A Study of the Vertical Continuous-Flow Conveyors*

By Tokio UEMATSU** and Toru OGAWA***

The authors studied experimentally and theoretically the characteristics of the vertical continuous-flow conveyors. In this paper two apparatus were used; one was small and the other was as large as one used practically. The theoretical formula of the chain tension was obtained from the equation based on the equilibrium of forces acting on materials in a duct having a rectangular section. It is easy to calculate the chain tension by the formula obtained here, and the calculated values are in good agreement with experimental ones for different kinds of materials and sizes of apparatus. From the results of experiments and numerical calculations, it is clear that the chain velocity has some effect on the volumetric efficiency and the chain tension, and there are optimum relations among the sectional dimension of the duct, the size of flight and the pitch.

1. Introduction

As the continuous-flow conveyors which can be used not only for horizontal but for vertical conveying have many merits, they are widely utilized to convey the pulverized and granular materials. The work on the vertical continuous-flow conveyors was previously made by Noguchi, Yamauchi and Tsukamaki[10]. They studied theoretically the basic relations between the characteristics of materials and the size of conveyors. There have been, however, few works based on the systematic experiments, and the authors intended, therefore, to analyze the vertical continuous-flow conveyors experimentally and theoretically.

In this paper two apparatus are used, one being small and the other being as large as one used practically. The volumetric efficiency and the chain tension are measured by changing the chain velocity and the kinds of materials. The materials used in this experiment are sand, coal and wheat.

The formula giving the chain tension is obtained from the equilibrium of forces acting on materials which are conveyed vertically upwards in the duct having a rectangular section.

2. Nomenclature

\[\begin{align*}
A & : \text{sectional area of duct} \\
A' & : \text{area bounded by the outer side of the flight} \\
A_1 & : \text{projected area of flight} \\
a & : \text{depth of duct} \\
a_1 & : \text{sectional size of flight} \\
b & : \text{width of duct} \\
G & : \text{weight of discharge per unit time} \\
H & : \text{lift} \\
h & : \text{depth from the discharge port} \\
k_1 & : \text{constant} \\
k_2 & : \text{constant} \\
m & : \text{hydraulic mean depth of the cross-section of duct} \\
p_s & : \text{vertical pressure of materials} \\
p_r & : \text{horizontal pressure of materials} \\
q & : \text{constant} \\
r & : \text{constant} \\
T & : \text{tension required for conveying materials} \\
t & : \text{pitch of flight} \\
v & : \text{mean velocity of materials} \\
v_c & : \text{chain velocity} \\
\gamma & : \text{apparent specific weight of materials} \\
\delta & : \text{clearance between the edge of flight and the wall of duct} \\
\eta & : \text{conveyor efficiency} \\
\eta_v & : \text{volumetric efficiency} \\
\eta_w & : \text{volumetric efficiency of the upper limiting value} \\
\eta_{\omega} & : \text{volumetric efficiency giving the maximum } \eta \\
\mu & : \text{coefficient of the internal friction} \\
\mu_s & : \text{coefficient of the friction between the wall of duct and materials} \\
\phi & : \text{angle of internal friction}
\end{align*}\]

3. Apparatus and procedure

The arrangements of the apparatus used in this paper are shown in Figs. 1 and 2*. For convenience' sake, the apparatus in Fig. 1 is called Apparatus I.

* The experiments using the apparatus shown in Fig. 2 were performed at the Daihatsu Machinery Works Co., Ltd.
Table 1 Dimensions of duct

<table>
<thead>
<tr>
<th></th>
<th>$a$ mm</th>
<th>$b$ mm</th>
<th>$A$ cm$^2$</th>
<th>$m$ mm</th>
<th>$A_l/A$</th>
<th>$t/m$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$t=25.4$mm</td>
<td>$t=50.8$mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apparatus I</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duct 1</td>
<td>47.9</td>
<td>53.2</td>
<td>25.5</td>
<td>12.6</td>
<td>0.177</td>
<td>2.02</td>
</tr>
<tr>
<td>Duct 2</td>
<td>54.8</td>
<td>63.9</td>
<td>35.0</td>
<td>14.7</td>
<td>0.129</td>
<td>1.73</td>
</tr>
<tr>
<td>Apparatus II</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duct 3</td>
<td>160</td>
<td>240</td>
<td>384</td>
<td>48</td>
<td>0.214</td>
<td>2.60</td>
</tr>
</tbody>
</table>

Table 2 Materials used in the experiment

<table>
<thead>
<tr>
<th></th>
<th>Sand</th>
<th>Coal A</th>
<th>Coal B</th>
<th>Wheat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apparent specific weight</td>
<td>$T$ kg/m$^3$</td>
<td>0.3~0.6</td>
<td>1.2~2.5</td>
<td>(Table 3)</td>
</tr>
<tr>
<td>Coefficient of internal friction</td>
<td>$\mu_l$</td>
<td>1.320</td>
<td>804</td>
<td>1.130</td>
</tr>
<tr>
<td>Coefficient of friction between wall and materials</td>
<td>$\mu_s$</td>
<td>0.49</td>
<td>0.40</td>
<td>0.48</td>
</tr>
</tbody>
</table>

and the one in Fig. 2 Apparatus II.

3-1 Apparatus I

The conveyor-chain used in this apparatus is the same chain as one used in horizontal conveying (2). The flights are welded to the chain at regular intervals. And they are made of mild steel wire with a square section of size $a_1=3.2$ mm, and bent into the shape shown in Fig. 1 (b).

The lift $H$ is 1.94 m as shown in Fig. 1.

The duct in which materials are conveyed upwards is interchangeable, and two kinds of the duct are used in this experiment. The dimensions of the duct are shown in Fig. 1 (b) and Table 1. The ratio of the projected area of the flight $A_l$, hatched in Fig. 1 (b), to the cross-sectional area of the duct $A$ is called an area ratio. As the value of $A_l/A$ is constant, these two ducts are distinguished from each other by the area ratio $A_l/A$.

The notation $m$ listed in Table 1 represents the hydraulic mean depth of the cross-section of duct.

Two kinds of materials, sand and coal A shown in Table 2, are used in the experiments for Apparatus I. The materials stored in the hopper are fed into the duct at a uniform rate through the orifice fitted at the bottom of the hopper. To change the discharge, the orifice plates having a circular hole of various sizes are used. The relation between the discharge of materials and the opening of the orifice has been preliminarily examined. The materials fed into the duct are conveyed upwards from the lowest part of the duct to the discharge port and returned to the hopper from there.

The chain velocity can be changed by replacing a spur gear in the reduction gear box with different ones, and in this experiment the velocity $v$ is selected as follows:

\[ v = 0.1, 0.3 \text{ and } 0.5 \text{ m/sec} \]

The chain tension is measured by means of the pick-up using strain gauges.

Table 3 Size of coal B

<table>
<thead>
<tr>
<th>Size mm</th>
<th>Weight percentage %</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.11</td>
<td>10</td>
</tr>
<tr>
<td>0.11~0.15</td>
<td>4</td>
</tr>
<tr>
<td>0.15~0.3</td>
<td>9</td>
</tr>
<tr>
<td>0.3~0.6</td>
<td>8</td>
</tr>
<tr>
<td>0.6~1.2</td>
<td>9</td>
</tr>
<tr>
<td>1.2~2.5</td>
<td>15</td>
</tr>
<tr>
<td>2.5~4.8</td>
<td>16</td>
</tr>
<tr>
<td>4.8~</td>
<td>20</td>
</tr>
</tbody>
</table>

![Fig. 1 Apparatus I](image)

3-2 Apparatus II

The lift of this apparatus is 4.35 m.

The conveyor-chain and the cross-section of the duct are shown in Fig. 2 (b), and their dimensions are also listed in Table 1. The pitch of flight of this chain is 125 mm and is about five times as large.
as that used in Apparatus I, and the chain having the same size as this is practically used for the continuous-flow conveyors.

Two kinds of materials, coal B and wheat in Table 2, are used in Apparatus II, and the sifted size of coal B is shown in Table 3. And the materials stored in the hopper are fed into the duct at a uniform rate through the opening of the gate mounted at the bottom of the hopper. The discharge can be changed by varying the opening of the gate. The materials fed into the duct are conveyed upwards to the discharge port and returned to the hopper through the circulating chute. The discharge is evaluated from the weight of materials led into the vessel on the weighing machine.

The chain velocity \( v_e \) can be easily changed. The values of the chain velocity are evaluated from the rotating velocity of the sprocket wheel, and their maximum value is about 1 m/sec, which is two times as large as that obtained in Apparatus I.

As the direct measurement of the tension is difficult, the tension is evaluated from the measured values of the motor input by using the performance curve of the electric motor and the loss of the reduction gear.

Though the apparatus has a horizontal part of length 1.9 m as shown in Fig. 2 (a), it is considered that there is no horizontal conveying since materials are fed at the end of the horizontal part.

3-3 Volumetric efficiency

When all the materials in the duct are conveyed with the same velocity as the chain, the discharge is given by \( \gamma A v_e \), where \( \gamma \) is the apparent specific weight, \( A \) the sectional area of the duct and \( v_e \) the chain velocity. Then the ratio of the actual discharge \( G \) to the maximum discharge in the ideal case \( \gamma A v_e \) is called the volumetric efficiency and denoted by \( \eta_v \), i.e.

\[
\eta_v = \frac{G}{\gamma A v_e}
\]

Therefore \( \eta_v \) is a dimensionless value of the discharge. Let \( v \) be the mean velocity of materials in the duct, then the discharge \( G \) can be expressed by

\[
G = \gamma A v.
\]

From Eq. (1) and the relation mentioned above,

\[
\eta_v = \frac{v}{v_e}
\]

then the volumetric efficiency \( \eta_v \) is the ratio of the mean velocity of materials to the chain velocity, and has the same expression as in horizontal conveying\(^{(2)}\).

3-4 Chain tension

The tension \( T \) required for conveying materials is defined by the difference between the total tension and the no-load tension. Neglecting the volume of the chain and the flight, the weight of all the materials in the duct is given by \( \gamma AH \). In this paper the relation between the dimensionless value \( T/(\gamma AH) \) and the volumetric efficiency \( \eta_v \) is studied.

3-5 Conveyor efficiency

The power needed for lifting materials up to the height \( H \) at a rate \( G \) per unit time is \( GH \), and the power given to the conveyor is \( T v_o \). Then the conveyor efficiency \( \eta \) is defined by the equation

\[
\eta = \frac{GH}{T v_o}
\]

Introducing the expression \( G = \gamma A v \) and Eq. (1) into Eq. (3)

\[
\eta = \frac{\eta_v}{(T/(\gamma AH))}
\]

which gives the relation between \( \eta \) and \( \eta_v \) treated here.

4. Formula for the chain tension

The authors make a few assumptions for forces acting on materials conveyed vertically upwards in the duct, and get the formula for chain tension required for conveying materials, by obtaining the sum of the forces acting on materials from the flight. Now the cross-section of the duct used in this paper has a rectangular section of sides \( a \) and \( b \), and the flight, which is made of the rod with a square section of size \( a_t \), is bent into the shape shown in Fig. 3.

The assumptions in this paper are as follows:

(1) The pressure of materials on the section normal to the vertical line, \( p_n \), is normal to the section and constant in every part. And also the vertical pressure \( p_h \) is a function of the depth from the discharge port to the section, \( h \).

(2) The increment of \( p_h \) for one pitch of the
flight \( t \) is \( \Delta p = t(\Delta p_0/\Delta t) \), and \( \Delta p_0 \) varies linearly as the increment of \( h \) between the flights.

(3) As shown in Fig. 3, the force acting from the flight is the pressure \( k_1p_0 \) at the upper surface of the flight and the frictional force per unit area \( k_2h_1p_0 \) on the side of the flight, where \( k_1 \) and \( k_2 \) are constant and \( \mu_1 \) is the coefficient of friction between the flight and materials. Let \( A_1 \) be the total area of the upper surface of the flight, then the area of the side on which the frictional force acts is equal to \( 2A_1 \).

(4) The frictional force on the wall of duct is \( k_2h_2p_0 \) per unit area as assumed previously for the side of the flight.

From these assumptions, the equilibrium equation of the forces, which act on materials within one pitch of the flight as shown in Fig. 3, is obtained as follows:

There are two kinds of forces acting upwards, one being the force by the flight, \( A_1(k_1+2k_2\mu_1)(p_0+\Delta p_0) \) and the other the vertical pressure of materials \( A(p_0+\Delta p_0) \). On the other hand, the forces acting vertically downwards are of three kinds. The first is the gravitational force expressed by \( \gamma A \) neglecting the volume of the chain and the flight, the second is the vertical pressure \( A p_0 \), and the last is the frictional force between the wall of duct and materials given by \( 2k_2h_2\mu_1(a+b)(p_0+\frac{1}{2}\Delta p_0) \).

Introducing the relation of the assumption (2) into the equilibrium equation,

\[
\frac{\Delta p_0}{\Delta t} = \frac{\gamma}{1+q-r(t/m)} \frac{p_0}{t} \]

where \( q = (k_1+2k_2\mu_1)A_1/A, r = k_2h_2 \), and \( m = ab/2(a+b) \).

Introducing Eq. (4) and using the condition \( p_0 = 0 \) at \( h = 0 \), \( \Delta p_0 \) is given by

\[
p_0 = \frac{\gamma t}{q-r(t/m)} \left[ 1 - e^{-[q-r(t/m)](t/H)/(1+q-r(t/m))} \right].
\]

The number of the flights contacting with materials in the duct, \( n \), is given by \( n = \frac{H}{t} \). The vertical pressure at the point of the \( i \)th flight from the discharge port, \( p_{0i} \), is

\[
p_{0i} = \frac{\gamma t}{q-r(t/m)} \left[ 1 - e^{-[q-r(t/m)](t/H)/(1+q-r(t/m))} \right]
\]

for the depth \( h \) is approximately equal to \( t \) at that point. The force, which acts on materials from the \( i \)th flight, is given by \( qAp_{0i} \). So the force \( T_i \) acting on materials from all of the flights in contact with materials, is represented by

\[
T_1 = \sum_{i=1}^{n} qAp_{0i} = \frac{q'At}{q-r(t/m)} \int_0^{H/t} \left[ 1 - e^{-[q-r(t/m)](t/H)/(1+q-r(t/m))} \right] dt.
\]

Therefore

\[
\frac{T_1}{\gamma AH} = 1 + \frac{r(t/m)}{q-r(t/m)} \left[ 1 - e^{-[q-r(t/m)](H/t)/(1+q-r(t/m))} \right]
\]

It is considered that materials fed into the lowest part of the duct are pushed into it with the mean velocity \( v \) against the pressure at that point \( p_{0i} \). So the power \( AP_{0i}Hv \) is required for pushing materials into duct, and the tension needed for giving this power, \( T_2 \), is represented by \( AP_{0i}Hv/\gamma \). Using Eq. (2) and \( p_{0i} \), the value of \( p_0 \) at the point \( h = H \),

\[
\frac{T_2}{\gamma AH} = \frac{T_2}{q-r(t/m)} \left[ 1 - e^{-[q-r(t/m)](H/t)/(1+q-r(t/m))} \right]
\]

Therefore the dimensionless number of the chain tension required for conveying materials is given by

\[
\frac{T}{\gamma AH} = \left( T_1 + T_2 \right) / (\gamma AH)
\]
The constants $k_1$ and $k_2$ used in the assumptions (3) and (4) are connected with the pressure of materials, and vary with materials as well as the coefficient of friction $\mu$. It is assumed for these values as follows:

AEDDB in Fig. 4 is a cross-section of the flight.

It is assumed that the materials ABC on the upper surface of the flight are moved with the flight and that the materials outside of ABC are conveyed upwards sliding on the faces CA and CB with a slightly slower velocity than that of flight. And it is also assumed that the horizontal pressure near the flight is equal to the vertical pressure owing to the effect of the flight. Therefore the faces CA and CB make an angle $(\pi/4)$ with the face AB, then the ratio $k_1$ of the pressure on the upper surface of the flight $p_0\tan^{2}(\pi/4)$ to the vertical pressure is given by

$$k_1 = \tan^{2}(\pi/4) + \phi_1(2)$$

where $\phi_1 = \tan^{-1}\mu$, is the angle of internal friction.

The authors tried to observe the motion of materials in the duct which is made of transparent plates. When the volumetric efficiency is small, the materials near the wall are scarcely conveyed upwards and move vertically up and down. As $\gamma_v$ grows larger, the amount of the materials conveyed along the wall increases, but the materials move also up and down. So let $p_0$ be the pressure of materials acting on the wall, and let it be assumed that the frictional force on the wall is represented by $(1+\gamma_v)/2 \mu p_0$ per unit area. Namely, it is considered that, when $\gamma_v = 0$, half of the materials in contact with the wall moves upwards, and when $\gamma_v = 1$, all of the materials move upwards. Now, if the two directions of the principal stresses of materials are vertical and horizontal, $p_0/p_0 = k_1$. Then $k_2$ contained in the assumptions (3) and (4) is expressed by

$$k_2 = (1+\gamma_v)/(2k_1)$$

If the characteristics of materials and the dimensions of the conveyor are given, the tension required for conveying materials can be calculated by Eqs. (5) to (9).

5. Experiments and calculations

For the case of sand being conveyed, the relation between $T/(\gamma AH)$ and $\eta_v$ is shown in Fig. 5. This experiment is performed with the chain velocity $v_0 = 0.1 \sim 0.5$ m/sec, and it seems that the chain velocity slightly affects the characteristics of the conveyors.

The effect of the pitch of flight is remarkable at the state of large $\phi_v$, namely at great discharging. When the chain of the smaller pitch is used, the value of $T/(\gamma AH)$ is not so large even for a higher value of $\eta_v$, but when the pitch is larger, $T/(\gamma AH)$ increases steeply together with $\eta_v$.

The calculated values are shown in the figure by the full lines. For sand shown in Table 2, the value of $h_1$ given by Eq. (8) is 3.0, and in the case of the duct 1 and the chain of $t = 25.4$ mm, i.e. $A_t/A = 0.177$ and $t/m = 2.02$, Eq. (7) becomes

$$T/(\gamma AH) = 1 + (548 + 4787\eta_v - 2427\eta_v^2)/(39.5 - 13.6\eta_v^2)$$

In this case the exponential term in the brackets of Eqs. (5) and (6) is very small compared with unity, then Eq. (7) can be simplified into Eq. (10) by neglecting this term.

For the case of the duct 1, $A_t/A = 0.177$, the calculated values are in good agreement with the experimental results, but for the duct 2 the calculation gives a larger value than the experiments. In the latter case the clearance between the flight and the wall is too wide compared with the size of materials, and the materials near the wall scarcely move. Therefore it is considered that Eq. (7) which is obtained by the equilibrium equation of the forces acting on all the materials in the duct, cannot be applied to the duct having a large clearance. In the experiments, by enlarging the cross-section of

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Fig. 4 Forces acting on materials on the flight

Fig. 5 Relation between $T/(\gamma AH)$ and $\eta_v$
the duct alone, the discharge does not increase but the total efficiency becomes lower. So the chain tension may be calculated by Eq. (7).

Fig. 6 shows the experimental results for coal A using the duct 2, and Fig. 7 the results for Apparatus II. If too much materials are fed, all of them cannot be conveyed. In this case the excess materials fed over the conveying power stay at the feeding port, and the chain tension increases suddenly. So there is an upper limit to the volumetric efficiency \( \eta_v \). Let this limiting value be denoted by \( \eta_{ve} \). From the experiments, the value of \( \eta_{ve} \) is represented by

\[
\eta_{ve} = \frac{A'}{A} \quad \text{(11)}
\]

where \( A' \) is the area bounded by the outer side of the flight. Then \( \eta_{ve} \) grows larger as the clearance \( \delta \) becomes smaller, but for too small \( \delta \) it happens that materials are clogged or crushed in that clearance. Therefore the clearance should be made about three times as large as the mean size of materials, just as in horizontal conveying\(^{(3)}\).

In the experiments for Apparatus II, the chain velocity \( v_c \) is changed between about 0.2 m/sec and 1.0 m/sec. Considering from the results of \( v_c < 0.6 \) m/sec shown in Fig. 7, the effect of the chain velocity scarcely appears. In the case of \( v_c > 0.6 \) m/sec, the limiting value of the volumetric efficiency \( \eta_{ve} \) is a little smaller than in the case of \( v_c < 0.6 \) m/sec. By the results for Apparatus I, in which the maximum chain velocity is nearly equal to 0.5 m/sec, the characteristics of the conveyors are not affected by the chain velocity. So it is seen that the velocity nearly equal to 0.6 m/sec is the most effective for conveying materials. However, if more discharge is required of the same device, the requirement will be satisfied by increasing the chain velocity though it causes a little decrease in the efficiency.

The calculated values for coal B shown in Fig. 7 are the results obtained by using the value of coal A for the coefficient of friction. As shown in Figs. 5 to 7, the calculated values of the chain tension coincide with the experimental ones fairly well, so the tension required for conveying materials is given by Eq. (7) for various sizes of device and for various kinds of materials.

From the calculations, it is clear that the value of \( \frac{T}{(\gamma AH)} \) becomes smaller for the larger value of \( A_1/A \) and for the smaller one of \( t/m \). But, when \( A_1/A > 0.2 \) and \( t/m < 2 \), the value of \( \frac{T}{(\gamma AH)} \) varies a little, so it is seen that the relations \( A_1/A \approx 0.2 \) and \( t/m \approx 2 \) give the effective dimensions of the conveying device.

The relation between the conveyor efficiency \( \gamma \) and the volumetric efficiency \( \eta_v \) is shown in Fig. 8, in which the results for Apparatus II are plotted. Let \( \eta_{ve} \) be the volumetric efficiency giving the maximum \( \gamma \). From the experiments, the following relation is given:

\[
\eta_{ve} 
\approx 0.8 \eta_v \quad \text{(12)}
\]

If the dimensions of the duct and the flight are given, \( \eta_{ve} \) is calculated by Eqs. (11) and (12), and the calculated value gives the effective condition for operation.
6. Conclusion

The chain velocity \(v_c\) affects the efficiency a little, and it is desirable to take the value which is nearly equal to 0.6 m/sec.

When the chain of the short pitch is used, the degree of tension is reduced. And the chain with the dimensions \(A_1/A_2=0.2\) and \(l/m=2\) is effective, since the tension does not grow large and the weight of the chain can be lessened.

The highest efficiency is attained at the state in which the volumetric efficiency is expressed by Eq. (12).

The calculated values of the chain tension by Eq. (7), which is given from the equilibrium of the forces acting on the materials in the duct, are in good agreement with the results of experiments in which the kind of the materials, the dimension of the flight and the size of the device are changed. Therefore this equation can be used to obtain the chain tension for conveying materials.

Acknowledgement

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References


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The Effect of Blowing or Suction on Heat Transfer

by Free Convection from a Vertical Flat Plate*

By Ikuo MABUCHI**

The effect of blowing or suction on free convection heat transfer about a vertical flat plate is analyzed by an approximate method by using the integral formulas for momentum and energy equations. There are similar solutions, if the surface temperature distribution is expressed by the equation \(T_x = T_w + A a^n\) (\(x\): distance from leading edge, \(A\) and \(n\): constants, \(T_w\): temperature in quiescent ambient fluid and the blowing or suction rate distribution is proportional to \(x^{(n-1)/4}\). Approximate similar solutions found under these conditions may be applied for any exponent \(n\) (0\(\leq n \leq 1\)) in a power law surface temperature distribution and the gases for any Prandtl number, if the blowing or suction Reynolds number is restricted within the following ranges.

At \(n = 0\)
\[
|\nu_x| |\nu| \leq 0.6 (G_{rs}/4)^{1/4}, \text{ for } P_r = 0.73 \\
|\nu_x| ^2 |\nu| \leq 0.5 (G_{rs}/4)^{1/4}, \text{ for } P_r = 1
\]

At \(n = 1\)
\[
|\nu_x| |\nu| \leq 0.8 (G_{rs}/4)^{1/4}, \text{ for } P_r = 0.73 \\
|\nu_x| ^2 |\nu| \leq 0.65 (G_{rs}/4)^{1/4}, \text{ for } P_r = 1
\]

where \(\nu\) is the kinematic viscosity of fluid and \(G_{rs}\) denotes the local Grashof number at the position \(x\).

1. Introduction

The studies on the mass transfer cooling are aimed at the reduction of heat transfer to the high speed vehicle and the heat insulation from the high temperature gas to the wall. The effect of blowing or suction on the free convection heat transfer about a vertical plate has been considered by Eichhorn. He investigated the similar solutions of

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