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Research Article

BOUNDARY LAYERS AND HEAT TRANSFER IN FLUID FLOW

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ABSTRACT
In this paper concept of Boundary layers and its various kinds are discussed. The phenomenon of Heat transfer and its types be narrated. Flow through porous medium is also stated.

Keywords: *Boundary layers, Porous medium*

1.1 INTRODUCTION

The concept of boundary layer arises in flow of fluid about a solid body. This phenomenon is further applicable to heat transfer and in Magnetohydrodynamic boundary layers. The separation of boundary layers is also very important field to study. Applications of various kinds of heat transfer in Atmospheric sciences, Medical Sciences attract the scientists to study the same.

1.2 BOUNDARY LAYERS

(i) Velocity boundary layer

The concept laminar boundary layer was first introduced by a German Scientist Ludwig Prandtl in the year 1904. Prandtl in his paper on "Fluid motion with very small friction" made a hypothesis that with very small viscosity the flow about a solid body can be divided into two regions.

(a) a very thin layer in the neighbourhood of the body termed as velocity boundary layer or viscous boundary layer in which the viscous effects may be considered to be confined and

(b) the region outside this layer where the viscous effects may be considered as negligible and so the flow is regarded as inviscid.

(ii) Thermal Boundary Layer

In fluids flow past heated or cooled bodies the transfer of heat takes place mainly by conduction and convection. When the conductivity of fluid is small the heat transfer due to conduction is comparable to convection only across a thin layer near the surface of the body i.e. temperature gradient spread from the body is limited to a narrow zone in the immediate vicinity of its surface is called as thermal boundary layer.

(iii) MHD boundary layer

The MHD boundary layers, which are of recent origin, may be divided into two types by considering the limiting areas of large and small electrical conductivity

(a) when the electrical conductivity of fluid is large (small magnetic diffusivity $\upsilon_H = \frac{1}{\sigma\mu_e}$, i.e. large magnetic Reynolds number.), then diffusion of the magnetic field takes place in a narrow zone, called the magnetic boundary layer.

(b) when the electrical conducting of the fluid is small (magnetic Reynolds no. is small). The thickness of the magnetic boundary layer is very large.

(iv) Separation of boundary layer

For ordinary boundary layer flow with adverse pressure gradients (pressure which is increasing in the direction of flow), the boundary layer flow will eventually separate from the surface. The reason of this separation is small kinetic energy of the fluid in the boundary layer and so fluid may reach a condition of stopping and reversing its direction. This separation of the flow causes many undesirable features over the whole field, like if separation occurs on the surface of an aerofoil, the lift of the aerofoil will decrease and drag will enormously increase. Various means have been proposed to prevent the separation of boundary layer such as:

(a) Suction

Suction is a very effective means for the prevention of separation, this was pointed out by Prandtl in his original work on the boundary layer in 1904. In this case the retarded fluid in the boundary layers is sucked, into the body. The point of suction should be near the point of separation, either slightly ahead or behind so that no back flow will occur.

It has been recognized that suction prevents transition of boundary layer flow to turbulent flow and this process is known as laminarization of flow, which consequently reduces the skin friction and heat transfer at the surface.

(b) Injection

In this process fluid is injected from the body into the boundary layer to increase the kinetic energy of the fluid in the boundary layer to delay the separation.

Although injection is not an effective mean to avoid separation but by injection of a coolant through a porous wall, a thick heat-insulating boundary layer can be established to protect the wall from high temperatures. This technique is used in combustion chambers in rockets, around turbines and jet motors. Injection of a coolant through a porous wall is also known as "sweat colling". Other methods like moving slots on body and with moving surfaces are not considered in this paper.

In the above methods, suction is a very effective mean for avoiding separation. Also Suction of the fluid along the surface of the body is able to keep the boundary layer laminar because boundary layer is kept so thin that the transition from a laminar boundary layer to a turbulent one is avoided.

1.3 HEAT TRANSFER

Heat transfer is a science that deals with the energy transfer in solids as well as fluids. Heat transfer takes place from the region of higher temperature to that of lower temperature. The study of heat transfer gained its importance because of its various applications in different branches of science and engineering like Atmospheric Sciences, Tidal energy, and in Medical sciences. Heat transfer occurs in three ways, termed as - conduction, convection and radiation. The problems of radiative heat transfer are not considered in this paper.

(i) Conduction

Process of the heat transfer in solids due to transfer of internal energy from one molecule to another, known as conduction. French mathematical physicist, Joseph Fourier has given a law of heat transfer, known as Fourier's law of heat conduction. Mathematically it is defined as

$$q_y = -k\frac{dT}{dY} \qquad \text{...(1.3.1)}$$

where q_y is Heat flux (heat flow per unit area) in positive direction. κ is thermal conductivity is the property that arises mostly in heat transfer, which is same as of viscosity in momentum transfer. In addition to thermal conductivity κ, a quantity known as thermal diffusivity α, is widely used in the heat transfer, which is defined as

$$\alpha = \frac{\kappa}{\rho C_p} \qquad \text{...(1.3.2)}$$

(ii) Convection

In the process of convection, heat transfer in fluids takes place because of physical movement of heated particles. Convection is classified as (a) Free convection, and (b) Forced convection.

(a) Free Convection

In Free convection the fluid motion arises due to internal forces like buoyancy forces generated because of temperature gradient. It is also termed as natural convection. In this process the velocity and temperature profiles are intimately connected and the Nusselt number depends on Grashoff number - Gr and Prandtl number - Pr.

(b) Forced Convection

If the motion of fluid arises due to some external forces the heat transfer termed as Forced convection. In this process buoyancy force is negligible in comparison with external force. Here first, the velocity profiles are found, then they are used to find the temperature profiles. Nusselt number depends on Reynolds number-Re and Prandtl number-Pr.

1.4 FLOW THROUGH POROUS MEDIUM

A medium consisting of interstices in it called Porous medium. The interstices may be in regular or irregular pattern. Flow through porous medium occurs in filtration of fluids and seepage of water in river beds. The researches of flow through porous medium have got considerable importance in fields like soil science, hydrology, recovery of oils and gases. Also, magnetohydrodynamics flow through porous medium is of great importance in geophysics. Porous medium may be used as insulators as they are considered to be useful in diminishing the natural convection around the heated body. Porosity of the medium can be taken into account for curtailing down the separation of boundary layer, and laminarization of the flow which helps in reduction the drag.

The fluid flow through porous medium is governed by the Darcy's Law (1856), which states that the flow through the porous medium is directly proportional to pressure gradient and inversely proportional to viscosity μ of the fluid.

Mathematically it is expressed as

$$\vec{\mu} = -\left(\frac{\kappa}{\mu}\right)\overrightarrow{\nabla p} \qquad ...(1.4.1)$$

where κ is the permeability of the medium.

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