Majumdar [17] considered the non-axisymmetrical problem of separate spheres in an incompressible viscous fluid when one of the spheres rotates slowly about an axis perpendicular to their line of centers and the other sphere remains at rest . Due to the complications associated with the non- axisymmetry of the problem ,the solution is obtained by applying special approximation methods . He proved that the resultant force acting upon the spheres is at right angles to the axis of rotation and the line of center. He also discussed the effect of the stationary sphere on the force and couple exerted by the liquid on the rotating sphere. Munson [18] solved the axisymmetrical case for stationary slow viscous flow using spherical polar coordinates instead of the bispherical coordinates . Due to the complications which appears , where the used system of coordinates is not appropriate for the boundary conditions , a series of computational approximations are done. He calculated the torque required to rotate the spheres at different rates in terms of the concentric torque ,the radius ratio and the eccentricity but he does not calculate the force acting on the spheres.Menguturk and Munson [19] constructed a device in order to realize experimentally the results obtained in the previous paper . They compared the theoretical values as the torques on the outer nonmoving sphere with those measured experimentally . The results are discussed here in the last chapter in comment with the results of the present work .

Noteworthy is that the model of the two eccentric spheres has proved to be a successful model in a wide range of applications which is mentioned breafly in the following :

(i)Numerical studies to determine heat transfer by natural convection between concentric and vertically eccentric spheres with mixed and isothermal boundary conditions are investigated [20,21] .In the two cases the results show that the heat and flow fields are primarily dependent on the Rayleigh number as well as on the annulus eccentricities .

(ii)Based on indirect mode matching, the exact analytical solution of the induced E.M.field in a layered eccentric spheres models of the human head is determined . This solution is applied to a six layer model of the head , where the model allows for eccentricity between the brain and the skul [22] . Numerical results was presented also for models adapted to adult and infant heads; [23] .

(iii)Finite element representation of a homogeneous eccentric spheres model of the inverse problem of electrocardiagraphy have been investigated [24,25] . The layerred inhomogenious eccentric spheres for three regions representing the lungs , muscle and subcutaneous fat has been studied by the same numerical method [26] .

(iv)An extension of the study by using finite element representation to the case of a realistic heart-torso geometry is carried out in a separate work [27] .

(v)By measuring the laplacian of the surface potential distribution in one hand and from body surface lap. maps on the other hand the eccentric spheres model of the heart-torso system is used and hence a numerical study of the electrical activity is investigated by many authors [28,29] .

Based on the last knowledge , it is worth while to mention that the motion of viscoelastic fluids in the annular region between two eccentric spheres has not been considered up to date. Hence, the present work deals with that boundary value problem ; i.e. the flow of a second-order (viscoelastic) fluid in the annular region between two eccentric spheres .

The present thesis includes six chapters where the introduction is being as the first chapter, besides appendix at the end of this thesis.

The definition of the boundary value problem as well as the formulation of the equations of motion, the method of approximation for the solution, the system of partial differential equations that govern the flow fields, the solution of the generating set of equations up to first-order and derivation of equations of second-order approximation with its boundary conditions are discussed in chapter two.

In chapter three, the solution of the inhomogenious biharmonic vector equation, which describes the flow field in the second-order approximation, is obtained using the proper Green's function.

The distribution of surface tractions, forces and torques on the boundaries are evaluated in chapter four.

The construction of the rheometer based on the eccentric spheres model is discussed in details in the fifth chapter.

The last chapter includes theoretical results and the experimental results obtained with the present device.

The system of the bispherical coordinates is described analytically in an appendix at the end of the thesis.