CHAPTER - 1

INTRODUCTION: SCOPE AND OBJECTIVE

The science of chemical engineering, broadly speaking, may be called as a veritable stimulation of equilibrium processes, transfer processes and kinetics and rate processes. As a corrollary therefore, studies on transfer characteristics in various chemical engineering systems has been attracting wide attention. Nevertheless, these studies have been confined essentially to what one might call the standard situations. Though most, if not all, of the transport systems encountered in actual practice involve irregular flow geometry, since the large number of parameters involved in their analysis induce lot of complicacies, the reported works in the literature have either resorted to experimental correlations which are highly empirical in nature or to simplified theoretical treatments with only limited number of parameters in consideration.

The principal objective of the present work is to make a brief analysis of the momentum and heat transfer characteristics for axisymmetric flow in irregular geometry using feasibly most rigorous mathematical tools and the subsequent experimental verification. The type of geometry chosen specifically for the present study is that of a UPCT (Uniform Periodically Constricted Tube). However, the mathematical model developed has been made quite flexible so that through proper allocation of the deviation parameter discussed shortly, it can be easily extended to other similar situations as well. This type of converging-diverging flow has been found to be specially attractive in augmentation of transfer efficiency and in proposing an improved model for packed beds and porous media. Among the different methods proposed in the literature for heat transfer augmentation, very few satisfy the two principal conditions such as

(a) keeping the pressure drop and consequently the power consumption within reasonable limits,

(b) absence of too many extra complicacies and accessories so that the method will not go unsuitable for large scale industrial practices.

The present work has been intended to meet the above two requirements satisfactorily. The work may be classified into two parts: (a) Momentum transfer study (b) Heat transfer study.

1.1. MOMENTUM TRANSFER STUDY:

A mathematical model has been formulated to develop the velocity profile in the annulus of a uniform, diverging - converging tube (inner tube, outer tube being a straight cylindrical column); assuming Newtonian, steady state, incompressible flow. Though the model has been developed for a UPCT (Uniform Periodically Constricted Tube), a parameter $r_w(Z)$ has been defined which may be called the deviation parameter. This accounts for the distance from the center of the tube to the tube wall which, for a tube with irregular geometry is a function of the axial distance Z and depends on the type of geometry under consideration. Therefore, by defining $r_w(Z)$ corresponding to the case under study, the model may be extended to systems of various other flow geometries.

To develop the mathematical model, Navier-Stokes' equation for two-dimensional flow has been used in terms of stream function and vorticity. The boundary conditions for the system are specified assuming no-slip condition at the tube walls. The boundary conditions at the inlet and outlet are generated through an iterative procedure which, in fact, is a part of the solution itself. Thus the formulation of boundary conditions has been performed in the most rigorous manner as they are generated during the solution instead of pre-specifying approximate values. This also takes care of the fact that the velocity profile is well-developed at the inlet as well as at the outlet.

The system of equations [redacted] [redacted] [redacted] are solved numerically using line successive over-relaxation method. The corresponding algorithm involves iterative procedure and its stability and speedy convergence have been assured by the proper adjustment of the over-relaxation factor and the two weighting factors involved in the scheme. The values of radial and axial components of the velocity vector are deduced from the solution, obtained.

The details of mathematical modelling and numerical computation have been presented in Chapter 3.

The theoretically predicted values have been compared against the experimental results. The experimental procedure has been discussed in detail in Chapter 4. Point velocities (axial as well as radial velocities) in the flowing fluid through the system have been measured using a head meter cum micro-manometer arrangement. Satisfactory agreement has been observed between the experimental values and the theoretically predicted ones.

The conclusions and inferences deduced from the results obtained have been discussed in Chapter 5.

1.2. HEAT TRANSFER STUDY:

The mathematical model developed for the momentum transfer study has been extended to determine the heat transfer characteristics in the system. The known values of the velocity components obtained from the solution of the Navier-Stokes' equation as described above have been substituted in the energy equation so as to derive the temperature profile numerically. The boundary conditions have been postulated on the basis of constant wall-temperature assumption.

The numerical algorithm used for the solution of energy equation is exactly analogous to that used for the momentum equations. Thus the solution is obtained iteratively using line successive over-relaxation method. The mathematical model has been discussed in Chapter 3.

The validity of the theoretical values obtained as above has been checked experimentally. Point temperatures in the fluid have been measured using copper-constonton thermocouples. The experimental procedure is given in Chapter 4 and the results discussed in Chapter 5.

The heat transfer coefficient has been determined for the constricted geometry and compared with that for a straight tube having the same surface area per unit length. Excellent enhancement in the transfer coefficient has been observed for the constricted tube as compared to the straight tube, with reasonably low pressure drop penalty.

1.3. PRACTICAL APPLICATIONS:

The major applications that can be cited for the present work are:

(a) In the study of structure of packed beds and porous media. The void space in a packed bed can be considered to be a periodically constricted capillary tube. The present work therefore provides an improved, generalized, mathematical model for determining the transfer characteristics in packed beds for which until now only empirical correlations derived on the basis of experimental results have only been available.

(b) As has been stated earlier, the model has been developed in such a way that it can be used for studying the transport phenomena in systems of any specified geometry by adjusting the deviation parameter defined in the text.

(c) Since marked enhancement of heat transfer coefficient with reasonably low pressure drop penalty has been observed for the constricted geometry under study as compared against a straight tube of equivalent surface area, this can definitely be advantageous in the design of heat exchangers and condensers (both shell and tube as well as the plate type), tubular reactors, evaporator tubes and similar heat transfer equipments. Even for equipments employed for mechanical separation and processing of materials such as the fluid energy mills, this type of construction could prove to be of improved efficiency. The increase in the cost of fabrication associated with this type of geometry may be compensated against the appreciable increase in transfer efficiency that can be achieved by utilising the same.

1.4. SCOPE FOR FUTURE DEVELOPMENTS:

Since the present work has been confined essentially to Newtonian, incompressible and steady state flow, there is excellent scope for future extension of this work to,

(a) Various other non-Newtonian fluids of known rheological behaviour

(b) Compressible flow

(c) Unsteady state transfer.

The heat transfer study could be extended further to,

(i) heat transfer with constant heat flux but variable wall temperature

(ii) heat transfer into fluids with density and viscosity highly dependent on temperature

(iii) heat transfer with chemical reaction.

As the present studies have been restricted to momentum and heat transfer characteristics in systems of irregular geometry, the mass transfer characteristics with and without chemical reaction remain still to be explored. All the while, there can be little doubt that studies in this direction will be specially attractive as it promises excellent prospects for improved and more efficient design of industrial equipments.