Numerical Investigation of Natural Convection Heat Transfer from a Cylinder in a Vented Enclosure

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Abstract

In this work, Natural convection heat transfer from a horizontal cylinder placed in a vented enclosure was investigated numerically to infer the effect of Rayleigh number (Ra) having the values $1*10^4$, $5*10^4$ and $1*10^5$, the effect of the ratio of the enclosure width to the cylinder diameter (W/D) having the values **1.5, 1.75, 2, 2.25, 2.5, 2.75, 3 and 3.5**, the effect of the ratio of the vent size to the enclosure width (O/W) for a range starting from 0 for a closed enclosure to 1 for an enclosure having two vertical walls only, and the effect of time variation, on the Nusselt number (Nu), the mass flow-rate, the flow and temperature patterns as well as the boundary layers, where the results showed that, Nu. number always increased with Ra. Number. Furthermore, Nu. number increased with the increase of the ratio W/D for ratios of O/W greater than 0.25, and Nu. number decreases with the increase of W/D for the range below this value.

Keywords : Convection , Enclosures , Cylinders Heat Transfer

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ĿơǘʅǆǆǄ!ƒ lƥǄǅƨ ǏǐƵ ƥǆǆǅƶ ǄǆǅnjǄ!Ăƒ Ü[1] LJǑƉƥƕǆǅƕ ƉƾƾƼ ĿǑl5Ǖƒ ƘǄLjƒĂƱʅǕƒ LJǆǅ lƧƒƧơ!ƒ ýǄlƙLjƒ lƥǄǅƨ LJƒ lƧƒƧùơ!ƒ ýǄlƙLjƒ ýƥƶǆǅ lƥǄǅƨ ƽǑƧƱ LJƵ ƧƤǛƒĂ (ƨLjǄƶƨ!ƒ ýǆǅƵ ƉƥƕǆǅǑ5 ǄǆǅǂǂǄ) ǐƧƒƧơ!ƒ ƩǄǆǅƙǂ! ĿǑơƱʅ!ƒ ǑηƧǄƤ ƧƥʅǆǅƽǑƧƱ LJƵ ǄǆǅƒlƥǄǅƨ!ƒ ljƦNj ƉƾƾĂ ÜĿLjƒĂƱʅǕǄƕ ƱǑơǆǅ!ƒ ƴƒǄǆǅ!ƒ ǂǂƧơ ĿƵƧʅ lƥǄǅƨ ýǖƤ LJǆǅ Ɖʅùl ljǑĂ .Ǒùƶǆǅʅ!ƒ ýǆǅơ!ƒ ƘǕǄơ Ǒ5 LJǄǑƧη!ƒ ýǂT ƧǑƺƼ ƽǑƧƱ LJƵ Ăƒ ǐƧʅl!ƒ ýǆǅơ!ƒ ƘǕǄơ Ǒ5 ǄǆǅǂǂǄ ýǆǅơ ǄǆǅƒĂnj5 Ü[2] lƧƒƧơ!ƒ LJƒƥl5 ĿǑǆǅƵ ƝǑ5 ăƧηƙ ǐƦ!ƒ ǑʅƥLjnj!ƒ ýǂT!ƒ Ɣʅơ LJǑǆǅʅƥ Ǐ!ƒ Ǒƶǆǅƕ!ƒ ýǆǅơ!ƒ ĂùƝĂ ÜƘǄùƺǆǅ!ƒ ýƤƒƥ ýǆǅơ Ăƒ .Ʊl5 ĂƺƱ!ƒ lĂl! ƥ!Ăǆǅ!ƒ ƠƱʅ!Ǆƕ lƧƒƧơ!ƒ ýǄlƙLjƒ ƧƛǆǅǑ ǂǑơ ƧơǑηƧǄƤ ĿùƱǑơǆǅ!ƒ ΘĂƱʅù!ƒĂ ƥù!Ăǆǅ!ƒ ƠƱʅ!ƒ ǏǐƵ ĿǆǅƤǄǆǅ!ƒ ƘǄlƕƱ!Ǆƕ lƧƒƧơ!ƒ ýǄlƙLjƒ ƧƛǆǅǑ ǂǑơ ƝlƕǄʅ LJǆǅ ƥlƵƒ .ăƧƤǕƒ

ǄnjǑƙƧĂƮùƕ LJǑƛơǄƕ!ƒ ýƕp LJǆǅ ƹƶʅƒĂ ƹǆǅǄǆǅƙNjƒ lƧơ!ƒ ĿLjƒĂƱʅǕƒ LJǆǅ lƧƒƧơ!ƒ ýǄlƙLjƒ ǂĂơƕ Ƙǐl!Ă ƒƦNj ýùǆǅơ!Ǆƕ lƧƒƧùơ!ƒ ýǄlƙLjƒ [3] ƝƙƵǄǆǅηĂ Clemes ǂơǄƕ!ƒ ƩƧƥ ÜĿǑǆǅƶ!ƒ ĿǑơǄLj!ƒ LJǆǅ5 .ĿǑƧƱLj!ƒĂ ĿǑǆǅƶ!ƒ LJƵ ƭƧƤƉ ƹƛơƕ [4] ƝƙƵǄǆǅηĂ Vilimpoc ƉƥƤ ǁ!ƦǂĂ .ĿƙƕǄƛ lƧƒƧơ ĿηƧƥ ƘƒƦ Ǒl5ƒ ĿLjƒĂƱʅƒ LJǆǅ Ǒƶǆǅƕ!ƒ ĿǆǅǄùT ĿùǑǆǅƵ ĿùʅƒƧƥ [5] A.Bejan ǂơǄƕ!ƒ ƯƧƵ ǄǆǅǂǂǄ .ƴƒǄǆǅƕ ĿƱǄơǆǅ ĿLjƒĂƱʅƒ LJǆǅ lƧƒƧơ!ƒ ýǄlƙLjƒ ǂùơǄƕ!ƒ ƉƥùƤ ƥùl5 ÜĿǑƧƱLj!ƒ ĿǑơǄLj!ƒ LJǆǅ Ǆǆǅƒ .ĿƱǑơǆǅ!ƒ ƴƒĂǆǅ!ƒ LJǆǅ ƳƒĂLjƒ lƥƵ ƹǆǅƥƤƙʅǆǅ lƧơ!ƒ ĿLjƒĂƱʅǖ! ăƥǆǅ LJǆǅƯ ƴƒǄǆǅƕ ĿƱǄơǆǅ ĿLjƒĂƱʅǕ Ǒƶǆǅƕ!ƒ ýǆǅơ!Ǆƕ lƧƒƧơ!ƒ ýǄlƙLjǕ ĿǑƥƥƵ ĿʅƒƧƥ [6] ƝƙƵǄǆǅηĂ Kuehn lƧƒƧơ!ƒ ýǄlƙLjǕ ĿǑƧƱLj ĿʅƒƧƥ [8] Ă [7] ƝƙƵǄǆǅηĂ Farouk ǂơǄƕ!ƒ ƉƥƤ ǁ!ƦǂĂ .Ʊl5 ǑơƒǄ5ƮƮ!ƒ LJǄǑƧη!ƒ ÜăƧùƤƒ lƧùǆǅ ƔƧƱƯùǆǅĂ lƧǆǅ ǑơƒǄ5ƮƮ LJǄǑƧη ĂƦ ƴƒǄǆǅƕ ĿƱǄơǆǅ Ǒl5ƒ ĿLjƒĂƱʅƒ LJǆǅ Ǒƶǆǅƕ!ƒ ýǆǅơ!Ǆƕ LJùǆǅ Ǒƶǆǅƕ!ƒ ýǆǅơ!Ǆƕ lƧƒƧơ!ƒ ýǄlƙLjǕ ĿǑǆǅƵ Ŀʅƒƥ [9] ƝƙƵǄǆǅηĂ Kuehn ǂơǄƕ!ƒ ƉƥƤ ĿnjƕǄTǆǅ lƧĂƮƕĂ Ʃù5Lj [10] ƝùƙƵǄǆǅηĂ Cho ǂùơǄƕ!ƒ ƉƥƤ ƹƧƱLjĂ .ƨǂƧǆǅ!ƒ ƱƤ ǄlƕǄƱƙǆǅ ƧǑƺĂ ƱƤ ǄlƕǄƱƙǆǅ LJǄƙLjƒĂƱʅƒ ýùǆǅơ!Ǆƕ lƧƒƧùơ!ƒ ýǄùlƙLjƒ [11] ƝƙƵǄǆǅηĂ Farouk ǂơǄƕ!ƒ ƩƧƥ ǁ!ƦǂĂ .ĿǑƥƥƵ lƧĂƮƕ LJǂ!Ă ĿʅƒƧƥ!ƒ .ƨǂƧǆǅ!ƒ ƱƤ ǄlƕǄƱƙǆǅ LJǄƙLjƒĂƱʅƒ LJǆǅ ƔƧƱƯǆǅ!ƒĂ ǑơƒǄ5ƮƮ!ƒ

ƴƒǄùǆǅǂ ƇƒĂùnj!ƒ ƘǆǅƥƤƙʅƒ ǑƙƘ ĿlƕǄʅ!ƒ ƘǄʅƒƧƥ!ƒ ýǂ LJǄ5 ÜƨǕƺƕ ĿƱǄơǆǅ ĿLjƒĂƱʅǕ! ĿƕʅLj!Ǆƕ Ǆǆǅƒ ýùǆǅơ!Ǆƕ lƧƒƧơ!ƒ ýǄlƙLjƒ [12] ƝƙƵǄǆǅηĂ Karim ǂơǄƕ!ƒ ƩƧƥ ǂǑơ ÜĿǑǆǅƵ ƘǄʅƒƧƥ ƘLjǄǂ ƨǕƺ!ƒ ǕǆǅƵ [13] ƝƙƵǄǆǅηĂ Sparrow ǂơǄƕ!ƒ ƉƥƤ ǄǆǅǂǂǄ .LJǑǑ!ĂƤǄT LJǑƧƒƥη LJǑƕ ĿƵĂƯĂǆǅ Ŀǆǅl5ƒ ĿLjƒĂƱʅƒ LJǆǅ Ǒƶǆǅƕ!ƒ ǂùơǄƕ!ƒ ƩƧƥ ǄǆǅǂǂǄ .LJǑ!ĂƨƶǆǅƵ LJǑƧƒƥη LJǑƕ ĿƵĂƯĂǆǅ Ŀǆǅl5ƒ ĿLjƒĂƱʅƒ LJǆǅ lƧƒƧơ!ƒ ýǄlƙLjƒ lƥǄǅƨ LJƵ ĿʅƒƧƥ ăĂùnjǆǅ ƨǕùƺ Ǒ5 ĿƵĂƯĂǆǅ Ŀǆǅl5ƒ ĿLjƒĂƱʅƒ LJǆǅ Ǒƶǆǅƕ!ƒ ýǆǅơ!Ǆƕ lƧƒƧơ!ƒ ýǄlƙLjƒ [14] ALMahroom ĿLjƒĂƱùʅƒ LJùǆǅ Ǒƶǆǅƕ!ƒ ýǆǅơ!Ǆƕ lƧƒƧơ!ƒ ýǄlƙLjƒ LJƵ ĿʅƒƧƥ [15] LJǄǆǅǑƒ ĿƛơǄƕ!ƒ ƘǆǅƥpĂ .ƘǄơƙ5!ƒ ƧƱǄljƙǆǅ .lƧƱǄljƙǆǅ ƧǑƺ ƘǄơƙ5 ǐƦ ăĂnjǆǅ ƨǕƺ Ǒ5 ĿƵĂƯĂǆǅ Ŀǆǅl5ƒ

ĿƶƕTùǆǅ ĿǑǆǅǄʅǆǅ ƱǄʅĂƾƕ lƇĂǆǅǆǅ ƹǆǅǄǆǅƙ ĿlǆǅƺǆǅƵ Ŀ5ǆǅƺƉ ǏǐƵ ǄnjƺǑǆǅη ƘǑƧƒ ƥl5 ĿǑƧƱLj!ƒ ƘǄʅƒƧƥ!ƒ ǄǆǅƉ ĿùƮǄƤ!ƒ Darcy-Oberbeck-Boussinesq ƘǕƥǄùƶǆǅ ýơ ƘƥǆǅƙƵƒ ǄnjƺǑǆǅηĂ ljǄǑǆǅ!ƒ LJǆǅ ĿlƕƱ ǄNjĂǆǅƶƙ HimasekharĂ [16] ƝùƙƵǄǆǅηĂ Farouk ǂùơǄƕ!ƒ LJùǆǅ ýùǂ Ŀùʅƒƥƥ Ǒù5 ǄǆǅǂǂǄ ÜĿǑǆǅǄʅǆǅ!ƒ ƱǄʅĂǖ! .[18] ƝƙƵǄǆǅηĂ Xuan Ă [17]ƝƙƵǄǆǅηĂ

ĿƵĂùƯĂǆǅ ĿLjƒĂƱùʅƒ LJǆǅ Ǒƶǆǅƕ!ƒ ýǆǅơ!Ǆƕ lƧƒƧơ!ƒ ýǄlƙLjǕ ĿǑƧƱLj Ŀʅƒƥƥ ǐƧηLj LJƉ ǄLjǑǆǅƙƧƒ ƒƦ! ĿùpǄƱ!ƒ ƯùƨơƔ Ŀù!ƥǄƶǆǅ ýùơ ƽǑƧƱ LJƵ lƧƱǄljƙǆǅ ƘǄơƙ5ƕ ý5ʅǕƒĂ ǏǐƵǕƒ LJǆǅ ăĂnjǆǅ ƨǕƺ ýƤƒƥ ĿǂƕùT ƝǑǆǅƵ ƳƨĂƙ ǐĂƙʅǆǅ LJǆǅƯ lƧTǄƕǆǅ ĿǑƥƥƵ ƽƒƒƧƱƕ ĿǑƧƒƧƱƙʅǕƒ Ŀ!ƥǄƶǆǅĂ ƉƤƨ!ƒ Ư5ơ ƘǕƥǄƶǆǅĂ ĿǑǆǅƶ!ƒ ƘǄʅƒƧƥ!ƒ Ǒ5 ǏƱƺƙ ƉƐ! ǑƙƘ ƘǄơǄʅǆǅ!ƒ ƐǆǅƵ ƨƥnjƕ ǁ!ƦĂ ǑǆǅƯƙ5ƙ!ƒ ýǑĂơƙ!ƒ ĿƱƒƧĂƕ ƱǄlǆǅljǆǅ!ƒ LJǆǅ ĿǑƥƥƵ!ƒ ĿlǑƧƱ!ƒ Ŀƥƶ ƽǑlơƙ Ǒ5 ƘǄʅƒƧƥ!ƒ ljƦNj ƥǄƙƵƒ ýǆǅ ljǕƵƒ lƧĂǂƦǆǅ!ƒ.

[illegible]

[illegible] [19] [illegible]

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \quad \text{(1)}$$

[illegible]

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho}\frac{\partial P}{\partial x}+\upsilon\nabla^2 u \quad \text{(2)}$$

[illegible]

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho}\frac{\partial P}{\partial y}+\upsilon\nabla^2 v-Body\,force \quad \text{(3)}$$

[illegible]

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \quad \text{(4)}$$

[illegible] v [illegible] u [illegible] T [illegible] P [illegible] υ [illegible] $\alpha=k/\rho C$ [illegible] ρ [illegible] $(-\rho g)$ [illegible] [16] [illegible] $\rho=\rho_o(1-\beta\Delta T)$ [illegible]

1. [illegible] (*No Slip Condition*) [illegible]
2. [illegible]

[illegible]

[illegible] (*Vorticity-Stream Function Formulation*) [illegible] $u=\partial\psi/\partial y$ [illegible] $\omega=\partial v/\partial x-\partial u/\partial y$ [illegible] $v=-\partial\psi/\partial x$ [illegible]

$$\frac{\partial T}{\partial t}+\frac{\partial\psi}{\partial y}\frac{\partial T}{\partial x}-\frac{\partial\psi}{\partial x}\frac{\partial T}{\partial y}=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \quad \text{(5)}$$

[illegible]

$$\frac{\partial \omega}{\partial t}+\frac{\partial \psi}{\partial y}\frac{\partial \omega}{\partial x}-\frac{\partial \psi}{\partial x}\frac{\partial \omega}{\partial y}=\upsilon\left(\frac{\partial^2 \omega}{\partial x^2}+\frac{\partial^2 \omega}{\partial y^2}\right)+g\beta\frac{\partial T}{\partial x} \quad \text{……………………. (6)}$$

[illegible] :

$$\frac{\partial^2 \psi}{\partial x^2}+\frac{\partial^2 \psi}{\partial y^2}=-\omega \quad \text{…………………………………………………….. (7)}$$

[illegible]

[illegible] $Ra=\rho_o g\beta D^3/\alpha\upsilon$ [illegible] $\Pr=\upsilon/\alpha$ [illegible] $X=x/D$ [illegible] $Y=y/D$ [illegible] $U=uD/\upsilon$ [illegible] $V=vD/\upsilon$ [illegible] $\tau=t\upsilon/D^2$ [illegible] $\phi=\psi/\upsilon$ [illegible] $\in=\omega D^2/\upsilon$ [illegible] $\theta=\left(T-T_{Fluid}\right)/\left(T_{Cylinder}-T_{Fluid}\right)$ [illegible]

[illegible] :

$$\frac{\partial \theta}{\partial \tau}+\frac{\partial \phi}{\partial Y}\frac{\partial \theta}{\partial X}-\frac{\partial \phi}{\partial X}\frac{\partial \theta}{\partial Y}=\frac{1}{\Pr}\left(\frac{\partial^2 \theta}{\partial X^2}+\frac{\partial^2 \theta}{\partial Y^2}\right) \quad \text{…………………………… (8)}$$

[illegible]

$$\frac{\partial \in}{\partial \tau}+\frac{\partial \phi}{\partial Y}\frac{\partial \in}{\partial X}-\frac{\partial \phi}{\partial X}\frac{\partial \in}{\partial Y}=\frac{Ra}{\Pr}\frac{\partial \theta}{\partial X}+\frac{\partial^2 \in}{\partial X^2}+\frac{\partial^2 \in}{\partial Y^2} \quad \text{……………………… (9)}$$

[illegible]

$$\frac{\partial^2 \phi}{\partial X^2}+\frac{\partial^2 \phi}{\partial Y^2}=-\in \quad \text{………………………………….. (10)}$$

[illegible] $\tau=0$ [illegible] $\phi=0.0$ [illegible] $\theta=1$ [illegible] $\theta=0.0$ [illegible] $\in=0.0$ [illegible] $\tau>0$ [illegible] $\phi=0.0$ [illegible] $\theta=1$ [illegible] $\theta=0.0$ [illegible] $\in$ [illegible].

[illegible]

[illegible]

[illegible] [20] [illegible] [21] [illegible] $\nabla^2\xi=0$ [illegible] $\nabla^2\eta=0$ [illegible] η [illegible] ξ [illegible] :

$$\alpha\frac{\partial^2 X}{\partial\xi^2}-2\beta\frac{\partial^2 X}{\partial\xi\partial\eta}+\gamma\frac{\partial^2 X}{\partial\eta^2}=0\ ,\ \alpha\frac{\partial^2 Y}{\partial\xi^2}-2\beta\frac{\partial^2 Y}{\partial\xi\partial\eta}+\gamma\frac{\partial^2 Y}{\partial\eta^2}=0 \quad \ldots\ldots \quad (11)$$

:LJǫ Łŏơ

$$\alpha=\left(\frac{\partial X}{\partial\eta}\right)^2+\left(\frac{\partial Y}{\partial\eta}\right)^2,\ \beta=\frac{\partial X}{\partial\xi}\frac{\partial X}{\partial\eta}+\frac{\partial Y}{\partial\xi}\frac{\partial Y}{\partial\eta}\ ,\ \gamma=\left(\frac{\partial X}{\partial\xi}\right)^2+\left(\frac{\partial Y}{\partial\xi}\right)^2 \ldots\ldots..\ (12)$$

.ljűƵƉ ƘŬƥƓǆdž!ƒ ýơ Ŏ5 1.8 ljƧƒƥlǆ ŁƑƥnjƙ ýǆƓǆdžƅ [22] *SOR* ŎƤƒƧƙ!ƒ ŁlŏƧƱ ƘǆƥƤƙƪƒĂ

ĬƓƒƨƟǁƐ ăNjŁƨDžǁƐ Ĭƺ ƅDžlƑƟǁƐ lŰơƑyDžǁƐ

ýƛǆ ŁǆŦƓơ!ƒ ƘŬƥƓǆdž!ƒ Ŏ5 lƥĂηĂǆ!ƒ Łŏǁ ư Ɠ5ƙ!ƒ ƥĂƥơǁ! ŎƅƓƪơ!ƒ ĭĂƙƪǆ!ƒ Ŏ5 ƧĂƓơǆ!ƒ ýƒƥƅƙƪƒ Džƙŏ ýŦT!ƒ ĬǁƵ ýƮơlj Łŏơ .[21]ŁǁƪǁƪƩ!ƒ lƥƵƓp ĬǁƵ ƥƓǆƙƵŬƓƅ ơl!ƒ … $\partial^2 \in /\partial X^2$ Ü $\partial\theta/\partial X$:ŁpƓƱ!ƒ Ʊ5ơ Ł!ƥƓǆǁ! ŎƙŬƒ

$$\frac{\partial\theta}{\partial\tau}+A\frac{\partial\theta}{\partial\xi}+B\frac{\partial\theta}{\partial\eta}=C\frac{\partial^2\theta}{\partial\xi^2}+E\frac{\partial^2\theta}{\partial\eta^2}+F\frac{\partial^2\phi}{\partial\xi\partial\eta} \quad \ldots\ldots\ \ldots\ldots\ldots\ldots\ldots\ldots..\ (13)$$

: Łŏơ

$$A=\left(\frac{\partial\phi}{\partial\xi}\frac{\partial\xi}{\partial Y}+\frac{\partial\phi}{\partial\eta}\frac{\partial\eta}{\partial Y}\right)\frac{\partial\xi}{\partial X}-\left(\frac{\partial\phi}{\partial\xi}\frac{\partial\xi}{\partial X}+\frac{\partial\phi}{\partial\eta}\frac{\partial\eta}{\partial X}\right)\frac{\partial\xi}{\partial Y}-\frac{1}{\mathrm{Pr}}\frac{\partial^2\xi}{\partial X^2}-\frac{1}{\mathrm{Pr}}\frac{\partial^2\xi}{\partial Y^2} \quad (14)$$

$$B=\left(\frac{\partial\phi}{\partial\xi}\frac{\partial\xi}{\partial Y}+\frac{\partial\phi}{\partial\eta}\frac{\partial\eta}{\partial Y}\right)\frac{\partial\eta}{\partial X}-\left(\frac{\partial\phi}{\partial\xi}\frac{\partial\xi}{\partial X}+\frac{\partial\phi}{\partial\eta}\frac{\partial\eta}{\partial X}\right)\frac{\partial\eta}{\partial Y}-\frac{1}{\mathrm{Pr}}\frac{\partial^2\eta}{\partial X^2}-\frac{1}{\mathrm{Pr}}\frac{\partial^2\eta}{\partial Y^2} \quad (15)$$

$$C=\frac{1}{\mathrm{Pr}}\left(\frac{\partial\xi}{\partial X}\right)^2+\frac{1}{\mathrm{Pr}}\left(\frac{\partial\xi}{\partial Y}\right)^2\ ,\ E=\frac{1}{\mathrm{Pr}}\left(\frac{\partial\eta}{\partial X}\right)^2+\frac{1}{\mathrm{Pr}}\left(\frac{\partial\eta}{\partial Y}\right)^2\ ,$$

$$F=\frac{2}{\mathrm{Pr}}\left(\frac{\partial\xi}{\partial X}\frac{\partial\eta}{\partial X}+\frac{\partial\xi}{\partial Y}\frac{\partial\eta}{\partial Y}\right)$$

:ƠƅƮƙ5 DžƤƨ!ƒ Ʊ5ơ Ł!ƥƓǆdž Ɠdžƒ

$$\frac{\partial\in}{\partial\tau}+A\frac{\partial\in}{\partial\xi}+B\frac{\partial\in}{\partial\eta}=C\frac{\partial^2\in}{\partial\xi^2}+E\frac{\partial^2\in}{\partial\eta^2}+F\frac{\partial^2\phi}{\partial\xi\partial\eta}+G \quad \ldots\ldots\ldots\ldots\ldots\ldots.(16)$$

: Łŏơ

$$A=\left(\frac{\partial\phi}{\partial\xi}\frac{\partial\xi}{\partial Y}+\frac{\partial\phi}{\partial\eta}\frac{\partial\eta}{\partial Y}\right)\frac{\partial\xi}{\partial X}-\left(\frac{\partial\phi}{\partial\xi}\frac{\partial\xi}{\partial X}+\frac{\partial\phi}{\partial\eta}\frac{\partial\eta}{\partial X}\right)\frac{\partial\xi}{\partial Y}-\frac{\partial^2\xi}{\partial X^2}-\frac{\partial^2\xi}{\partial Y^2} \quad \ldots\ldots\ (17)$$

$$B=\left(\frac{\partial\phi}{\partial\xi}\frac{\partial\xi}{\partial Y}+\frac{\partial\phi}{\partial\eta}\frac{\partial\eta}{\partial Y}\right)\frac{\partial\eta}{\partial X}-\left(\frac{\partial\phi}{\partial\xi}\frac{\partial\xi}{\partial X}+\frac{\partial\phi}{\partial\eta}\frac{\partial\eta}{\partial X}\right)\frac{\partial\eta}{\partial Y}-\frac{\partial^2\eta}{\partial X^2}-\frac{\partial^2\eta}{\partial Y^2} \quad \ldots\ldots\ (18)$$

$$C=\left(\frac{\partial \xi}{\partial X}\right)^2+\left(\frac{\partial \xi}{\partial Y}\right)^2,\ E=\left(\frac{\partial \eta}{\partial X}\right)^2+\left(\frac{\partial \eta}{\partial Y}\right)^2,\ F=2\left(\frac{\partial \xi}{\partial X}\frac{\partial \eta}{\partial X}+\frac{\partial \xi}{\partial Y}\frac{\partial \eta}{\partial Y}\right)$$

$$G=\frac{Ra}{\Pr}\left(\frac{\partial \theta}{\partial \xi}\frac{\partial \xi}{\partial X}+\frac{\partial \theta}{\partial \eta}\frac{\partial \eta}{\partial X}\right)$$

[illegible]:

$$A\frac{\partial \phi}{\partial \xi}+B\frac{\partial \phi}{\partial \eta}+C\frac{\partial^2 \phi}{\partial \xi^2}+E\frac{\partial^2 \phi}{\partial \eta^2}+F\frac{\partial^2 \phi}{\partial \xi \partial \eta}=-\in \qquad \text{…… …………….. (19)}$$

[illegible]:

$$A=\frac{\partial^2 \xi}{\partial X^2}+\frac{\partial^2 \xi}{\partial Y^2},\ B=\frac{\partial^2 \eta}{\partial X^2}+\frac{\partial^2 \eta}{\partial Y^2},\ C=\left(\frac{\partial \xi}{\partial X}\right)^2+\left(\frac{\partial \xi}{\partial Y}\right)^2,$$

$$E=\left(\frac{\partial \eta}{\partial X}\right)^2+\left(\frac{\partial \eta}{\partial Y}\right)^2$$

$$F=2\left(\frac{\partial \xi}{\partial X}\frac{\partial \eta}{\partial X}+\frac{\partial \xi}{\partial Y}\frac{\partial \eta}{\partial Y}\right) \qquad \text{……………………………………………… (20)}$$

[illegible] [23]:

$$\frac{\partial \xi}{\partial X}=\frac{1}{J}\frac{\partial Y}{\partial \eta},\quad \frac{\partial \eta}{\partial X}=-\frac{1}{J}\frac{\partial Y}{\partial \xi},\quad \frac{\partial \xi}{\partial Y}=-\frac{1}{J}\frac{\partial X}{\partial \eta},\quad \frac{\partial \eta}{\partial Y}=\frac{1}{J}\frac{\partial X}{\partial \xi}$$

[illegible] $J=\frac{\partial X}{\partial \xi}\frac{\partial Y}{\partial \eta}-\frac{\partial Y}{\partial \xi}\frac{\partial X}{\partial \eta}$ [illegible] J [illegible]

[illegible] .[21]

[illegible] $\frac{\partial^2 \xi}{\partial X^2}$ [24]:

$$\frac{\partial^2 \xi}{\partial X^2}=\left(\frac{\partial \xi}{\partial X}\frac{\partial^2 Y}{\partial \xi \partial \eta}+\frac{\partial \eta}{\partial X}\frac{\partial^2 Y}{\partial \eta^2}\right)-\left(\left(\frac{\partial \xi}{\partial X}\right)^2\frac{\partial J}{\partial \xi}+\frac{\partial \xi}{\partial X}\frac{\partial \eta}{\partial X}\frac{\partial J}{\partial \eta}\right)\Big/ J \qquad \text{………… (21)}$$

[illegible]

[illegible] Hopscotch [26 Ă 25] [illegible] ξ [illegible]

[illegible]

1. [illegible]:

[illegible]

2. [illegible]:

[illegible] [27] [illegible]

$$\phi_{i,m-1} = \phi_{i,m} - \frac{\partial \phi}{\partial n} + \frac{1}{2!}\frac{\partial^2 \phi}{\partial n^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (22)$$

[illegible]:

$$\in_{i,m}^{k+1} = 2E\left[\left(\phi_{i,m} - \phi_{i,m-1}\right) - \left(1 + B/2\right)\frac{\partial \phi}{\partial \eta} - \frac{1}{2E}\left(A\frac{\partial \phi}{\partial \xi} + C\frac{\partial^2 \phi}{\partial \xi^2} + F\frac{\partial^2 \phi}{\partial \xi \partial \eta}\right)\right] \qquad (23)$$

[illegible]:

$$\in_{i,m}^{k+1} = 2E\left[\left(\phi_{i,m} - \phi_{i,m-1}\right) - \frac{F}{2E}\frac{\partial^2 \phi}{\partial \xi \partial \eta}\right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (24)$$

[illegible] [27].

3. [illegible]:

[illegible] [10] [illegible] [22] [illegible]

Nu lǂƨǆ ǫǫY ƒǅƨθ

Ǆķùŏ5 ƘǙƪùǉ ββùƵ ýβƶǆ Ǵǆƒ $Nu_L = -\left.\dfrac{\partial \theta}{\partial n}\right|_{Cylinderl}$ ǂ!βǴƶǆ!ƒ ǇǆŎƶưĂǆ!ƒ ƘǙƪǉ ββƵ ƔǴƪơ Ǆķŏ

ǂùǆŏp ƔǴƪùơ Ǆùķ ƘǙƪùǉ ββƵ ǂǆŏp ǂpβ lβǴŏƨ!Ă . $Nu = -\dfrac{1}{n}\sum_{i=1}^{n}\left.\dfrac{\partial \theta}{\partial n}\right|_{Cylinder}$ ǂ!βǴƶǆ!ƒ Ǉǆ ǊǴƪơ

.ŎǴƪơ!ƒ ĬĂķƪǆ!ƒ ǇǆĂ ŎǅǴŏƨŏ5!ƒ ĬĂķƪǆ!ƒ Ǉǆ $\left.\dfrac{\partial \theta}{\partial n}\right|_{Cylinder}$

ƅƐǊǈǁƐ ǂǂl üǅƾǂƐ ƒǅƨθ

Ŏ5 ǂƱlǉ ý ǂ! ǇƒĂǌ!ƒ ǂ5ǴǂǊƧưĂ ǛĂǱ ƻŏƧƬķ!ƒ ƔǴƪơ ƾŏƧƱ ǇƵ ǂǂķǂ!ƒ ǇǴŏƧƞ ƔǴƪơ Ǆķŏ

:ŎķǴŏ Ǵǆǂ Ǵǂƶ!ƒ ǂơķƾ! ǂǂķǂ!ƒ ýǴlķǉƒ ǂŏǆǂ ǇĂǂķƪ ƒƦ! . Ĭƾƪ!ƒĂ Ǵǂƶ!ƒ ǇŏķơķƾƒƖ

$$\dot{m} = \sum_{UpperVent} \rho_{i,m} \cdot \frac{v_{i,m} + v_{i+1,m}}{2} \cdot \Delta X_i \Big|_{\eta = m}$$

.ǴưŏǱ Ĭƾƪ!ƒ ǂơķƾ!ƒ Ǉǆ ýƤƒβ!ƒ ǂǂķǂ!ƒ ýǴlķǉƒ ƔǴƪơ! ǉǖƵǱ ǂ!βǴƶǆ!ƒ Σƾǉ ƾǂƱķĂ

lƒǴķǁƐ ǂǁƒθ

:ǂŏķǗƒ ƱĂƧƬ!ƒ ýŏǆƞ Ǆķķ ǴǆβǉƵ ƘǴǂ ǂ!Ǵơ Ŏ5 ǄǴƲǉ!ƒ Ƨķƶƒ

1. ǇƒăĂǴƪķķ ǄŏpƵ ββƵ ƘǙƪǉ ǇƧƾ! ƨǂŏǉǆ ǂǉŏǗýlķ ǇƵ 20 ǂŏǉǴǂ.

2. ǇƒăĂǴƪķķ ǄŏpƵ ǂǂķǂ!ƒ ýƤƒβ!Ă ǕǁƧǴƤ!ƒ ǂķĂǂǇ ǂķǂǴǂ ǇƧƾ! ƨǂŏǉǆ ǗƵ lķǉ 20 ǂŏǉǴǂ.

3. ǇƒăĂǴƪķķ ǄŏpĂ ƘǴƞƧβ ǇƧƒƧơ!ƒ ǂβƶǂǖ!ƒ ǂŏǆƒǍ!ƒ ǂβƶǂǖ!ƒ ǇŏƧƬƶ! ǇβĂǴƶǆ ĬǁƵ ǂǂƪǴơ!ƒ.

4. Ǵǆƒ ǄŏpƵ ǂ!ƒβ ǇƧŏƧƞ!ƒ ǇǴŏƧƞ ǄķŏƧ ǴǊƧǴķƤƒ Ǵǉŏ5 ƾǂƱŏ ǇƧǆ ý ǂ! ǍǆǴǉƧǂ!ƒ ǂǂĂǉǉǴǂ Ǵǆǂ ǂ!βǴƶǆ ýƱp ǂǆǂǴƐ.

üθǁƐ ǂθT ƫ θʒ

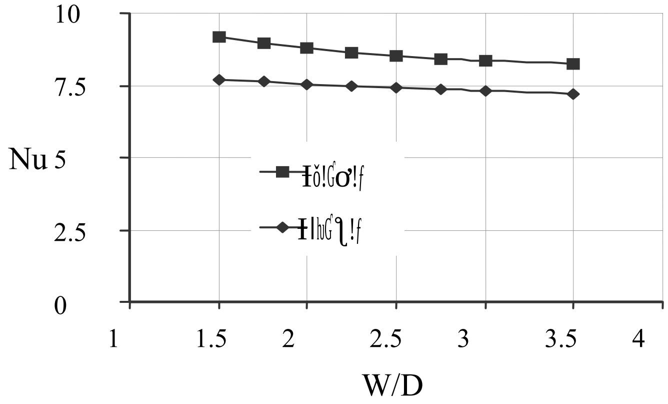
ǂǂǂǴƪù!ƒ ǂǂǆǆƶ!ƒ ƘǴƪƒƧβ!ƒ Ǉǆ ƯƶǂýǆƘǴǉƧǴlǆ!ƒ Ǉǆ ββƵ ǇƒƧƞƒ Ǆķ ýơ!ƒ ǂơƬ Ǉǆ βǂǴķǂ!

:ŎķǴŏ Ǵǆǂ ƘǉǴǂ ǂǂǆǆƶ!ƒ ƘǴǉƧǴlǆ! ǂƪǉ!Ǵ5 ǗǄǴǗƱǉ!ƒ ƘǖƤβǆ ƯƶǂĂ

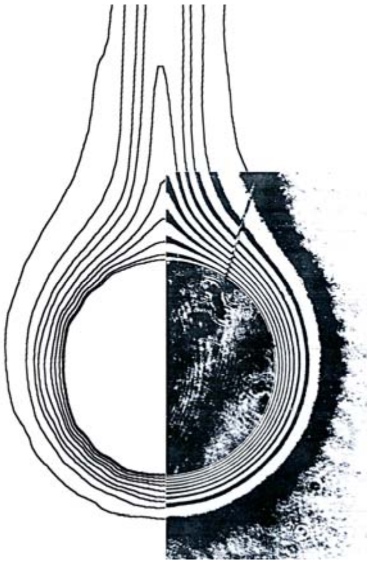
1. ǇǉƧĂp ƘǉǴǂĂ ǋƒǴķǉ!ƒ ǆǆƶ!ƒ ǂƪƒƧβ!ƒ ýǆ ǋƒǴķǉ!ƒ ƘǉǴǂĂ [14] ǄǉǴƹ ǂơǴǂ! ǂǂǆǆƶ!ƒ ǂƪƒƧβ!ƒ Ŏ5 ǂƞƧƤķƪǆ!ƒ ǂǂǆǆƶ!ƒ ƘǴǂƵǂǅƒ ǇβƵ ǇǆƞǂƧǆĂ ǴǉķŏǉǴĂ ǂùŏββƶ!ƒ ƔǴƪùơ!ƒ ƾƒƒƧƱ Ŏ5 ǂǆβƤƪǆ!ƒ ǂŏββƶ!ƒ ƘǴǂŏƧǂķ!ƒĂ ǂŏβơ!ƒ ƱĂƧƬ!ƒ Ŏ5 ƘǴǂŏƧǂķ!ƒ ƘǴǆǆƶ!ƒ ƧǴǂƵǗƒ ƧǉǴǂ ƦùƤǗƒ ýǆ lƧĂǂƦǆ!ƒ ǂƪƒƧβ!ƒ ΣǴǆ!ƒ lƨǉƞǱ ǂpβ Ǉǆ lβ!ĂķǆƒƒƧǴǆ!ƒ ǂǆǆƶ!ƒ ǇǴƱƤǗƒ ǇƒƒǴǂƶǆ ǴǴǆ! ƠưķŏǄƪƧ!ƒ Ǉǆ ƦƒƤ.ƾƧǴ5!ƠưĂŏ (1) ýǂT!ƒĂ .ǂƞƧƤķƪǆ!ƒ ǋƒǴķǉ!ƒ ĬǁƵ lƒƧƞǆ ǂŏƒƬơǗƒ ýƬùŏ ǂùŏơǂ ƻǖʒ!ƒ ƯƧƵ lβǴŏƨǂ ǋƒǴķǉ!ƒ ƔƧǴķķ ǴǆǉŏǂǂŏǂǴƞķŏ Ǘ %16 ƨĂǴƞķŏ Ǘ ƘǙƪǉ ββƵ Ŏ5 ƾƧ5 Ƨǂǂƒ .%12 Ĭ!ƒ ƾƧ5!ƒ

2. ǇƒǂĂp ýǂT ǋƒǴķǉ!ƒ ǴưŏƒǴ ýǆ ǂƪƒƧβ!ƒ ǂǂǆǆƶ!ƒ ǇǂƒơǴǂ! Goldstein Ă Kuehn [6] ƘǉǴǂĂ ǋƒǴùķǉ!ƒ ƾǴƞǂŏ W/D=4.8 ǊŏƧ ƻǖʒǂ ǂƱǴơǆ ǂǉƒƱƪǉ ĬǁƵ ǂǉƧǴǆ!ƒ ǉǱǊ ƘǆǴķ Ǘ(2) ýǂT!ƒ Ŏ5 Ǵǆǂ ǂǂǴƱķǆ ǂǆǂŏ ƻǖʒ!ƒ ƧŏǆǴķ ǇǴ ǉǂ ǂǂǴƪ!ƒ ƘǴƪƒƧβ!ƒĂ ǂơǴ!ƒ Ǉǆ ǂƞƧƤķƪǆ!ƒ ǋƒǴķǉ!ƒ ƔƪơǇƧơ ǂǉƒƱƪǉ ýǂǆķ ǊǴǉ!Ǵǆ ǂǆ10^5 ǂǉƒƱƪǉǛĂ ǊǆƒƧ ǂǆŏǉ! O/W=0.67Ă Ǘ(ǊǴǆǴƞǉ ǂƱǴơǆ Ƨķǆ 0.0356 ǊǴƧƱp ǂǉƒƱƪǉǛĂ .ǇƒĂǌ!Ǵ

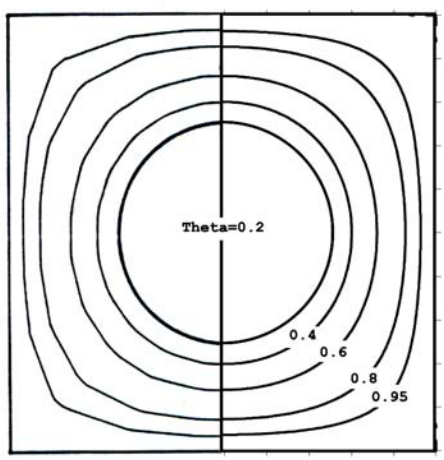
3. ǇǆǂĂpĂ ýǂT ǋƒǴķǉ!ƒ ǴưŏƒǴ ýǆ ǂǂǆǆƶ!ƒ ǂƪƒƧβ!ƒ ǂŏƧƱǉ! Kao Ă Goldman [28] ƘǉǴǂĂ ǋƒǴķǉ!ƒ Ǵǆǂ Ŏ5 ýǂT!ƒ Ǘ(3) ƘǆǴķ ǉǱǊ ǂǉƧǴǆ!ƒ ĬǁƵ ǂǉƒƱƪǉ ǂƱǴơǆ ƻǖʒǂ ƾǂʒǆ Ɛǂķǆǆ ǇƒĂǌ!Ǵ ǊŏƧ W/D=2.



.[14]ŧlhĈʅ ŧöǁdžZ ŧʅƒSþ ydž ŧǰSĈldž :(1) ýŧT!ƒ

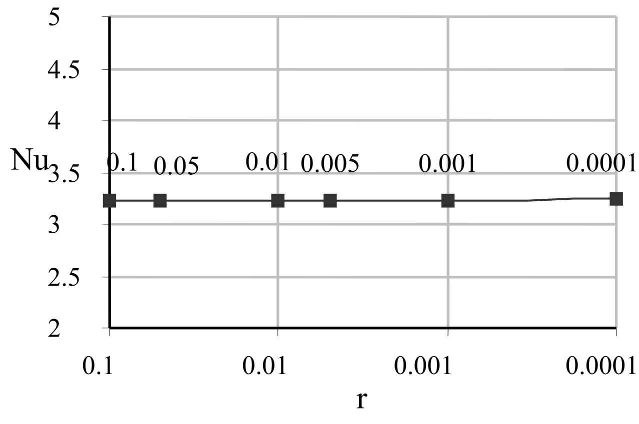


.[6] ŧlhĈʅ ŧöǁdžZ ŧʅƒSþ ydž ŧǰSĈldž :(2) ýŧT!ƒ

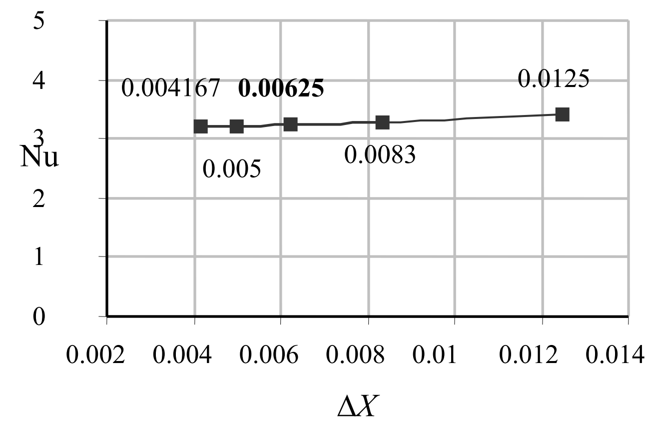


.[28] ŧlhĈʅ ŧöǁdžZ ŧʅƒSþ ydž ŧǰSĈldž :(3) ýŧT!ƒ

.[29] ŧlhĈʅ ŧöǁdžZ ŧʅƒSþ ydž ŧǰSĈldž :(4) ýŧT!ƒ



.r ǈdž Džöþ ǉþz! ýƠ!ƒ ŧƠƮ ƒ Ơǯ :(5) ýŧT!ƒ



.ΔX ǈdž Džöþ ǉþz! ýƠ!ƒ ŧƠƮ ƒ Ơǯ :(6) ýŧT!ƒ

.Conduction

.4 [29] O/W=0.785 W/D=3.5 10^4 .(4)

.1 $r = \alpha \Delta \tau / (\Delta X)^2$ r (5)

.2 ΔX (6) 0.00625

O/W=0.8 W/D=2.5 $1E5 \leq Ra$

8 7 9 11 .10

12 $Ra \leq 100$ 13

lƨƨσ!ƒ ýĜlkljƒ LJĂ∔ $Ra \leq 100$ ŎǏlŏƒƨ þþƵ Džŏp ăþdž! DžĂþƶdž NhhT LJĂ∔ŏ ŎǏlŏƒƨ þþƶhv ƘǏlƛlj þþƵ ƨλdk LJĜ5 þùljƵ ǏdžUƶ!ƒ NJkdžŏp ýƮŏ LJƒ Ǐ!ƒ ŎǏlŏƒƨ þþƵ lþĜŏahv ƀŏηŏƨþk ƘǏlƛlj þþƵ þŏƒaƙŏ ÜýĜηdž!ƒ ƒ₹Nj Ŏ5 ýŏƮĂk!Ghv .ŎǏlŏƒƨ þþƶ! ∔džŏp ǏǏlƵƒ

Dþhvŏ LJĜŏƨη!ƒ LJƒ ∔ŏσ 14 ý∔T!ƒ Ŏ5 LJŏhdž Gdž∔ Ănj5 ƘGhλ!ƒ ∔!Gσ Ŏ5 ŎǏlk∔!ƒ LJĜŏƨη!ƒ ýþƶdž! ∔hvƛlj!GhÅ ǐD .ăþùdž!ƒ ƒ₹ùNj LJĂþ Gdž! DžĂþƶdž LJĜŏƨη!ƒ ƨGhkƵƒ LJ∔džŏÅ $Ra \leq 100$ ŎǏlŏƒƨ þþƵ Džŏp ăþdž! ƘGσƙs!ƒ Ŏ5 Džŏù!! LJdžɛ!ƒ yđž ŎǏlk∔!ƒ LJĜŏƨη!ƒ ýþƶdž ∔pǔƵ ƠuĂŏ 15 ý∔T!ƒÅ .ýŏƮĂk!Ghv lƨƨσ!ƒ ýĜlkljƒ ýĜηdž LJdžư ∔ùŏ!Gƶ!ƒ Ŏùlŏƒƨ þþƵ Džŏ!! lƨŏhv∔ LJĂ∔k ƘGhλ!ƒ ∔!Gσ ýhvp GnjǏƮŏ Ŏk!ƒ ǏdžUƶ!ƒ ∔džŏ!!ƒ LJƒ UσǔljÅ ŎǏlŏƒƨ þþƵ . $Ra \leq 100$ ŎǏlŏƒƨ þþƵ Džŏ!! DžþƶljkĂ

Ü∔ljfĂƉùlŬƒ LJŏùdžŏ ǏǏlƵ ∔ŏ∔ŏ!Ăƨþônj!ƒ ∔džPĜkdž!ƒ ∔lhƉ!ƒ Ŏ5 ∔ƵƨlǏ! ∔džŏp ǏǏlƵƒ LJŏhv ∔pǔƶ!ƒ LJƒ Gdž∔ ∔ù∔σ!ƒ DþùhvkĂ $Ra \leq 100$ Ŏùlŏƒƨ þþùƵ Džŏp ăþdž! 2ǔʒ!ƒ ýPƒþ ∔∔σ þĂηĂ DžþƵ LJŏhvk Ü16 ý∔T!ƒ LJŏùhvkŏ 17 ý∔T!ƒ ∔Uσǔdž LJdžĂ .ŎǏlŏƒƨ þþƶ! ∔džŏp ǏǏlƵƒ þljƵ ǏdžUƶ!ƒ Gnjkdžŏp ýƮk Ǐkơ ƀŏηŏƨþk ƨĂnjU!Ghv Σsljhv LJĂ∔ŏ LJĜŏƨη!ƒ LJƒ Gưŏƒ ý∔T!ƒ ƠuĂŏ Gdž∔ $Ra > 100$ ŎǏlŏƒƨ þþƵ ∔džŏp ydž LJĜŏƨη!ƒ ∔ŏfþhv ƀưŏƒ Ćlj! .∔kĂGskdž Yƨlhv LJ∔!Ă lƨĂ∔₹dž!ƒ ∔!GσǏ! ljGηkŬƒ

ŀσưĂdž!ƒÅ ŎǏlŏƒƨ þþƵ LJŏhvÅ ∔ljfĂƉlŬƒ LJŏdžŏ ǏǏlƵ ŀŏƨƒσ!ƒ ∔džPÐkdž!ƒ ∔lhƉ!ƒ LJŏhv ∔pǔƶǏ! ∔hvljƒ Gdžf ýĜùlkljƒ ∔!Gσ ydž ŀŏTĜdžkdž ŎNjĂ 100≤Ra ŎǏlŏƒƨ þþƵ Džŏp ăþdž! ŀŏƉP ∔pǔƵ Gnjljƒ Uσǔŏ5 Ü18 ý∔T!ƒ Ŏ5 .ŎǏlŏƒƨ þþƶ! ∔džŏp ǏǏlƵD þljƵ CĆljσljƒ Ǐ ƮpD Ǐ!ƒ ýƮk Ǐkơ ƀŏηŏƨþk ŎljσljkĂ Üýŏ ƮĂk!Ghv lƨƨσ!ƒ

GùNjƨGhkƵƒ LJ∔džŏ 100 ŎǏlŏƒƨ þþƵ ∔džŏp LJǫ ýĂl!ƒ GljLj∔džŏ ∔lhvG!ƒ ýĜ∔TŪƒ Ŏ5 ƘGpǔƶ!ƒ ∔Uσǔdž LJdžĂ ýùdžσ!Ghv Gùnj!Glkljƒ Ǐù!ƒ ýŏù ƮĂk!Ghv lƨƨσ!ƒ ýĜlkljƒ LJdž lƨƨσ!ƒ ýĜlkljƒ ∔lŏƨƉ ýĂσkk GNjþljƵ ∔ηƨσ ∔džŏp .ŎzŏhvƉ!ƒ

l∔ɛdž qqqY Ă∔Y þǐkƑ∔llɛ

W/D hvGƨdžllɛ þǐkƑ∔

O/W=0 ∔hvlùlj!ƒ ∔ùdžŏp LJĂ∔k GdžfljƵ W/D ∔hvlj!ƒ ∔džŏp lþGŏahv ƘǏlƛlj þþƵ þGŏþaƒ 19 ý∔T!ƒ LJdž Uσǔlj Džkùŏ ∔ljfĂƉùlŬƒ LJùdž lþĂùlsdž!ƒ lƨƨσ!ƒ ∔ŏdž∔ LJĜ5 ƒ₹! 2ǔʒ!ƒ ýPƒþ ƨĂƮσdž CƒĂnj!ƒ LJĂ∔ ǁ!₹ YhvlĂ þùljƵĂ f ĜƮkdžŬƒ ∔σĜlđ lþGŏa Ǐ!ƒ ǐþđŏ 2ǔʒ!ƒ Ư ƨƵ lþGŏa LJƒĂ ÜƉl5 2ǔʒ!ƒ LJdž ∔ldžGƒ∔ GnjƮĜƮkdžf lþĂlsdž!ƒ lƨƨσ!ƒ ýdžηdž f ĜƮkdžGhv DžĂlŏ ∔ŏσ ÜNηƨĜP Ǐ!ƒĂ 2ǔʒ!ƒ ýPƒþ Ǐ!ƒ LJĜŏƨη!ƒ Dþhvŏ ∔σks!ƒ ƨĂnjU Ŏùlŏƒƨ þþùƶ! ƉùlŏdžFĜp ljƨŏλdk Ǐlhvŏ ∔ŏσ 2ǔʒ!ƒ ƨĂþ þþσkŏ ∔σks!ƒ Ư ƨƵ CĆŏþaGhvĂ .∔ljfĂƉlŬƒ LJdž .ƘǏlƛlj þþƵ ǏǏlƵ ƀŏ∔ƶ ƨŏλdk!Ghv 2ǔʒ!ƒ þƶhvv lþGŏa!ƒ Dþhvk ∔σks!ƒ Ư ƨƵ lþGŏahvĂ Ư ₅Pljdž!ƒ

O/W hvGƨdžllɛ þǐkĐ∔

ýþùƶdž ýùlŏĂ ∔ùlŏŏl!ƒ W/D ∔hvlj!ƒ Džŏ!! ∔σks!ƒ ƨĂnjUhv ƘǏlƛlj þþƶ! ƨŏhv∔!ƒ þGŏþaŬƒ 20 ý∔T!ƒ LJdž Uσǔlj ∔ùdžŏp þljƵ %96 Ŏ!ƒÅσ ŎNj þGŏþaƒ ∔džŏp ƨhv∔ƒ LJƒ Uσǔdž!ƒ LJdž ₹f W/D ∔hvlj!ƒ þGŏþaGhv ƀŏηŏƨþk þGŏþaŬƒ ∔džŏ!Ă W/D=3.5 þljƵ %24 Ŏ!ƒÅσ ŎNj þGŏþaƒ ∔džŏp ýpfĂ 1E5 ŎǏlŏƒƨ þþƵ ∔džŏ!Ă W/D=1.5 ∔hvlj!ƒ f ĜƮkdžƒ ƀhvlđ ∔σks!ƒ Ư ƨƵ lþGŏahv þfþaŏ CƒĂnj!ƒ LJGŏƨη LJƒ ĂNj ƘfþGŏa!ƒ ljRNj ƳhvlĂ .1E4 ŎǏlŏƒƨ þþƵ .∔ljfĂƉlŬƒ LJdž ∔ηkGlj!ƒ lƨƨσ!ƒ ƨhv∔ƒ

Ra Ǐ∔ǐɛþ qqqY þǐkĐ∔

ƘǏlùlj þþƶ! ∔ŏĂƒdž lþGŏa ýpf LJƒ Uσǔlj 21 ý∔T!ƒ LJdž5 .ƘǏlƛlj þþƵ ǏǐlƵ ƨhv∔Ŭƒ ƨŏλGk!ƒ ŎǏlŏƒƨ þþƵ ₹Pdŏ ∔hvlùlj!ƒ ∔ùdžŏ!Ă W/D=3.5 ∔hvlùlj!ƒ ∔džŏp þljƵ %44 Ŏ!ƒÅσ ŎNj 1E5 Ǐ!ƒ 1E4 LJdž ŎǏlŏƒƨ þþƵ ƨŏʒkhv LJĂù∔k Ƙfþĝùŏɛ!ƒ ŎpĜùhv LJƒĂ W/D=1.5 Ă O/W=1 þùljƵ %94 Ŏ!ƒÅσ ŎNj lþGŏa ǏǏlƵƒĂ O/W=0 .∔ǏlXGdžkdž þGƶhvGhvĂ ăþdž!ƒ ƒ₹Nj LJdžư lƨĂƮσdž

lƑШƑƚǆƚƨŰƐ

ǅƒþƤƙùƮǤƾ ǑǆǆǤǆǕƒ ǈǊǆƤƙ!ƒ ƚǀƧƱ ƫǀǚƱƙ þƶǀ ǑǀǍƮǤơ!ƒ ǋǆǤǇƧǀ!ƒ ǈǆ ƚƞƧƤƙƮǆ!ƒ ǋƑǤǇ!ƒ ƚƞ!Ǥƶǆ Ƙǆƙ

ýưù5ƒ Ĭù!ƒ ýƮǍƙ! ǑƱƤ!ƒ Ƨǒƺ þþƶƙǆ!ƒ Ƨǒþƙ!ƒ þǆƙƵƒǍ 5.0 ƚƤƮǉ!ƒ Statistica ǑƑǤƮơǕƒ ǋǆǤǇƧǀ!ƒ

.[30]ƘǤþǖƶ!ƒ

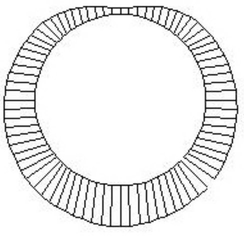
.0.92 ǉƧƒþǆ ƱǤǀƙƧƒ ýǆǤƶǆǀ ƚ!ǀƮǆ!ƒ ƘƒƧǒƺƙǆ ƚǀǀ yǆ Ƙ!Ʈǉ þþƵ ƧǒǤƺƙ ƚǒ!Ǥƙ!ƒ ƚþǖƶ!ƒ Ƙ5ƮǍ

$$Nu = 0.256 * Ra^{0.242} + 0.932 * (W/D)^{0.498} - 0.618 * (W/D)^{0.100} + 0.111 * Ra^{0.360} * (W/D)^{-0.488} * (O/W)^{0.882}$$

:ƚþǖƶ!ƒ ǋƘ5ƮǍ5 ƚǀƙƚ!ƒ ǈǤǒƧƞ ýþƶǆ Ǥǆƒ

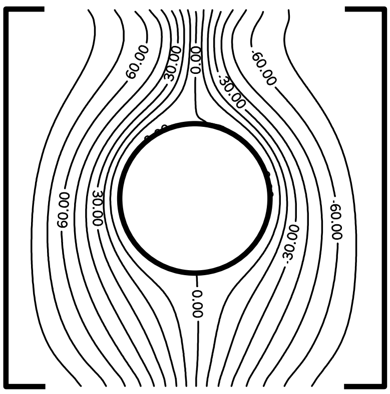
$$\dot{m} = 1.384 * Ra^{0.160} * (O/W)^{1.059} + 0.930 * (W/D)^{0.884} * (O/W)^{0.305} - 7.217 * Ra^{-0.058} * (W/D)^{-0.606} * (O/W)^{3.068}$$

.0.98 ǉƧƒþǆ ƱǤǀƙƧƒ ýǆǤƶǆǀǍ



9.083sec

ƘƖƮǉ þþƵ yǒƨǍƙ :9 ýƚƬ!ƒ



9.083sec (l-2-5)

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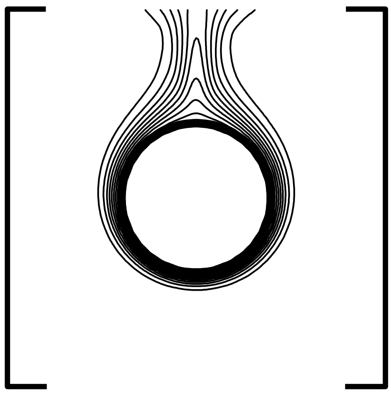
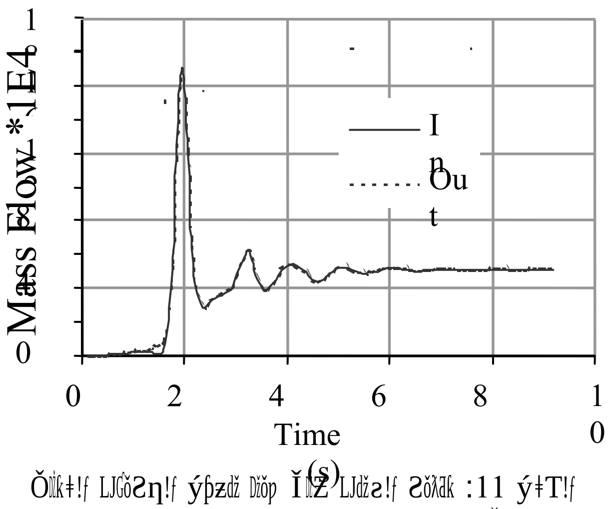
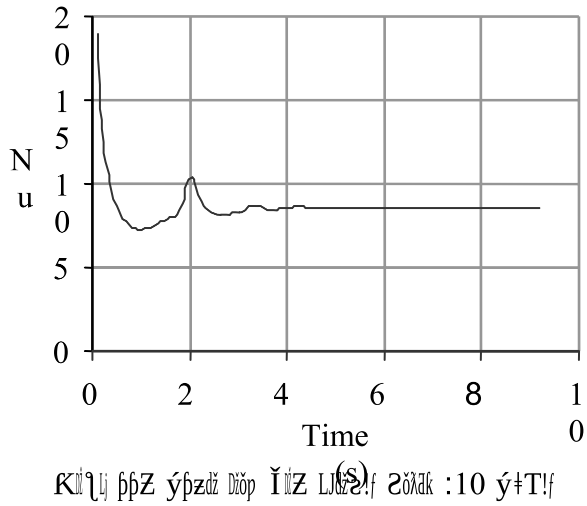


9.083sec (l-1-5)

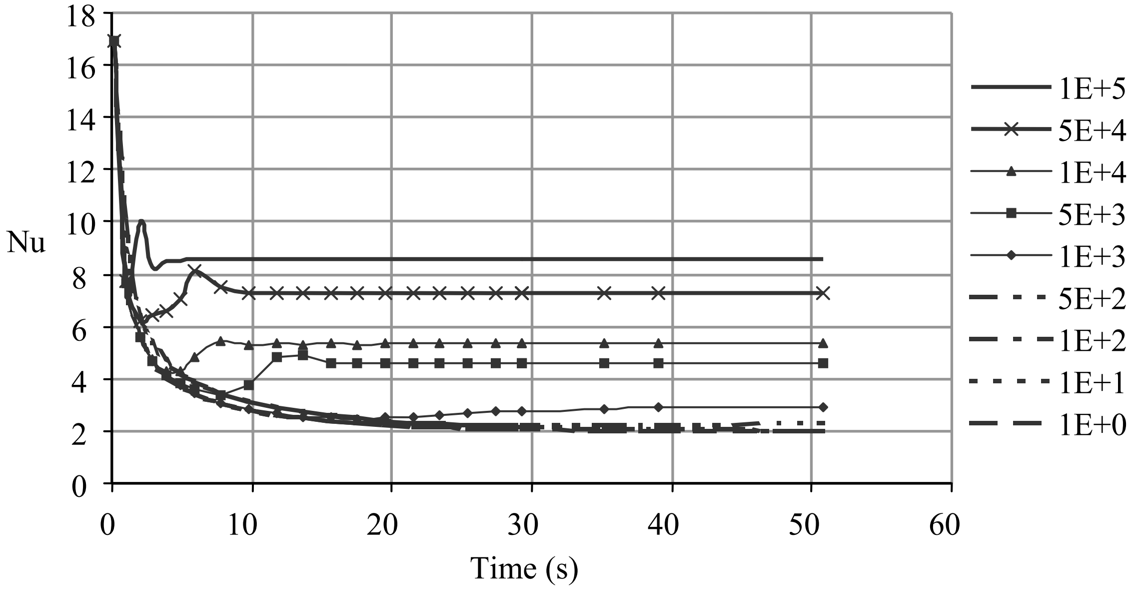
lƧƒƧơ!ƒ ƘǤƞƧþ ƘǍǀǆ ƱǍƱƤ :7 ýƚƬ!ƒ



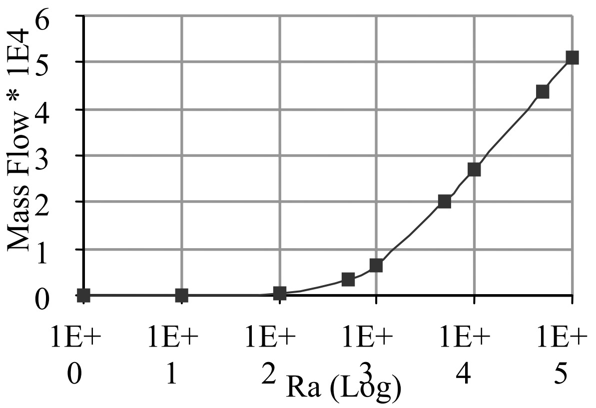
ǑƖƙƚ!ƒ ǈǤǒƧƞ!ƒ ýþƶǆ ǅǒp ĬƖƵ ǈǆƨ!ƒ Ƨǒǆƙ :11 ýƚƬ!ƒ
ШƧǤƤ!ƒǍ ýƤƒþ!ƒ



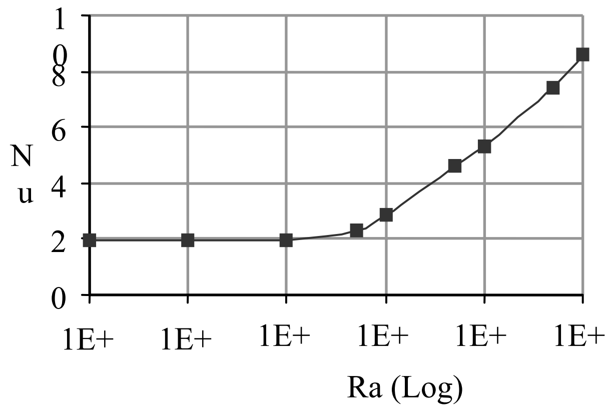
ƘƖƮǉ þþƵ ýþƶǆ ǅǒp ĬƖƵ ǈǆƨ!ƒ Ƨǒǆƙ :10 ýƚƬ!ƒ



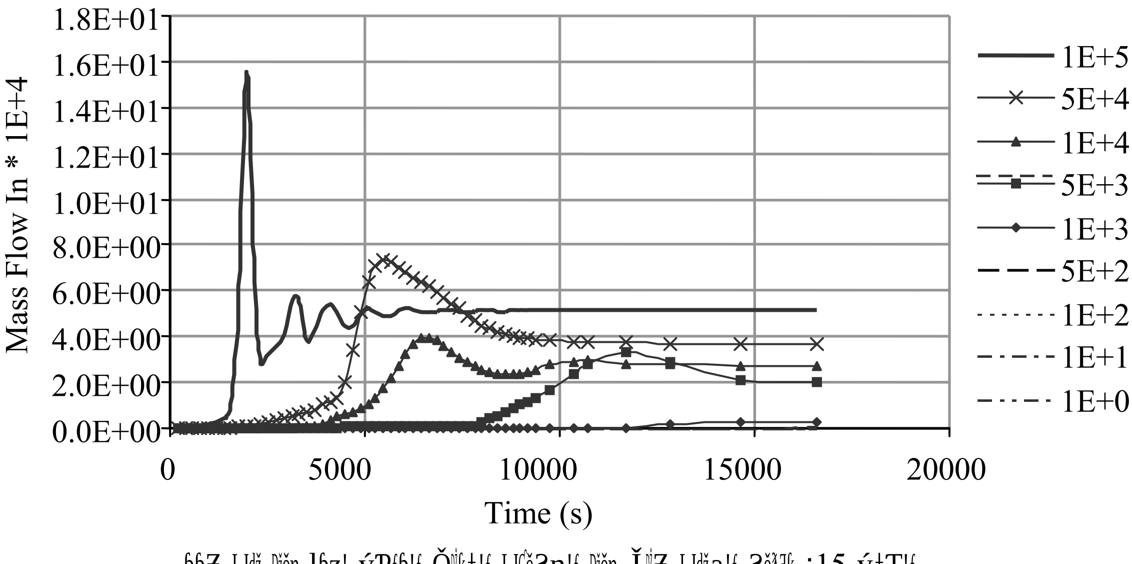
ǑďöƒƧ þþƵ ǇDž Ďöp ƙþz! Ƙďƪǉ þþƵ Ďöp ǏďƵ ǇDžꞩ!ƒ Ƨöǩk :12 ýꞮT!ƒ



Ɨ!Ɠơ! ǑďöƒƧ þþƵǍ ǑďkꞮ!ƒ ǇƓöƧƞ!ƒ Ǉöu Ɨpǖz!ƒ :14 ýꞮT!ƒ
ƘƓǹ!ƒ



Ɨ!Ɠơ! ǑďöƒƧ þþƵǍ ƘďƪǉþþƵ Ǉöu Ɨpǖz!ƒ :13 ýꞮT!ƒ
ƘƓǹ!ƒ



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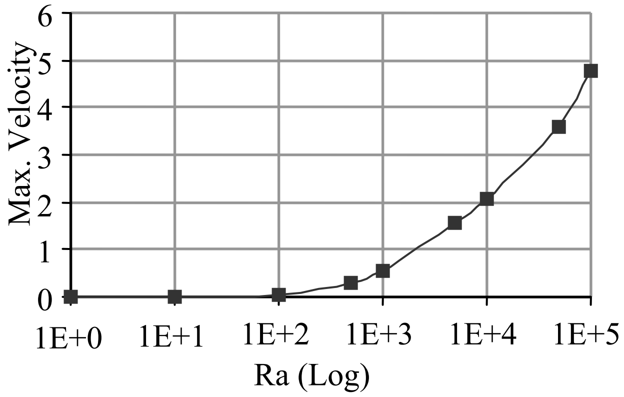
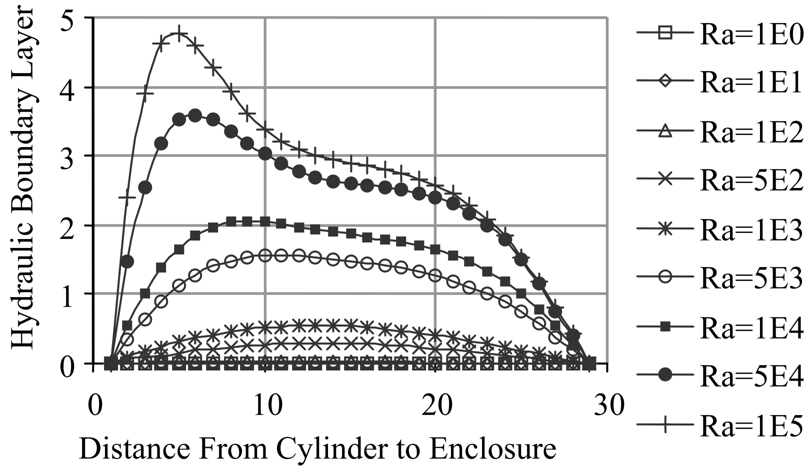
ǑďöƒƧ



ǑǐǒƒƧ ƥƥƵ ǈǰǒǖǍ ŧǆǆƤƉǆǆ!ƒ ŧǀǁƱ!ƒ Ǒ5 ŧƵƧƪǐ! ŧǆǆǒp ǏǐƵƉ ǈǰǒǃ ŧpǖz!ƒ :16 ýŧT!ƒ



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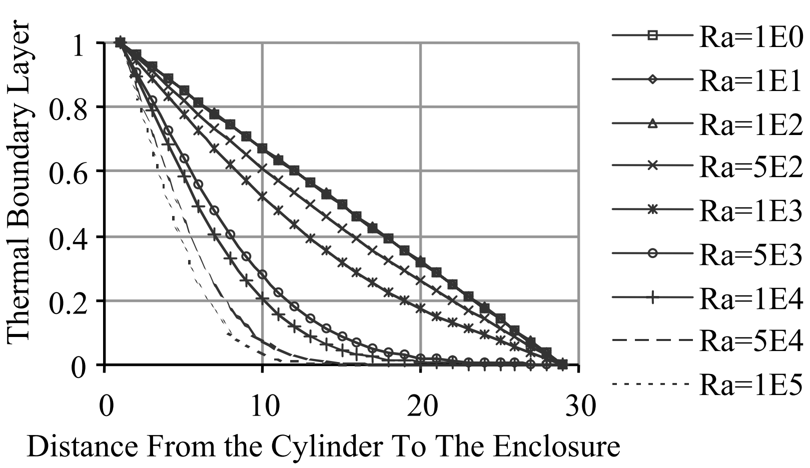

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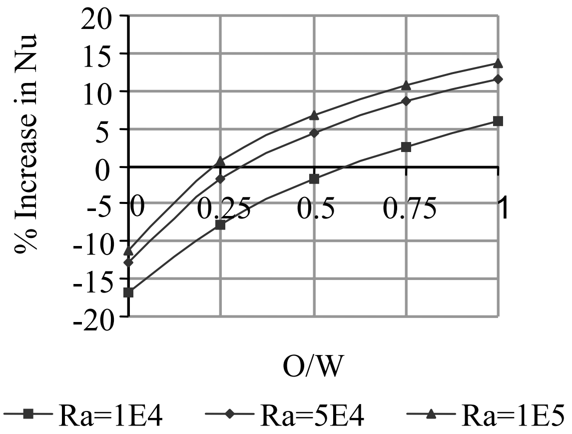
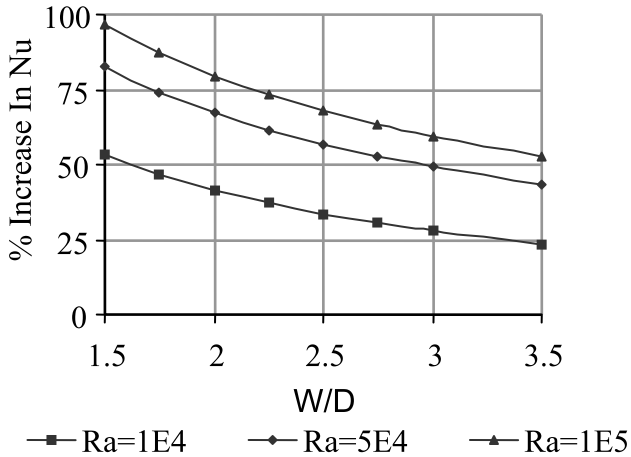
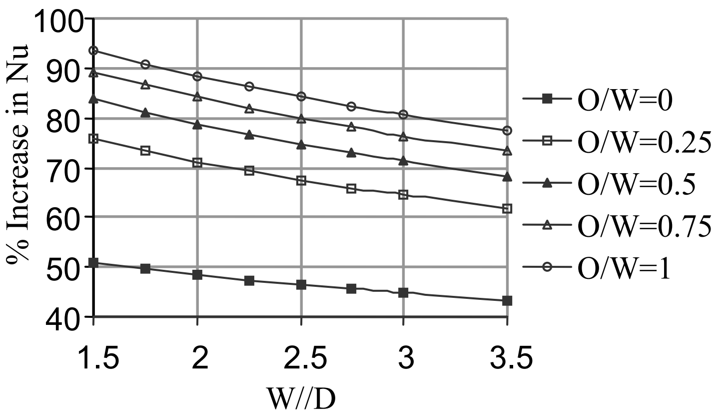


ŀƲƪǰ!ƒ ƪƥĜǒƨŀ ƘǁƪǰƥƥƵ ƪƥĜǒƨ! ŀǒǍƒǆ!ƒ ŀƲƪǰ!ƒ :19 ýǂT!ƒ
.O/W ŀƲƪǰ!ƒ Džǒl! 3.5 Ĭ!ƒ 1.5 ǇǆǆW/D



ŀơƙ!ƒ ƧǍnjƱŀ ƘǁƪǰƥƥƵ ƪƥĜǒƨ! ŀǒǍƒǆ!ƒ ŀƲƪǰ!ƒ :20 ýǂT!ƒ
.W/D ŀƲƪǰ!ƒ Džǒl!



.W/D ŀƲƪǰ!ƒ Džǒl! ǑǁǒƒƧ ƥƥƵ ƪƥĜǒƨŀ ƘǁƪǰƥƥƵ ƪƥĜǒƨ! ŀǒǍƒǆ!ƒ ŀƲƪǰ!ƒ :21 ýǂT!ƒ

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
m	[illegible]	D	m^2	[illegible]	A_i
- - -	[illegible]	Gr	m/s^2	[illegible]	g
W/m.K	[illegible]	k	- - -	[illegible]	J
- - -	[illegible]	n	m	[illegible]	L
- - -	[illegible]	Nu	- - -	[illegible]	Nu_L
N/m^2	[illegible]	P	m	[illegible]	O
W	[illegible]	Q	- - -	[illegible]	Pr
- - -	[illegible]	Re	- - -	[illegible]	Ra
s	[illegible]	t	K	[illegible]	T
- - -	[illegible]	U	m/s	[illegible]	u
- - -	[illegible]	V	m/s	[illegible]	v
- - -	[illegible]	*w*	m	[illegible]	W
- - -	[illegible]	X	m	[illegible]	x
- - -	[illegible]	Y	m	[illegible]	y
			kg/s	[illegible]	$\dot{m}$

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1/K	[illegible]	β	m^2/s	[illegible]	α
- - -	[illegible]	η	- - -	[illegible]	ϕ
- - -	[illegible]	θ	m^2/s	[illegible]	υ
- - -	[illegible]	τ	kg/m^3	[illegible]	ρ
- - -	[illegible]	ξ	1/s	[illegible]	ω
- - -	[illegible]	$\in$	m^2/s	[illegible]	ψ

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.15 ăĂǌď ƻ ǖ ƹ Ŏ5 ŁžĂ ư Ăď Łŏl5ƒ ŁljĂƱ Ɩ ƒ LJď Ŏžŏ Ʊ!ƒ ýď ơ!Ĝ lƧƒƧơ!ƒ ýĜlƙljƒ" ÜŎlŽ þďơď LJĜďŏƒ
.2002Üý Ƭ Ăď!ƒ ŁžďĜŋ ÜƧŏƙ ƪ ŋĜď ŁơĂƧƱDÜ "lƧƱĜljƙď Ƨŏ ƹ ƘĜơƙ5 ĭ Ʀ

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