SYNOPSIS

The high heat transfer coefficients associated with impinging gas jets has encouraged their use in a broad range of industrial applications. These applications include the drying of textiles, paper and film materials, and the annealing of metal and plastic sheets. The importance of using cooling air in gasturbine airfoils to permit higher turbine inlet temperature is well documented in the open literature. One of the most effective means used to cool the leading edge of a turbine airfoil is to impinge jets of cooling air against its inside surface. The attractive features of the impinging jets are the simplicity of the equipment, the ease of control for a given mass flow rate and the attainment of high heat transfer coefficients with small temperature differences.

The use of single round jet, row of round jets, array of round jets, single slot jet, and rows of slot jets, particularly impinging on flat surfaces has been studied extensively by many investigators. However, work on the impingement cooling onto curved surfaces are comparatively less in number. This thesis deals with analysis of fluid flow and heat transfer by impinging jets on concave semicylindrical as well as concave hemispherical surfaces.

The flow pattern of impinging jets from single round nozzle or slot nozzle can be subdivided into four distinct flow regions : the region of flow establishment, the region of established flow, the stagnation region and the wall jet region. The salient features of the present investigations are :

iv

(i) To introduce theoretical techniques for predicting fluid flow and heat transfer parameters in the stagnation region in case of a slot jet impinging on a concave semicylindrical surface and a round jet impinging on a concave hemispherical surface, and to develop expressions for the estimation of the said parameters at the stagnation point for both the cases under consideration.

(ii) To study the cases of a cylinder and a sphere in unlimited laminar parallel flow by applying the methods as applied to impinging jets.

(iii) To employ finite element technique to establish the potential flow field and the shape of the free surface boundary in jet efflux and jet impingement problems and to evaluate velocity and pressure distribution along the streamlines following the jet central axis and the impingement surface (flat or semicylindrical).

(iv) To experimentally determine the static pressure distribution on the impingement surface for the case of a slot jet impinging on a concave semicylindrical surface and a single round jet impinging on a concave hemispherical surface.

(v) To determine experimentally the average heat transfer rates when a slot jet, a single-row of round jets and a triple-row of round jets impinge onto a concave semicylindrical surface and when a single round jet impinges onto a concave hemispherical surface.

(vi) To express Nusselt number as a function of Reynolds number, Prandtl number and some nondimensional geometrical parameters for each case described in (v).

The thesis consists of six Chapters. Chapter I and II devoted to the introduction and review of literature, respectively.

Chapter III deals with the theoretical analysis of fluid flow and heat transfer by impinging jets on to curved surfaces. Theoretical analysis is made for the stagnation region formed by the impinging jet. The stagnation region is treated to contain two layers: an inner region corresponding to the conventional boundary layer and an outer one resembling a turbulent free jet. The external flow field is described by use of well established free jet theory and the inner flow or wall boundary layer behaviour is described by the standard boundary layer methods. Because of the strong favourable pressure gradient in the stagnation region where the flow is turning, the inner layer behaviour in this region can be analysed as a laminar boundary layer.

Two theoretical models in impinging jet are considered : (a) A slot jet impinging onto a concave semicylindrical surface and (b) A round jet impinging onto a concave hemispherical surface. The stagnation region wall boundary layer behaviour is described by use of Walz's modification of the Karman-Pohlhausen integral method [85] for the case (a), whereas for the case (b) the method adopted is based on the work of Scholkemeier [85] as applied to the bodies of revolution. In both the cases (a) and (b) the thermal boundary layer behaviour and hence the heat transfer is solved using the integral method of Squire [85]. Expressions have been developed for estimation of boundary layer parameters and heat transfer parameters at the stagnation point for both cases (a) and (b) by using free jet quantities as well as the jet exit quantities.

This Chapter also includes, as a case study, the problem of a cylinder in unlimited laminar parallel flow and that of a sphere

vi

in unlimited laminar parallel flow for the estimation of fluid flow and heat transfer parameters.

The finite element technique based on variational principle and employing velocity potential approach is presented in Chapter IV to solve three different two-dimensional problems. Methods as outlined by Chan and Larock 12 have been extended to take care of both jet efflux and jet impingement problems. The problem of flow around a cylinder between parallel walls is solved for developing and checking the finite element programme which will be finally used for solving problems involving free surfaces. The effect of cylinder size w.r.t. wall spacing is analysed in detail. The finite element programme is used to analyse problems of slot jet efflux with free surface flows and slot jet impinging on either a flat surface or a semicylindrical surface. The location of the initially unknown free surfaces are determined by use of an iterative procedure that satisfied the conditions that the pressure on the free surface be constant, i.e., the free surfaces are streamlines of constant velocity. Initia-11y, the location of the free surface is judiciously selected and the velocity components at each free surface node are calculated. Then the free surface location is adjusted by curve fitting techni-The computation cycle is repeated until a prescribed error crique. terion is satisfied such that the normal velocity on the free surface is almost zero. After establishing the convergence through the above iterative procedures, the velocity and pressure distribution have been evaluated along the streamline following the jet central axis and the impingement surface.

Chapter V deals with the experimental investigations.

Pressure distribution measurements along the impingement surface are made for the cases when a slot jet impinges onto a concave semicylindrical surface and a single round jet impinges onto a concave hemispherical surface. The measured pressure distribution is used to calculate the maximum velocity variation at the edge of the inner boundary layer in the stagnation region. Detailed derivation relating maximum velocity variation at the edge of the inner boundary layer in the stagnation region to the pressure distribution on the impingement surface with the without considering the viscous effects caused by mising with the ambient are made in the theoretical analysis for the said two cases.

Since the average heat transfer coefficient is more practical and useful in engineering applications, it is desired to find out its variation with different geometrical parameters, flow rates and nozzle to heat transfer surface separation when a slot jet, a singlerow of round jets, and a triple-row of round jets impinge onto a concave semicylindrical surface and a single round jet impinges onto a concave hemispherical surface. Separate methods are described for the estimation of insulation losses and radiation losses from the heat transfer surfaces. Finally, the functional form of dependence of Nusselt number on Reynolds number, Prandtl number and some nondimensional geometrical parameters are derived using the method of dimensional analysis; and the experimental observations are correlated to find out useful correlations for each case of nozzle and surface combinations.

The conclusions based on the results of the present study and a brief description of the scope for further work are provided in Chapter VI.

vili

Appendices intended to serve as supplements to certain topics in the thesis are provided at the end along with a list of references arranged in alphabetical sequence.