

Chapter 2

Natural Convective Heat Transfer from Narrow Vertical Plates

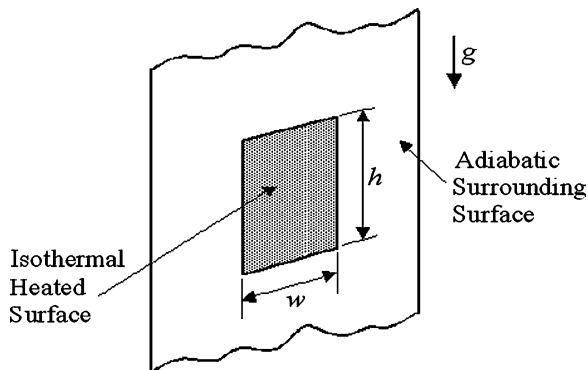
Keywords Natural convection • Narrow plates • Vertical plates • Isothermal plates • Uniform surface heat flux • Numerical • Empirical equations

2.1 Introduction

As discussed in the preceding chapter, two-dimensional natural convective heat transfer from wide vertical plates has been extensively studied and many equations for predicting the mean and local heat transfer rates from such plates have been derived. However, when the width of the plate is relatively small compared to its height, i.e., when the plate is narrow, the heat transfer rate can be considerably greater than that predicted by these wide plate equations. As explained in [Chap. 1](#), the increase in the heat transfer rate from a narrow plate relative to that from a wide plate under the same conditions results from the fact that fluid flow is induced inwards near the edges of the plate and the flow near the edge of the plate is, thus, three-dimensional. With a wide plate the effects of this edge flow are negligible but with a narrow plate these effects can be very significant. The increase in the heat transfer rate is often, therefore, said to be due to “three-dimensional edge effects” or just “edge effects”. Situations that can be approximately modeled as narrow vertical plates occur in a number of practical situations, so there exists a need to be able to predict heat transfer rates from such narrow plates.

In the present chapter, numerically determined natural convective heat transfer rates from narrow vertical plates for a relatively wide range of dimensionless plate widths will be discussed. Attention has here been restricted to plates having a uniform surface temperature and to plates having a uniform surface heat flux. Results will be presented for a Prandtl number of 0.7, this being approximately the value for air at ambient conditions and the results thus apply to the conditions existing in many applications in which the present results are relevant.

Fig. 2.1 Flow situation considered



Previous studies of natural convective heat transfer from narrow vertical plates were discussed in [Chap. 1](#). The work described in this chapter is based on the studies reported by Oosthuizen and Paul [1, 2].

2.2 Isothermal Plates

Attention will first be given to the case where the surface of the plate is at a uniform temperature, i.e., where the plate is isothermal. The flow situation considered is shown in [Fig. 2.1](#). The vertical isothermal plate, as shown in this figure, is surrounded by an adiabatic surface in the same plane as the heated plate. The width of the plate, w , is assumed to be less than the vertical height of the plate, h .

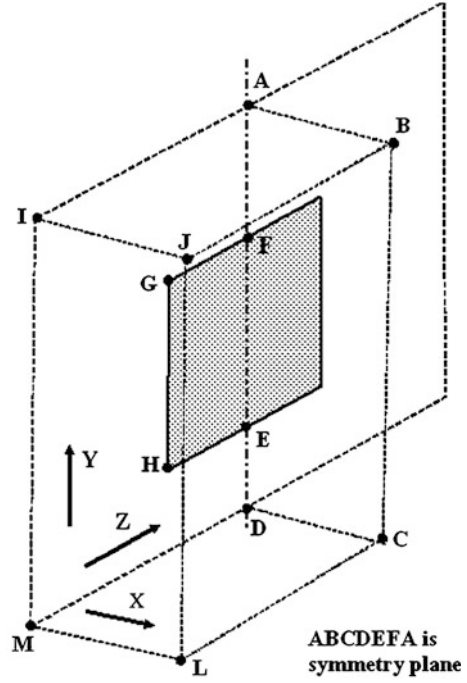
2.2.1 Solution Procedure

In obtaining the results discussed here, the flow has been assumed to be laminar and it has been assumed that the fluid properties are constant except for the density change with temperature which gives rise to the buoyancy forces, this having been treated by using the Boussinesq approach. It has also been assumed that the flow is symmetric about the vertical center-plane of the plate. The solution has been obtained by numerically solving the full three-dimensional form of the governing equations, these equations being written in terms of dimensionless variables using the height, h , of the heated plate as the length scale and the overall temperature difference ($T_H - T_F$) as the temperature scale, T_F being the fluid temperature far from the plate, and T_H being the uniform surface temperature of the plate.

Defining the following reference velocity:

$$u_r = \frac{\alpha}{h} \sqrt{RaPr} \quad (2.1)$$

Fig. 2.2 Solution domain
ABCDEFGHIJM



where Pr is the Prandtl number and Ra is the Rayleigh number based on h , i.e.,:

$$Ra = \frac{\beta g (T_H - T_F) h^3}{\nu \alpha} \quad (2.2)$$

the following dimensionless variables have then been defined:

$$\begin{aligned} X &= \frac{x}{h}, \quad Y = \frac{y}{h}, \quad Z = \frac{z}{h}, \quad U_X = \frac{u_x}{u_r}, \quad U_Y = \frac{u_y}{u_r}, \\ U_Z &= \frac{u_z}{u_r}, \quad P = \frac{(p - p_F)h}{\mu u_r}, \quad \theta = \frac{T - T_F}{T_H - T_F} \end{aligned} \quad (2.3)$$

where T is the temperature. The X -coordinate is measured in the horizontal direction normal to the plate, the Y -coordinate is measured in the vertically upward direction and the Z -coordinate is measured in the horizontal direction in the plane of plate as shown in Fig. 2.2.

In terms of these dimensionless variables, the governing equations are:

$$\frac{\partial U_X}{\partial X} + \frac{\partial U_Y}{\partial Y} + \frac{\partial U_Z}{\partial Z} = 0 \quad (2.4)$$

$$U_X \frac{\partial U_X}{\partial X} + U_Y \frac{\partial U_X}{\partial Y} + U_Z \frac{\partial U_X}{\partial Z} = \sqrt{\frac{Pr}{Ra}} \left(-\frac{\partial P}{\partial X} + \frac{\partial^2 U_X}{\partial X^2} + \frac{\partial^2 U_X}{\partial Y^2} + \frac{\partial^2 U_X}{\partial Z^2} \right) \quad (2.5)$$

$$U_X \frac{\partial U_Y}{\partial X} + U_Y \frac{\partial U_Y}{\partial X} + U_Z \frac{\partial U_Y}{\partial X} = \sqrt{\frac{Pr}{Ra}} \left(-\frac{\partial P}{\partial Y} + \frac{\partial^2 U_Y}{\partial X^2} + \frac{\partial^2 U_Y}{\partial Y^2} + \frac{\partial^2 U_Y}{\partial Z^2} \right) + T \quad (2.6)$$

$$U_X \frac{\partial U_Z}{\partial X} + U_Y \frac{\partial U_Z}{\partial Y} + U_Z \frac{\partial U_Z}{\partial Z} = \sqrt{\frac{Pr}{Ra}} \left(-\frac{\partial P}{\partial Z} + \frac{\partial^2 U_Z}{\partial X^2} + \frac{\partial^2 U_Z}{\partial Y^2} + \frac{\partial^2 U_Z}{\partial Z^2} \right) \quad (2.7)$$

$$U_X \frac{\partial \theta}{\partial X} + U_Y \frac{\partial \theta}{\partial Y} + U_Z \frac{\partial \theta}{\partial Z} = \frac{1}{\sqrt{RaPr}} \left(\frac{\partial^2 \theta}{\partial X^2} + \frac{\partial^2 \theta}{\partial Y^2} + \frac{\partial^2 \theta}{\partial Z^2} \right) \quad (2.8)$$

Because the flow has been assumed to be symmetric about the vertical center-line of the plate the solution domain used in obtaining the solution is as shown in Fig. 2.2. Considering the surfaces shown in Fig. 2.2, the assumed boundary conditions on the solution in terms of the dimensionless variables are, since flow symmetry is being assumed:

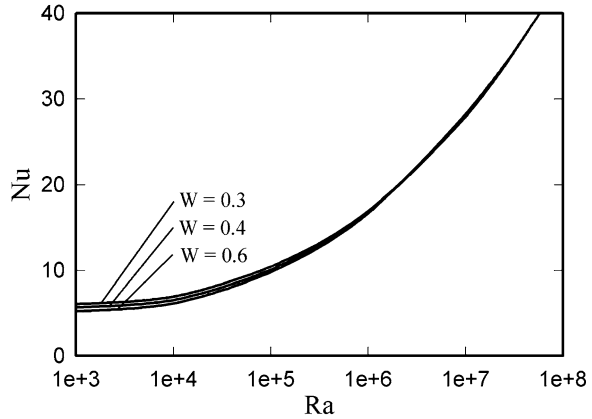
$$\begin{aligned} \text{FEHG:} \quad & U_X = 0, U_Y = 0, U_Z = 0, \theta = 1 \\ \text{AFEDMI except for FEHG:} \quad & U_X = 0, U_Y = 0, U_Z = 0, \frac{\partial \theta}{\partial X} = 0 \\ \text{IJLM:} \quad & U_Y = 0, U_X = 0, \theta = 0 \\ \text{DCLM:} \quad & U_X = 0, U_Z = 0, \theta = 0 \\ \text{BCLJ:} \quad & U_Y = 0, U_Z = 0, \theta = 0 \\ \text{ABCDEF:} \quad & U_Z = 0, \frac{\partial U_Y}{\partial Z} = 0, \frac{\partial U_X}{\partial Z} = 0, \frac{\partial \theta}{\partial Z} = 0 \end{aligned}$$

The mean heat transfer rate from the heated plate has been expressed in terms of the following mean Nusselt number:

$$Nu = \frac{\bar{q}'}{k(T_H - T_F)} \quad (2.9)$$

The above dimensionless governing equations subject to the boundary conditions listed above have been numerically solved using the commercial CFD solver FLUENT[®]. Extensive grid and convergence criterion independence testing was undertaken. This indicated that the heat transfer results presented here are to within 1 % independent of the number of grid points and of the convergence criterion used. The effect of the positioning of the outer surfaces of the solution domain (i.e., surfaces MLCD, IJBA, IJLM, and BCLJ in Fig. 2.2) from the heated surface

Fig. 2.3 Typical variations of mean Nusselt number with Rayleigh number for various W values



was also examined and the positions used in obtaining the results discussed here were chosen to ensure that the heat transfer results were independent of this positioning to within 1 %.

2.2.2 Results

The solution has the following parameters:

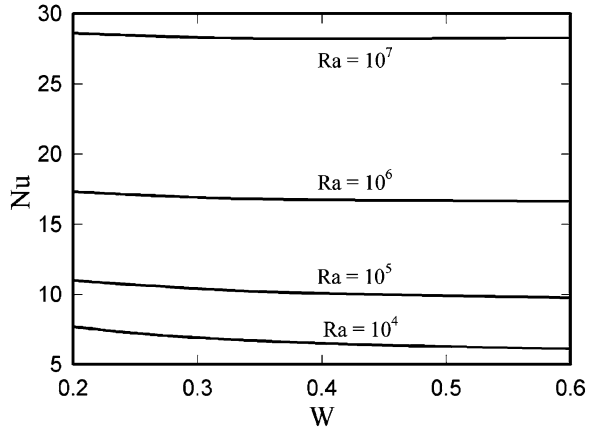
1. The Rayleigh number, Ra , based on the plate height, h , and the overall temperature difference between the plate temperature and the fluid temperature.
2. The dimensionless plate width, $W = w/h$.
3. The Prandtl number, Pr .

As previously mentioned, results have been obtained only for $Pr = 0.7$. Ra values between 10^2 and 10^8 and W values between 0.2 and 0.6 have been considered. Attention has therefore been restricted to laminar flow over the plates. The effect of the development of turbulent flow will be discussed in a later chapter.

Typical variations of the mean Nusselt number for the plate with Rayleigh number for various dimensionless plate widths are shown in Fig. 2.3. It will be seen from these results, particularly at the lower Rayleigh numbers, that the mean Nusselt number tends to increase with decreasing W . This is further illustrated by the results shown in Fig. 2.4. It will be seen from the results in Fig. 2.4 that for $Ra = 10^4$, the mean Nusselt increases by approximately 25 % as W decreases from 0.6 to 0.2. For $Ra = 10^7$, however, the increase is less than 2 %.

As mentioned previously, the increase in the Nusselt number with decreasing W arises from the fact that there is an induced inflow toward the plate from the sides and this causes the heat transfer rate to be higher near the vertical edges of the plate than it is in the center region of the plate. This edge effect is illustrated by the results given in Figs. 2.5 and 2.6 which show the local heat transfer rate

Fig. 2.4 Typical variations of mean Nusselt number with W for various Rayleigh number values



distributions over the plate surface. The results given in these two figures illustrate how the edge effect grows more significant as W is decreased and how the extent of the edge regions increases compared to the overall plate area. Since the extent of the edge region will also be a function of the boundary layer thickness which increases as the Rayleigh number decreases, the importance of the edge effect increases as the Rayleigh number decreases.

In order to obtain an approximate equation for the Nusselt number for narrow plates, it has been assumed that for wide plates, i.e., for situations in which the edge effects are negligible, Nu is approximately given by the widely used Churchill and Chu correlation [3], that is by:

$$Nu_0 = 0.68 + \left\{ \frac{0.67}{\left[1 + (0.492/Pr)^{9/16} \right]^{4/9}} \right\} Ra^{0.25} \quad (2.10)$$

the subscript 0 indicating that this value of the Nusselt number applies to a wide plate. This equation gives for $Pr = 0.7$:

$$Nu_0 = 0.68 + 0.513Ra^{0.25} \quad (2.11)$$

A comparison between the results given by this equation and the numerical results for $W = 0.6$ at the higher Rayleigh numbers considered is shown in Fig. 2.7. It will be seen from Fig. 2.7 that there is good agreement between the numerical results and the correlation equation for Rayleigh numbers above 10^4 . At the lower Rayleigh numbers, the numerical results are higher than the correlation equation results due to edge effects.

Because of the assumed form of the variation of Nu when edge effects are negligible, it has been assumed that the Nusselt number for a plate of dimensionless width W is given by an equation of the form:

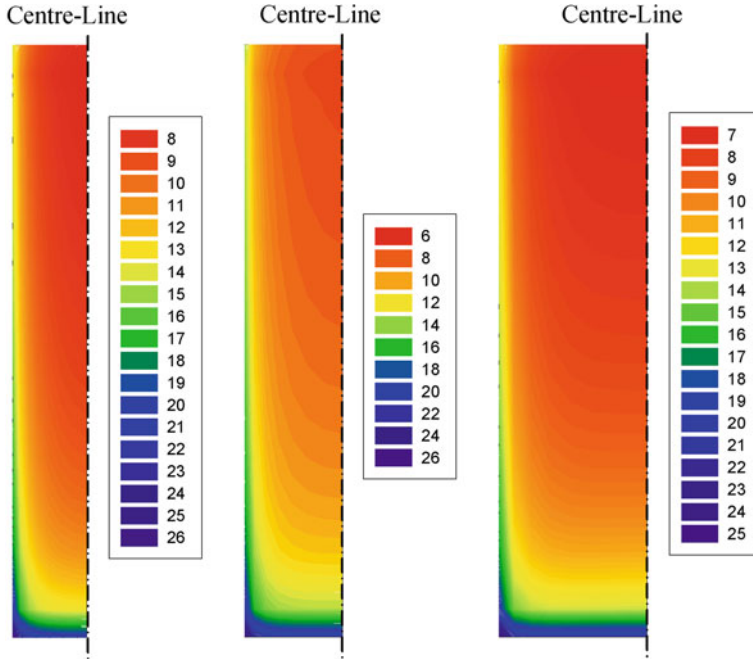


Fig. 2.5 Local Nusselt number (based on h) distributions over plate for $Ra = 10^5$ for $W = 0.25$ (left), 0.35 (center) and 0.5 (right)

$$\frac{Nu}{Ra^{0.25}} = \frac{Nu_0}{Ra^{0.25}} + \text{function}(Ra, W) \quad (2.12)$$

The function of Ra and W was determined from the numerical results. It was found that the edge effects are dependent on the value of $WRa^{0.5}$ and that the heat transfer results obtained numerically can be approximately described by:

$$\frac{Nu}{Ra^{0.25}} = \frac{Nu_0}{Ra^{0.25}} + \frac{7.1}{(WRa^{0.5})^{1.25}} \quad (2.13)$$

A comparison of the results given by this equation and some of the numerical results is shown in Fig. 2.8. It will be seen that the equation describes 95 % of the computed results to an accuracy of better than approximately 5 %.

If three-dimensional effects (i.e., edge effects) are assumed to be negligible when:

$$\frac{Nu/Ra^{0.25} - Nu_0/Ra^{0.25}}{Nu_0/Ra^{0.25}} < 0.01 \quad (2.14)$$

then, since $Nu_0/Ra^{0.25}$ is approximately equal to 0.5, the above equation gives the following approximate criterion for when three-dimensional edge effects are negligible:

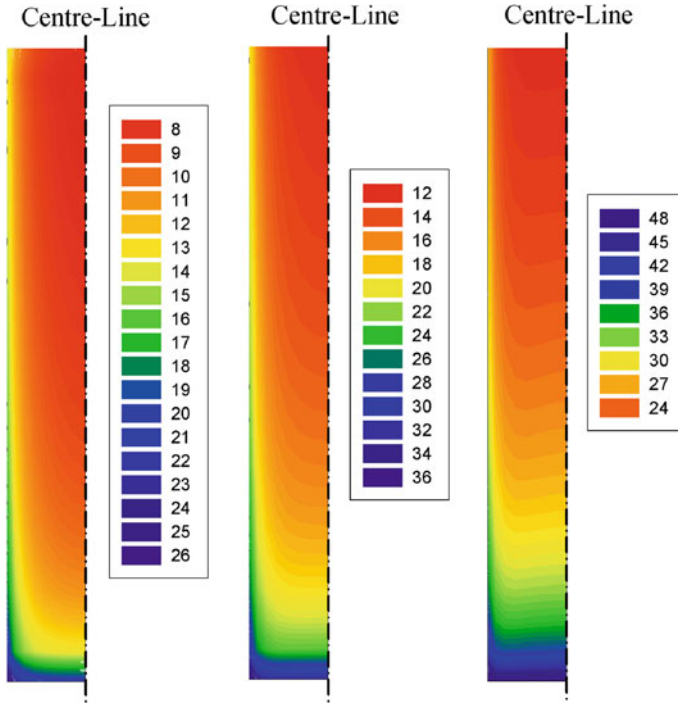
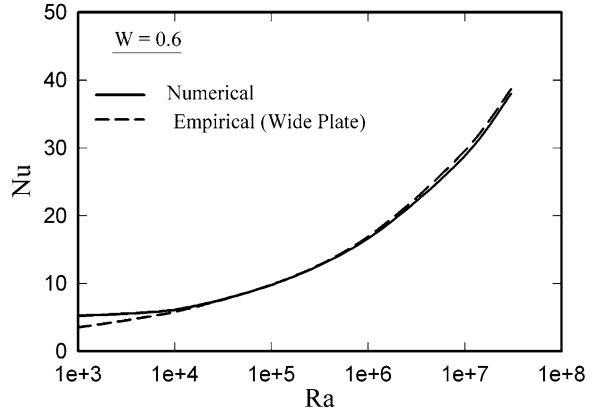


Fig. 2.6 Local Nusselt number (based on h) distributions over plate for $W = 0.25$ for $Ra = 10^5$ (left), $Ra = 10^6$ (center) and $Ra = 10^7$ (right)

Fig. 2.7 Comparison between numerical results for $W = 0.6$ and the Churchill and Chu correlation equation for wide vertical plates



$$\frac{Nu}{Ra^{0.25}} - \frac{Nu_0}{Ra^{0.25}} < 0.005 \quad (2.15)$$

Fig. 2.8 Comparison of correlation for narrow plates with numerical results

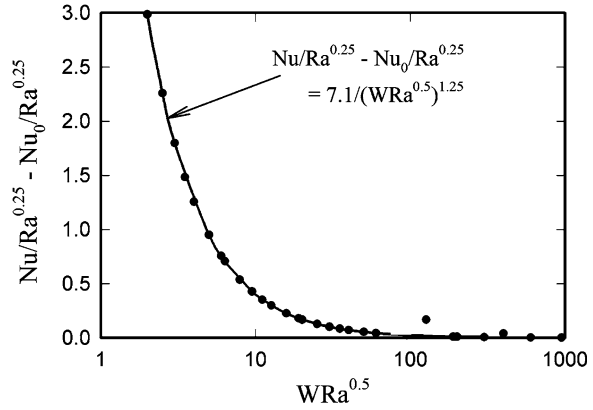
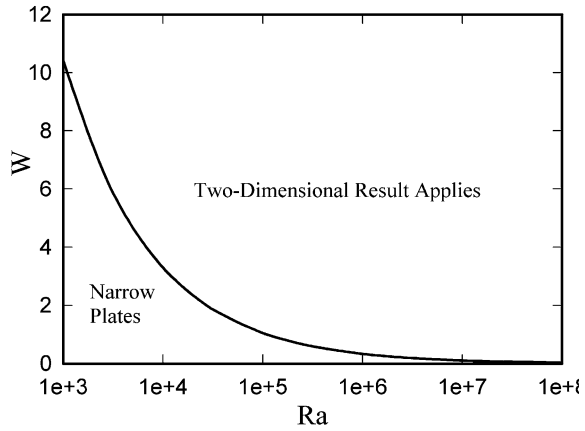


Fig. 2.9 Variation of W value above which edge effects are negligible with Ra



i.e., using Eq. 2.13 when:

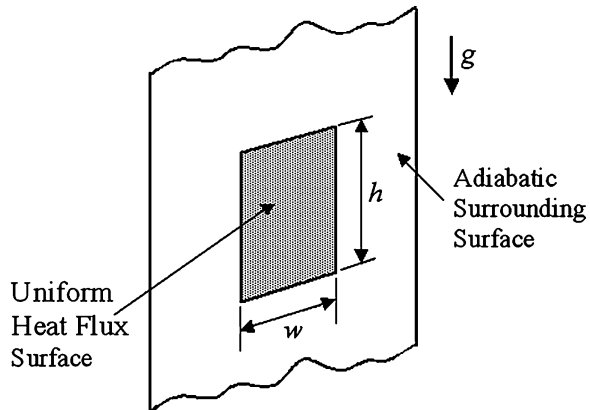
$$\frac{7.1}{(WRa^{0.5})^{1.25}} < 0.005, \quad \text{i.e.,} \quad WRa^{0.5} > 330, \quad \text{i.e.,} \quad W > \frac{330}{Ra^{0.5}} \quad (2.16)$$

Using this result, the variation of the value of W above which three-dimensional edge effects on Nu are negligible (to within approximately 1 %) with Ra can be determined and is shown in Fig. 2.9.

2.2.3 Concluding Remarks

The dimensionless plate width has been shown to have a significant influence on the mean Nusselt number for natural convective heat transfer from a vertical isothermal flat plate. This effect has been shown to increase with decreasing

Fig. 2.10 Flow situation considered



Rayleigh number. The following empirical equation for the mean heat transfer rate from narrow plates has been derived from the numerical results.

$$\frac{Nu}{Ra^{0.25}} = \frac{Nu_0}{Ra^{0.25}} + \frac{7.1}{(WRa^{0.5})^{1.25}}$$

where Nu_0 is the Nusselt number that would occur with a wide plate under the same conditions, its value being given by Eq. 2.11. The above correlation equation indicates that three-dimensional edge effects will be negligible if:

$$W > \frac{330}{Ra^{0.5}}$$

2.3 Plates with a Uniform Surface Heat Flux

Attention will next be given to the case where the plate has a uniform heat flux over its surface. The flow situation considered is shown in Fig. 2.10. The vertical plate is, as shown in this figure, again surrounded by an adiabatic surface in the same plane as the heated plate. The width of the plate, w , is again assumed to be less than the vertical height of the plate, h .

2.3.1 Solution Procedure

The same basic assumptions that were used in dealing with the isothermal plate have been adopted, i.e., the flow has again been assumed to be steady and laminar and it has again been assumed that the fluid properties are constant except for the density change with temperature which gives rise to the buoyancy forces, this having been treated by using the Boussinesq approach. It has also been assumed that the flow is symmetric about the vertical center-plane of the plate and the

solution has again been obtained by numerically solving the full three-dimensional form of the governing equations, these equations being written in terms of dimensionless variables using the height, h , of the heated plate as the length scale and $q'_w h/k$ as the temperature scale. Defining the following reference velocity:

$$u_r = \frac{\alpha}{h} \sqrt{Ra^* Pr} \quad (2.17)$$

where Pr is the Prandtl number and Ra^* is the heat flux Rayleigh number based on h , i.e.,:

$$Ra^* = \frac{\beta g q'_w h^4}{k \nu \alpha} \quad (2.18)$$

the following dimensionless variables have then been introduced:

$$\begin{aligned} X &= \frac{x}{h}, \quad Y = \frac{y}{h}, \quad Z = \frac{z}{h}, \quad U_X = \frac{u_x}{u_r}, \quad U_Y = \frac{u_y}{u_r}, \\ U_Z &= \frac{u_z}{u_r}, \quad P = \frac{(p - p_F)h}{\mu u_r}, \quad \theta = \frac{T - T_F}{q'_w h/k} \end{aligned} \quad (2.19)$$

where T , is the temperature and T_F is the fluid temperature far from the plate. As with the isothermal plate, the X -coordinate is measured in the horizontal direction normal to the plate, the Y -coordinate is measured in the vertically upward direction and the Z -coordinate is measured in the horizontal direction in the plane of plate.

In terms of these dimensionless variables, the governing equations are:

$$\frac{\partial U_X}{\partial X} + \frac{\partial U_Y}{\partial Y} + \frac{\partial U_Z}{\partial Z} = 0 \quad (2.20)$$

$$U_X \frac{\partial U_X}{\partial X} + U_Y \frac{\partial U_X}{\partial Y} + U_Z \frac{\partial U_X}{\partial Z} = \sqrt{\frac{Pr}{Ra^*}} \left(-\frac{\partial P}{\partial X} + \frac{\partial^2 U_X}{\partial X^2} + \frac{\partial^2 U_X}{\partial Y^2} + \frac{\partial^2 U_X}{\partial Z^2} \right) \quad (2.21)$$

$$U_X \frac{\partial U_Y}{\partial X} + U_Y \frac{\partial U_Y}{\partial Y} + U_Z \frac{\partial U_Y}{\partial Z} = \sqrt{\frac{Pr}{Ra^*}} \left(-\frac{\partial P}{\partial Y} + \frac{\partial^2 U_Y}{\partial X^2} + \frac{\partial^2 U_Y}{\partial Y^2} + \frac{\partial^2 U_Y}{\partial Z^2} \right) + T \quad (2.22)$$

$$U_X \frac{\partial U_Z}{\partial X} + U_Y \frac{\partial U_Z}{\partial Y} + U_Z \frac{\partial U_Z}{\partial Z} = \sqrt{\frac{Pr}{Ra^*}} \left(-\frac{\partial P}{\partial Z} + \frac{\partial^2 U_Z}{\partial X^2} + \frac{\partial^2 U_Z}{\partial Y^2} + \frac{\partial^2 U_Z}{\partial Z^2} \right) \quad (2.23)$$

$$U_X \frac{\partial \theta}{\partial X} + U_Y \frac{\partial \theta}{\partial Y} + U_Z \frac{\partial \theta}{\partial Z} = \frac{1}{\sqrt{Ra^* Pr}} \left(\frac{\partial^2 \theta}{\partial X^2} + \frac{\partial^2 \theta}{\partial Y^2} + \frac{\partial^2 \theta}{\partial Z^2} \right) \quad (2.24)$$

Because the flow has been assumed to be symmetric about the vertical center-line of the plate the solution domain used in obtaining the solution is as shown in

Fig. 2.11 Solution domain
ABCDIJLM

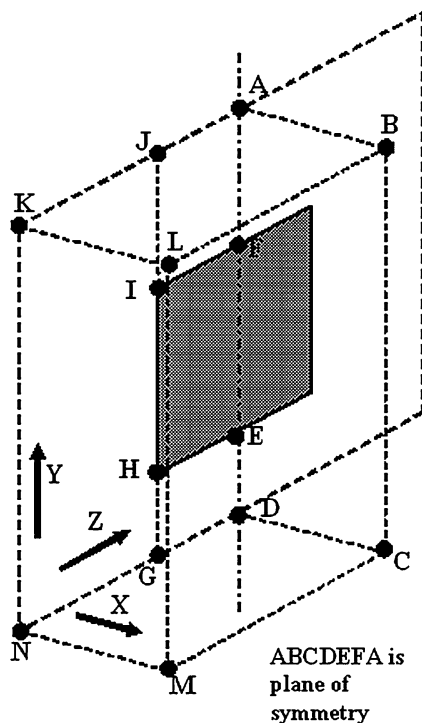


Fig. 2.11. Considering the surfaces shown in Fig. 2.11, the assumed boundary conditions on the solution in terms of the dimensionless variables are, since flow symmetry is being assumed:

$$\begin{aligned}
 \text{FEHIF: } & U_X = 0, U_Y = 0, U_Z = 0, \frac{\partial \theta}{\partial X} = -1 \\
 \text{AFEDGNKJA except for FEHIF: } & U_X = 0, U_Y = 0, U_Z = 0, \frac{\partial \theta}{\partial X} = 0 \\
 \text{KLMNK: } & U_Y = 0, U_X = 0, \theta = 0 \\
 \text{CMNDC: } & U_X = 0, U_Z = 0, \theta = 0 \\
 \text{BCMLB: } & U_Y = 0, U_Z = 0, \theta = 0 \\
 \text{ABCDEFA: } & U_Z = 0, \frac{\partial U_Y}{\partial Z} = 0, \frac{\partial U_X}{\partial Z} = 0, \frac{\partial \theta}{\partial Z} = 0
 \end{aligned}$$

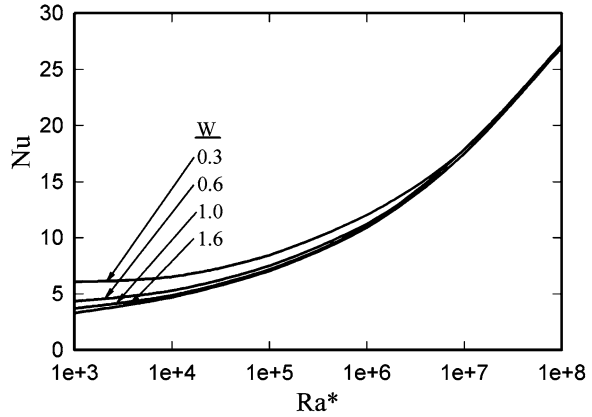
The mean Nusselt number for the heated plate is defined by:

$$Nu = \frac{q'_w h}{k(\bar{T}_H - T_F)} \quad (2.25)$$

where $\bar{T}_H$ is the mean surface temperature of the plate.

The above dimensionless governing equations subject to the boundary conditions listed above have been numerically solved using a commercial CFD code. Extensive grid and convergence criterion independence testing was again

Fig. 2.12 Typical variations of mean Nusselt number with Rayleigh number for various W values



undertaken. This indicated that the heat transfer results presented here are to within 1 % independent of the number of grid points used and of the convergence criterion used. The effect of the positioning of the outer surfaces of the solution domain (i.e., surfaces MLCD, IJBA, IJLM, and BCLJ in Fig. 2.11) from the heated surface was also examined and the positions used in obtaining the results discussed here were again chosen to ensure that the heat transfer results were independent of this positioning to within 1 %.

2.3.2 Results

The solution has the following parameters:

1. The heat flux Rayleigh number, Ra^* ,
2. The dimensionless plate width, $W = w/h$.
3. The Prandtl number, Pr .

As already mentioned, results have again only been obtained for $Pr = 0.7$. Ra values between 10^2 and 10^8 and W values between 0.2 and 1.6 have been considered.

Typical variations of the mean Nusselt number for the plate with Rayleigh number for various dimensionless plate widths are shown in Fig. 2.12. It will be seen from these results that, particularly at the lower Rayleigh numbers, the mean Nusselt number tends to increase with decreasing W . This is further illustrated by the results shown in Fig. 2.13. In this figure, it has been noted that with two-dimensional flow over a wide vertical plate that has a uniform heat flux over its surface:

$$\frac{Nu}{Ra^{*0.2}} = \text{function}(Pr) \quad (2.26)$$

Fig. 2.13 Typical variations of $Nu/Ra^{*0.2}$ with W for various Rayleigh number values

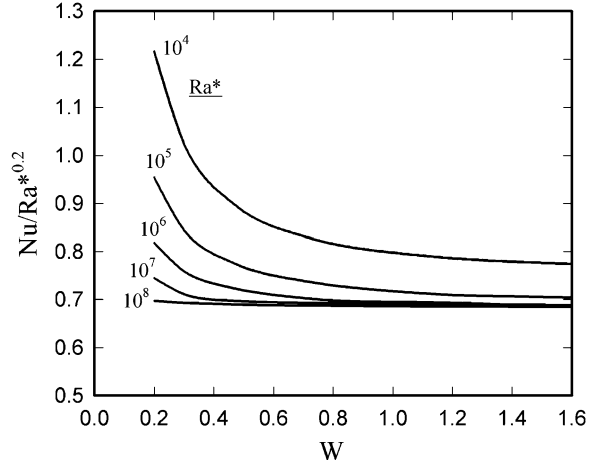


Figure 2.13 therefore shows the variation of $Nu/Ra^{*0.2}$ with the dimensionless plate width, W , for various values of Ra^* . It will be seen that at the larger values of W and Ra^* the quantity $Nu/Ra^{*0.2}$ does tend to a constant value of approximately 0.68 which is the value given by the similarity solution for two-dimensional flow over a wide plate with a uniform heat flux at the surface for a Prandtl number of 0.7, e.g., see Kakac and Yener [4]. It will also be seen from Fig. 2.13 that, at the lowest values of W and Ra^* considered, the value of $Nu/Ra^{*0.2}$ is more than 70 % above the two-dimensional flow value. However, at the highest value of Ra^* considered the two-dimensional value applies at W values down to about 0.3. As mentioned before, the increase in the Nusselt number with decreasing W arises from the fact that there is an induced inflow toward near the edges of the plate which causes the heat transfer rate to be higher near the vertical edges of the plate than it is in the center region of the plate.

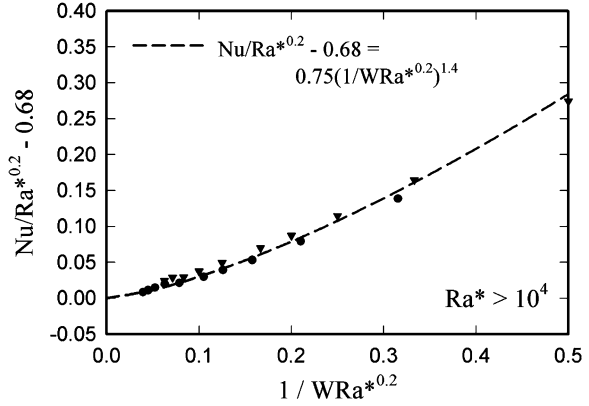
In order to obtain an approximate equation for the Nusselt number for narrow plates with a uniform surface heat flux, it has been assumed that for wide plates, i.e., for situations in which the edge effects are negligible, Nu is given for $Pr = 0.7$, by the following equation (see, for example, Kakac and Yener [4]):

$$Nu = 0.68 Ra^{*0.2} \quad (2.27)$$

As discussed above, Fig. 2.13 shows that this equation gives results that are in good agreement with the present numerical results at the larger values of W and Ra^* considered. Because of this assumed form of the variation of Nu with Ra^* when edge effects are negligible, it has been assumed that the Nusselt number for a plate of arbitrary dimensionless width W is given by an equation of the form:

$$\frac{Nu}{Ra^{*0.2}} = 0.68 + \text{function}(Ra^*, W) \quad (2.28)$$

Fig. 2.14 Comparison of correlation equation for narrow plates with numerical results



The function of Ra^* and W was determined from the numerical results which indicated that the Nusselt number results obtained numerically could be approximately described by:

$$\frac{Nu}{Ra^{*0.2}} = 0.68 + \frac{0.75}{(WRa^{*0.2})^{1.4}} \quad (2.29)$$

A comparison of the results given by this equation and the numerical results is shown in Fig. 2.14. The quantity $WRa^{*0.2}$ is basically a measure of the ratio of the plate width to the boundary layer thickness. When this ratio is large, the extent of the plate area that is affected by three-dimensional effects is small and three-dimensional flow (edge) effects are negligible.

If three-dimensional effects (i.e., edge effects) are assumed to be negligible if:

$$\frac{Nu/Ra^{*0.2} - Nu_0/Ra^{*0.2}}{Nu_0/Ra^{*0.2}} = \frac{Nu/Ra^{*0.2} - 0.68}{0.68} < 0.02 \quad (2.30)$$

then the above equation gives the following approximate criterion of when three-dimensional effects are negligible:

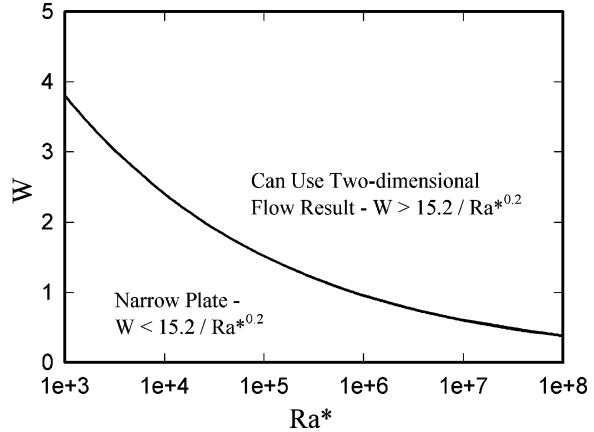
$$\frac{Nu}{Ra^{*0.2}} - 0.68 < 0.014 \quad (2.31)$$

i.e., using Eq. 2.5:

$$\frac{0.75}{(WRa^{*0.2})^{1.4}} < 0.014, \quad \text{i.e.,} \quad WRa^{*0.2} > 15.2, \quad \text{i.e.,} \quad W > \frac{15.2}{Ra^{*0.2}} \quad (2.32)$$

Using this result, the variation of the value of W above which three-dimensional edge effects on Nu are negligible (to within approximately 2 %) with Ra^* can be determined and is shown in Fig. 2.15.

Fig. 2.15 Variation of W value above which edge effects are negligible with Ra



2.3.3 Conclusions

The dimensionless plate width has been shown to also have a significant influence on the mean Nusselt number for natural convective heat transfer from a vertical flat plate with a uniform heat flux at the surface. This effect has been shown to increase with decreasing dimensionless plate width and decreasing Rayleigh number. The following empirical equation for the mean heat transfer rate from narrow plates has been derived from the numerical results:

$$\frac{Nu}{Ra^{*0.2}} = 0.68 + \frac{0.75}{(WRa^{*0.2})^{1.4}}$$

This equation indicates that three-dimensional effects will be negligible if:

$$W > \frac{15.2}{Ra^{*0.2}}$$

References

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Oosthuizen, P.H.; Alkandari, M.

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