Chapter 1

Introduction

1.1 Introduction

To release heat rapidly and efficiently from the engineering equipment thermal management demands special attention. On one hand, failure of engineering devices (e.g., electrical transformer, air-cooled engine, nuclear reactor, miniaturized electronic equipment) depends highly on the limiting temperature. On the other hand, rapid and efficient heat removal from a system like solar heater/nuclear reactor makes the system more effective. Therefore, there remains an ever-growing need for the rapid and reliable heat removal from the miniaturized system to achieve the desired goal. This invites researchers to look for a better thermal management solution.

The heat transport processes are usually classified as conduction, convection and radiation and generally occur in combined modes, albeit single mechanism may be responsible for the major share of the heat transfer in some cases. Convection and radiation problems poses greater challenges to heat transfer engineers compared to conduction problems. In technological applications involving material with low emissivity, radiative heat transport components can be treated negligible compared to convective mode of heat transport especially for a low working temperature limit. Convection is a heat transport phenomena, in which fluid motion transport heat. The word convection is traced back from the Latin words “convecto-are” or “conveh-o-phere” which means “to bring together” or “to carry into one place”. Some schools of thought believe that convective transport is not a separate heat transfer mechanism as it involves conduction in bulk fluid motion.

Convection may broadly be characterized as forced and natural (or free) convection. Forced convection occurs predominantly due to the flow of fluid by the external agents, namely, fans and pumps. On the other hand, free convection is developed within the fluid
predominantly by the presence of density gradient arising out either from concentration gradient or temperature gradient, or both.

To cope up well with the demand of superior engineering equipment, there remains an ever-increasing need of miniaturization introducing a remarkable rise in heat generation from the system. Under such circumstances, the effect of natural convection along with forced convection, also called as mixed convection, may play a decisive role to remove heat from the system. Mixed convection has been the problem of great interest lately because of its practical application in heat exchangers, electronic equipment, nuclear reactors and other thermal devices, etc., where the fluid velocity produced by external agents like pumps or blowers is relatively small.

The inlet velocity in mixed convection may be considered as the supplement of forced convection and natural convection velocities. Fan produces the forced convection velocity, while the natural convection velocity occurs due to the flow generated by buoyancy. The flow created by natural convection produces a nominal pressure drop across the length of axial flow. On the other hand, the occurrence of forced flow necessitates the pressure drop to be imposed. Thus, for a specified axial velocity at the inlet, produced pressure drop is due to the forced convection velocity component alone irrespective of mixed or forced convection. It may therefore be possible to segregate the forced and natural convection velocity components in a mixed convective situation. This will render fan selection procedure easier.

Since the temperature limits are in general fixed, thus there remain two ways to enhance the heat transfer: (i) one is to increase the convection coefficient \( h \) and (ii) other is to increase the surface area. An enhanced value of \( h \) can usually be achieved by creating appropriate conditions of forced flow over the surface. As in the most engineering applications, an increase in \( h \) is not possible or economical, thus, extended surfaces are ubiquitous in engineering applications wherever there is a need to enhance heat transfer.
between a hot surface and the adjoining coolant. However, the combination of increased surface area coupled with increased heat transfer coefficient in a suitable form may provide a superior thermal management.

The term extended surface or fin is used in many references that provides additional surface for heat transfer through conduction, convection and radiation between its boundary and surroundings. To extend the functionality and life span of the equipment, it is common tradition to use extended surface to dissipate heat efficiently and effectively. It provides a viable solution to the demand of heat removal challenges in thermal management, which is economical yet reliable. Further, it causes no trouble and noise. Therefore, one of the best engineering approach is to increase the heat transfer surface area by introducing extended surface. Materials used for fin are commonly of high thermal conductivity and low emissivity, e.g., aluminium and copper, which provide nominal contribution of radiation in most of the cases. Fin can be of various shapes, but rectangular fins find common application for its simplicity in fabricating the same. Therefore, studies on fin are very much relevant and justified.

The studies of fin may be performed experimentally as well as computationally. Experimental studies are very much essential, but large number of experiments is prohibitively costly. In that sense, computation provides some resort to the researchers. Further, the experimental study of isothermal fin is far removed. Therefore, computational study may be fruitful to find the departure of non-isothermal fin performance from isothermal fin. Convective medium in the computation may be chosen to follow Boussinèsq/non-Boussinèsq fluid with constant/variable thermo-physical properties.

Any enhancement of heat transfer performance is usually achieved at the expense of increased power. However, the Second law dictates that increased heat transfer from the system enhances the entropy generation with an estimate of systems’ departure from
Therefore, the viability of further enhancement of a thermodynamic system, it is very much essential to perform Second law analysis along with the heat transfer analysis.

To compete with the demand of higher heat transport, additional resort may be identified other than the use of extended surface. The secondary flow being one of such examples may be used to enhance the heat transfer. Appearance of vortices surrounding the protrusion is extended towards the hydrodynamic boundary layer resulting in an additional heat transfer. Keeping all these factors in mind, a study has been attempted on mixed convection heat transfer from a vertical fin array with and without vortex generator.

1.2 Layout of the thesis

In the thesis, Chapter 1 deals with the general introduction to mixed convection heat transfer highlighting the importance of second law as well as vortex generator in the light of extended surface/fin.

In Chapter 2, a brief review of relevant literature covering natural convection, forced convection, and mixed convection over the both horizontal and vertical fin array is presented to focus the scope and objectives of the present study. Chapter 2 also covers pertinent literature to summarize the effects of variable fluid property consideration with and without vortex generator.

Chapter 3 is concerned with the investigation of the entry region mixed convection from a vertical isothermal fin array, which finds little attention in the past literatures. Further, a concept of decoupling is introduced to segregate inlet mixed convection velocity into forced and natural convection velocity components. Pressure drop correlation is proposed for the geometry considered.

Since, in reality all fin materials will have finite conductivity non-isothermal fin heat transfer using variable property non-Boussinéq fluid is brought in and discussed in chapter 4. Induced natural convection velocity is correlated with the governing parameters, which will
render the fan selection easier in mixed convection problems. A correlation of overall Nusselt number with the governing parameters is proposed to conclude the chapter.

Chapter 5 describes the optimum condition based on both the First and the Second law of thermodynamics. Chapter will also enlighten the variation of pumping power ratio, which is an important quantity to pump the heat out. While chapter 6 reveals an additional resort on heat transfer by placing vortex generator on the adiabatic shroud instead of base-fin surface.

To summarize the results concluding remarks are addressed in Chapter 7.