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# TURBULENT NATURAL CONVECTION ON A VERTICAL PLATE AND IN A VERTICAL LAYER

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**Abstract**—An experimental investigation was carried out on the hydrodynamics of a turbulent free-convection boundary layer at a vertical plate and in a vertical film of ethyl alcohol closed at both ends. Herein are presented longitudinal component profiles of the mean velocity vector and fluctuation rate of the same velocity vector component. On the basis of the present data and experimental results of other authors, the existence is shown of a quasi-stationary wall layer in the turbulent boundary layer at a vertical plate, the thickness and maximum velocity of which satisfy the condition

$$Re_1 Pr^{\frac{1}{2}} = \frac{U_{max}\delta_1}{(\nu a)^{\frac{1}{2}}} = \text{const.}$$

It is found experimentally that along the middle of the vertical cross-section in the central part of the film the temperature gradient is $dT/dx$ = const. Within the region of constant temperature gradient in the turbulent boundary layer there is a quasi-stationary wall layer for which

$$Re_1 = \frac{U_{max}\delta_1}{\nu} = \text{const.}$$

The number $Re_1$ is a function of the relative temperature gradient

$$\frac{1}{\Delta T}\frac{dT}{dx}$$

in the external side of the boundary layer.

## NOMENCLATURE

- $X$, longitudinal coordinate;
- $\tilde{x}$, dimensionless longitudinal coordinate; $x/H$;
- $y$, coordinate normal to heat transfer surface;
- $\delta$, thickness of boundary layer;
- $l$, thickness of vertical film;
- $H$, height of vertical film;
- $h$, relative height of vertical film $H/l$;
- $\delta_1$, distance from wall to maximum velocity coordinate in film;
- $T_{1,2}$, temperature of heated and cold heat transfer surfaces, respectively;
- $\Delta T$, temperature difference between vertical heat transfer surfaces $T_1 - T_2$;
- $T_0$, temperature outside the boundary layer;
- $U$, longitudinal component of mean velocity vector;
- $U_{max}$, maximum mean velocity in a given horizontal cross-section;
- $u'$, longitudinal component of velocity fluctuations;
- $\theta'$, transverse component of velocity fluctuations;
- $\alpha$, thermal diffusivity;
- $\nu$, kinematic viscosity;
- $\rho$, density;
- $\beta$, volume expansion coefficient;
- $Pr$, Prandtl number $\nu/a$;
- $Re_1$, Reynolds number $U_{max}\,\delta_1/\nu$;
- $Ra_l$, Rayleigh number $\beta g \Delta T l^3/\nu a$;
- $Ra$, Rayleigh number for horizontal cross-section $\beta g \Delta T x^3/\nu a$;
- $\frac{1}{\Delta T}\frac{dT}{dx}$, relative temperature gradient;
- $\beta h$, dimensionless temperature gradient $\frac{H}{\Delta T}\frac{dT}{dx}$.

NOWADAYS the theories of heat and mass transfer with turbulent free convection, based on solution of the integral equations of motion and energy, stem from the assumption that relationships for friction and heat transfer are similar to those for forced flow in a turbulent boundary layer.

Such a theory [1] satisfactorily describing an experiment on heat transfer at a vertical plate within a limited range of *Ra* has failed in describing temperature distribution and hydrodynamics of a turbulent boundary layer with free convection [2, 3].

Another approach to an analysis of turbulent free convection is given in reference [4]. It is believed that near the heat transfer surface there exists, adjoining the wall, a quasi-stationary layer of liquid defined at $Pr = 1$ by the condition of constancy of a characteristic value of, and in the outer part of the boundary layer there is a region of intense molar exchange.

The paper presents results on investigation of the hydrodynamics of a turbulent boundary layer with free convection at a vertical plate and in a closed vertical film. On the basis of the present hydrodynamic investigations and other authors' experiments [2, 3] a quasi-stationary layer is determined from the condition of constancy of a characteristic Reynolds number [4].

An experimental investigation of hydrodynamics with turbulent free convection at a vertical plate was conducted on the installation, the schematic drawing of which is given in Fig.

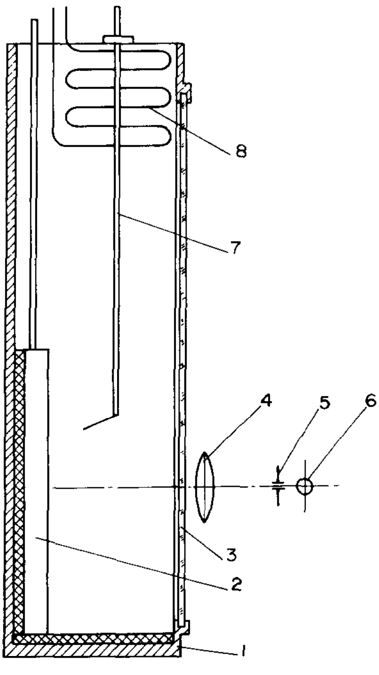
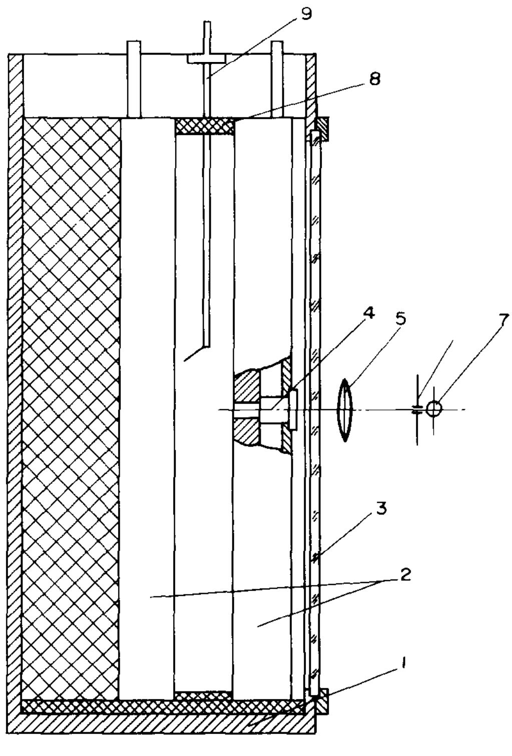
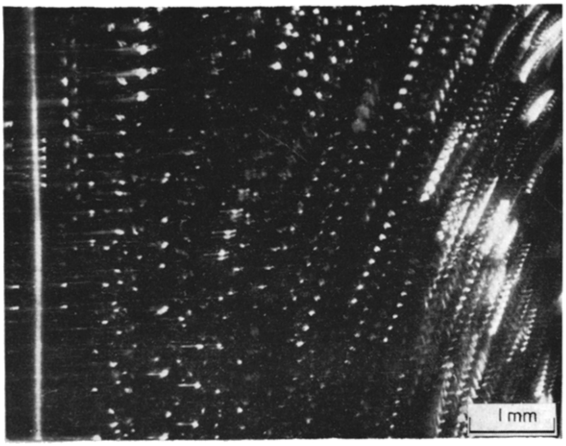


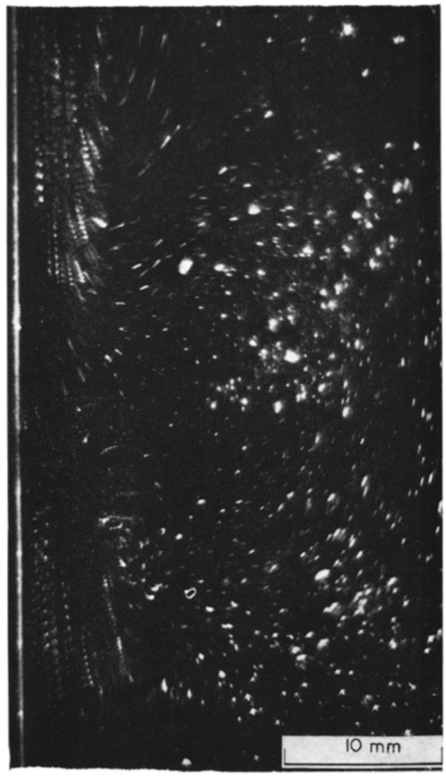

FIG. 1. (a) The experimental installation for investigation of free convection at a single vertical plate 1—container; 2—flat heat exchanger; 3—glass window; 4—condenser lens; 5—slot; 6—flash lamp; 7—thermocouple probe; 8—tubular heat exchanger.



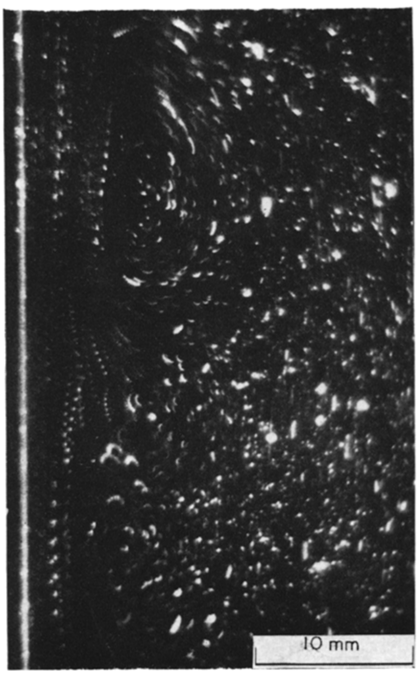

(b) The experimental installation for investigation of free convection in a vertical confined film. 1—container; 2—flat heat exchanger; 3—glass window; 4—organic glass window 8 × 15 mm, 20 mm dia.; 5—condenser lens; 6—slot; 7—flash lamp; 8—calibrated frame; 9—thermocouple probe.




(a) $Ra = 8{\cdot}45 \,.\, 10^7$; $H = 395$ mm; $l = 30$mm.




(b) $Ra = 2{\cdot}4 \,.\, 10^7$; $H = 395$ mm; $l = 49$mm.




(c) $Ra = 7{\cdot}05 \,.\, 10^7$; $H = 395$ mm; $l = 49$mm.

FIG. 2. Pictures of liquid flow near the the heat-transfer surface.

1a. Heat-exchanger (2) with dimension of 450 × 80 × 20 mm made of copper was installed into container (1), 900 × 140 × 110 mm, which was provided with transparent front and lateral walls. Constant temperature of the heat transfer surface was provided by water from a thermostat circulated through the heat exchanger cavity (420 × 68 × 7 mm). The temperature of the heat transfer surface was measured with nichrome–constantan thermocouples 0·2 mm dia. positioned in the middle cross-section at different heights. Thermocouples were passed through openings 1·5 mm dia., placed along the heat transfer surface at a distance of 0·5 mm from the latter, then led out to the surface through a hole 0·5 mm dia. and caulked in. E.M.F. of the thermocouples was measured with potentiometer p 2/1.

The heat transfer surface was ground and polished. Constancy of liquid temperature over the height of the working volume (outside the boundary layer) and with time was provided by tubular heat exchanger (8) installed in the upper part of the container, the temperature of which was maintained constant with the help of circulating water from a thermostat. As measurements showed, the temperature of the working volume was constant with time and changed slightly with height. To prevent liquid penetration from the ends into the boundary layer, the heat exchanger was pressed from one side to the ground front glass and, from the other side, a screen of organic glass was mounted. The heat transfer surface temperature measured was $10^{-2}$°C/cm.

A vertical liquid film was formed by two heat exchangers (2) Fig. 1b made of copper with dimensions of 450 × 80 × 20 mm; 700 × 80 × 30 mm. Constant temperatures $T_1 > T_2$ of heat transfer surfaces were provided by circulation of water from a thermostat through heat exchanger cavities. Heat exchangers were installed into a container 900 × 140 × 110 mm. The film geometry was provided by a graduated frame (8) against which the heat exchangers were pressed. By its vertical end surfaces the heat exchangers were set tightly to the front container wall.

Thus, the operating volume was limited by the heat transfer surfaces, frame and front container glass. The variation of temperature of the heat transfer surface with height was 0·02°C/cm. The temperature in the vertical film was measured with a thermocouple probe in the following manner:

A thermocouple (nichrome–constantan, 0·2 mm dia.) was inserted through a capillary, 3 mm o.d., and let out so that the junction was at 35 mm distance normal to the capillary. The probe passed through an opening in the vertical end-face of the frame along the vertical end-face wall. Transverse displacement of the thermocouple junction was provided by turning around the axis. The distance from the heat transfer surface and the vertical coordinate were measured with the help of a microscope placed on a traversing equipment. Velocity measurement in the turbulent boundary layer with free convection were conducted under nonisothermal conditions with low-frequency fluctuations and negative values of instantaneous (Fig. 2b) and averaged (Fig. 9) velocities. The flow peculiarities mentioned impose certain conditions on the applicability of different methods of hydrodynamic investigations.

Measurement of an instantaneous velocity with a thermoanemometer needs a device for compensation of temperature fluctuations. Within the small or zeroth mean velocity range an instantaneous velocity may have negative values. In this boundary layer region the use of a thermoanemometer insensitive to fluid flow direction is incorrect [2, 3].

Measurement of the velocity both in the vicinity of the wall and of the forced flow is difficult because of "filament-wall" heat transfer and due to the fact that the flow is distorted by the probe. Application of the Pitot tube for velocity measurement is limited not only because of flow direction but its sensitivity as well [5].

Visual (photographic) methods are free of these drawbacks therefore they appear to offer more perspective for the investigation of turbulent natural convection in liquids.

The present hydrodynamic measurements were carried out by the method of stroboscopic flow visualization with the help of an electronic stroboscope designed in the Thermal Physics Institute, Siberian Branch of the U.S.S.R. Academy of Sciences [6, 7].

An electronic stroboscope permits to obtain a train of 8 flashes with the prescribed frequency. Flash durability is 50 $\mu$cs. Figure 1a presents an optical circuit of the experiment. A beam of light through slot (6) of 20 × 0·2 mm from photoflash lamp ИФК-120 was projected by light condenser (5) through the transparent lateral wall of the container (3) onto the heat exchanger (2) so that liquid flow near the heat transfer surface was illuminated with a narrow light beam 0·2–0·3 mm thick.

Particles of aluminium in a layer cut with optical knife were photographed using lateral lighting and discontinuous tracks were obtained on a motionless film. The particles of aluminium, suspended in alcohol, were of 5–15 $\mu$c. To investigate the hydrodynamics in a film the heat exchanger positioned near the transparent container wall was fitted with drilled openings. In these holes (4) were placed copper plugs or optical inserts 20 mm dia. (8 × 15 mm) made of organic glass.

The copper and optical plugs were set out flush with the heat transfer surface. For the photographing of the wall region of the boundary layer a four fold magnification was employed. The photograph (Fig. 2a) presents an instantaneous velocity field. The mean hydrodynamic characteristics was obtained by averaging with respect to a great number of photos. For this purpose 150 photographs were used.

Figure 3 presents the mean velocity profiles in a turbulent boundary layer with free convection at an individual vertical plate. The graph gives comparison between the experimental profile and that predicted by the theory of Eckert and Jackson [1]. The comparisons made and data from [2, 3] show, that the theory based on the supposition of the existence of an analogy in heat and mass transfer relationships with turbulent free and forced convections fails in describing the hydrodynamics of free-convective turbulent boundary layer at $Pr$ = 0·72–14.

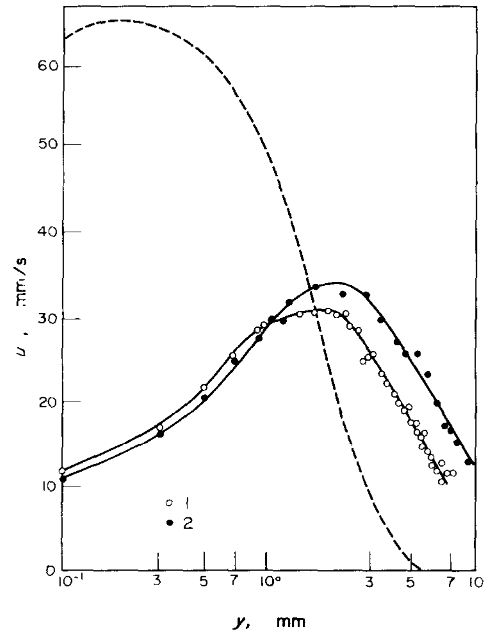



FIG. 3. Mean velocity profiles in the turbulent boundary layer at a single plate
1. $Ra = 2{\cdot}15 \cdot 10^{10}$; $x$ = 275 mm; $\Delta T$ = 11·8°C; $T_0$ = 29·2°C.
2. $Ra = 4{\cdot}83 \cdot 10^{10}$; $x$ = 363 mm; $\Delta T$ = 11·6°C; $T_0$ = 29·4°C.
--- Theory [1] for $Pr$ = 13·2; $x$ = 360 mm; $\Delta T$ = 11·6°C.

The problem lies in the determination of a quasi-stationary layer, the dimensions and velocity of which are defined by constancy of the $Re_1$ value [4]. It is known that the magnitude of the quasi-stationary layer in a turbulent boundary layer at a plate with forced flow is estimated by the linear law of the averaged velocity change with a transverse coordinate.

To estimate the velocity behaviour near the wall with free turbulent convection, let us consider the flow parallel to the heat transfer surface. In the vicinity of the wall the turbulent shear stress $\tau' = -\rho\overline{u'v'}$ is considerably less than the molecular friction value $\mu\partial u/\partial y$ and the equation of motion is

$$\nu \frac{\partial^2 u}{\partial y^2} = -\beta g \Delta T. \qquad (1)$$

With the boundary conditions $u(0_1\, x) = 0$,

$$\left.\frac{du}{dy}\right|_{y=0} = \frac{\tau_w}{\mu}$$

we have

$$u = -\iint \frac{\beta g \Delta T}{\nu} d^2 y + \frac{\tau_w}{\mu} y. \qquad (2)$$

As is seen from relation (2), in the vicinity of the heat transfer surface with natural convection the linear law of the velocity change with the transverse coordinate is not valid, therefore the quasi-laminar layer value can not be estimated by the linear character of the velocity change.

The singular point in the averaged velocity profile is the coordinate of the maximum velocity position in the layer ($\delta_1$), where $(\partial u/\partial y) = 0$ and molecular friction near this point is infinitesimal compared with the turbulent one $(-\rho\overline{u'\theta'})$.

As experiments showed (Fig. 4), in the vicinity of this point ($\delta_1$) there takes place the maximum root-mean-square fluctuation of the longitudinal velocity. Within $0 < y < \delta_1$ there is observed a growth of velocity fluctuations up to the maximum value (Fig. 4). A similar change of root-mean-square fluctuations takes place in the laminar sublayer of a turbulent boundary layer in a forced flow past a flat plate.

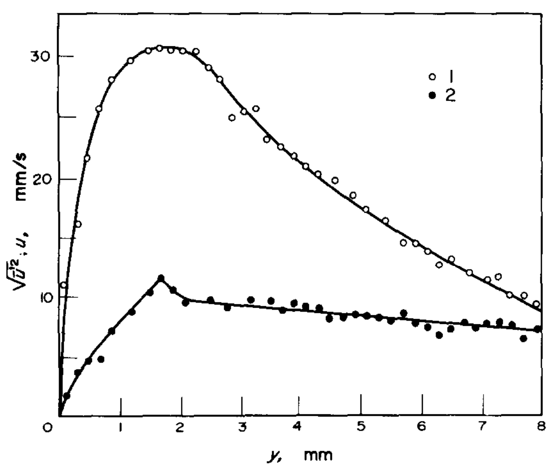



FIG. 4. Mean velocity profiles and fluctuation rate of the longitudinal component of the velocity vector $Ra = 2{\cdot}15 \,.\, 10^{10}$; $x = 275$ mm; $\Delta T = 11{\cdot}8$°C; $T_0 = 29{\cdot}2$°C.

Figure 5 presents experimental values of

$$Re_1 \,.\, Pr^{\frac{1}{2}} = \frac{u_{max}\delta_1}{(a\nu)^{\frac{1}{2}}}$$

based on maximum flow velocity in the boundary layer and thickness $\delta_1$ vs. $Ra$. Physical properties of the liquid are taken at the mean

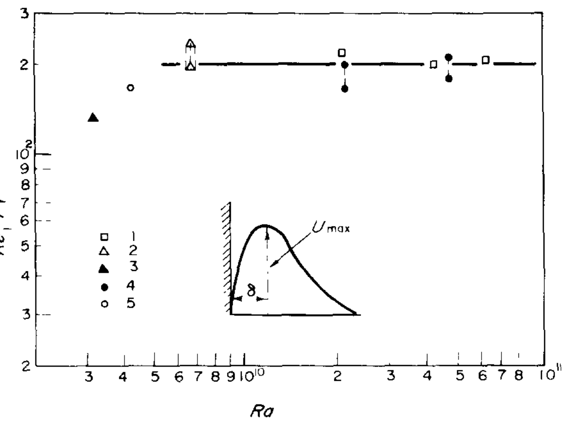



FIG. 5. $Re_1 Pr^{\frac{1}{2}}$ vs. $Ra$ for a vertical plate
1—from experiments [2] $Pr = 0{\cdot}72$.
2—from experiments [3] $Pr \approx 4$.
3—from experiments [3] $Pr = 6{\cdot}6$, transition region.
4—experiments of the present paper $Pr = 13{\cdot}2$.
5—from experiments [5] $Pr = 0{\cdot}72$.

temperature

$$T_m = \frac{T_1 + T_0}{2}$$

Since the maximum velocity position is not clearly expressed, Fig. 5 gives range of $Re_1 \,.\, Pr^{\frac{1}{2}}$.

As is seen from Fig. 5, the value

$$\frac{U_{max}\delta_1}{(a\nu)^{\frac{1}{2}}}$$

for $Pr = 0{\cdot}72$; 4; 13·2 does not change much within the range $Ra = 7 \,.\, 10^9$–$7 \,.\, 10^{10}$ i.e. within the developed turbulent flow region.

According to experimental data [2], the lower limit of the developed turbulent flow, determined by a change of heat transfer mode at $Pr = 0{\cdot}72$, corresponds to $Ra \geqslant 7 \,.\, 10^9$. The experimental results of [3] and [5], in the latter friction and heat transfer in the transition region at $Ra < 7 \,.\, 10^9$ are investigated in detail, are plotted in Fig. 5. As is seen from the figure, some decrease of $Re_1 Pr^{\frac{1}{3}}$ occurs in the transition region.

Thus, within the region of the developed turbulent flow at an individual vertical plate the wall layer of liquid $0 < y < \delta_1$ is characterized by constancy of $Re_1 Pr^{\frac{1}{3}}$.

In a vertical liquid film, closed at the two ends, there are observed several flow regimes. In the lower part of the heated plate and in the upper part of the cold plate, a laminar regime of flow takes place which little by little turns into developed turbulent flow in the central part of the film. In the upper part of the film, near the heated plate, and in the lower part, near the cold plate, turbulence progressively degenerates. According to experimental investigations [8] the developed turbulent regime in the film occurs at $Ra_{cr} h^3 = 10^{10}$. In the present paper all the measurements were made within the turbulent flow region at $Ra > Ra_{cr}$.

The behaviour of liquid flow could be judged from visual observations. Figure 2b and c present pictures of the turbulent liquid flow in a vertical gap near the heat transfer surface.

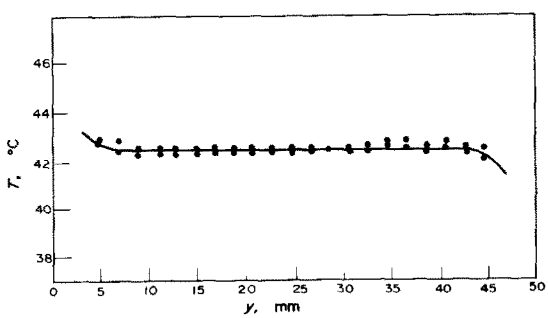



FIG. 6. Temperature profile in the central part of the film $x = 0{\cdot}5H$; $Ra_l = 3{\cdot}45 \,.\, 10^8$; $H = 680$ mm; $l = 49$ mm; $\Delta T = 28{\cdot}9$°C; $T_m = 42{\cdot}4$°C.

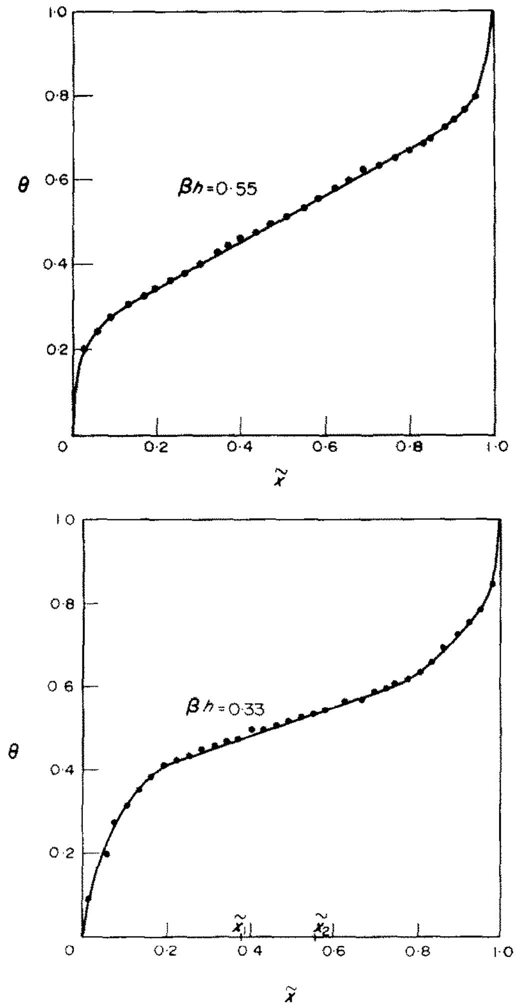



FIG. 7. Temperature profiles in a vertical cross-section of the film $y = 0{\cdot}5\,l$
(a) $Ra_l = 1{\cdot}06 \,.\, 10^8$; $H = 395$ mm; $l = 49$ mm; $\Delta T = 11{\cdot}7$°C; $T_m = 28{\cdot}5$°C.
(b) $Ra_l = 8{\cdot}85 \,.\, 10^7$; $H = 680$ mm; $l = 31$ mm; $\Delta T = 29$°C; $T_m = 42{\cdot}5$°C.

Temperature measurements across the film width showed that in the middle the liquid is characterized by a constant averaged temperature, for a given horizontal cross-section, (Fig. 6). Hence, for determining the temperature change with height measurements in the cross-section need only be taken at $y = 0{\cdot}5l$. As measurements showed (Fig. 7), in the central part of the film there exists a constant temperature gradient with height

$$\beta h = \frac{H}{\Delta T}\frac{\mathrm{d}T}{\mathrm{d}x}.$$

Under different boundary conditions at the film ends, a different behaviour of the change in temperature gradient $\beta h$ was observed. Thus in [8] the temperature gradient measurements along the height of the vertical gap were carried out for the case when the upper end face was open. For the heat flux from the open surface, due to evaporation of the operating liquid, near the upper end face there was observed a negative temperature gradient and in the film centre $\beta h = 0$.

The turbulent flow in a vertical gap closed at the ends occurs under conditions when the temperature outside the boundary layer changes linearly with height. Figure 8 presents the averaged velocity profiles measured in the constant temperature gradient range $(\mathrm{d}T/\mathrm{d}x)_{y>\delta}$. Measurements were made in the film with $H = 680$ mm, $l = 49$ mm, $Ra_l = 3{\cdot}45 . 10^8$ at two heights $\bar{x}_1$, $\bar{x}_2$, coordinates of which are shown in Fig. 7b.

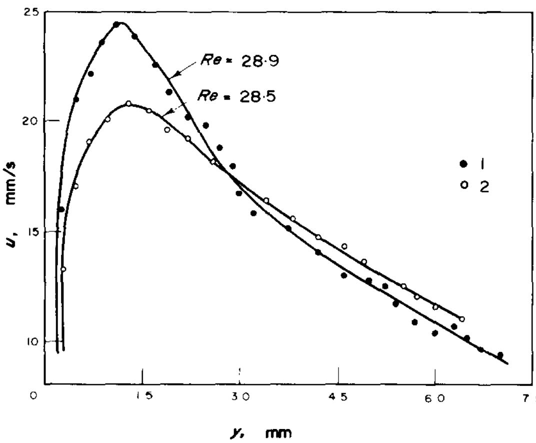



FIG. 8. Mean velocity profiles at different heights in a vertical film
$Ra_l = 8{\cdot}85 . 10^8$; $H = 680$ mm; $l = 31$ mm; $\Delta T = 28{\cdot}8$°C; $T_m = 42{\cdot}7$°C.
1—$x = 260$ mm.
2—$x = 385$ mm.

From Fig. 8 it follows that within the constant temperature gradient region there is a wall layer characterized by a constant $Re_1$, calculated with respect to the maximum velocity in the film and thickness $\delta_1$, within which the velocity growth is observed.

The maximum value of root-mean-square fluctuations of the longitudinal velocity coincides with the maximum velocity position in the given horizontal cross-section (Fig. 9). The

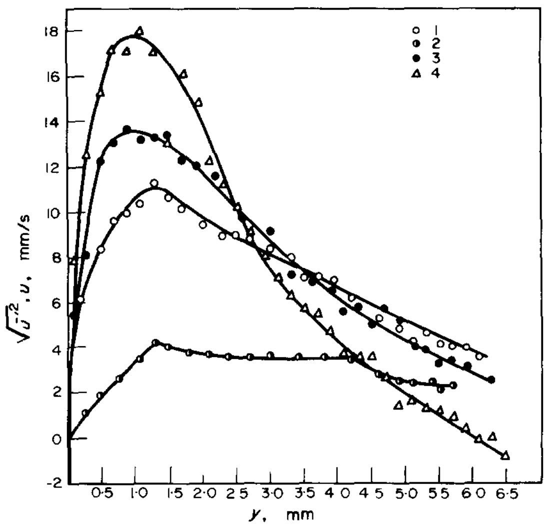



FIG. 9. Mean velocity profiles and fluctuation rate of the longitudinal component of the velocity vector in the film $H = 395$ mm, $l = 49$ mm; $x = 0{\cdot}5H$.
1, 2—mean velocity and fluctuation rate
$Ra_l = 10^8$; $\Delta T = 11{\cdot}3$°C; $T_m = 27{\cdot}0$°C.
3—$Ra_l = 1{\cdot}7 . 10^8$; $\Delta T = 17{\cdot}9$°C; $T_m = 31{\cdot}07$°C.
4—$Ra_l = 3{\cdot}28 . 10^8$; $\Delta T = 29{\cdot}0$°C; $T_m = 39{\cdot}3$°C.

nature of the change in the intensity of fluctuation is the same as that in the boundary layer at an individual vertical plate.

Figures 9 and 10 give mean velocity profiles measured at height $x = H/2$ for different values of $H$, $l$, $Ra_l$.

Numbers $Re_1 = U_{max}\delta_1/\nu$ calculated by experimental profiles (Figs. 3, 8–10) are given in Fig. 11. The kinematic viscosity value was taken with respect to the mean boundary layer

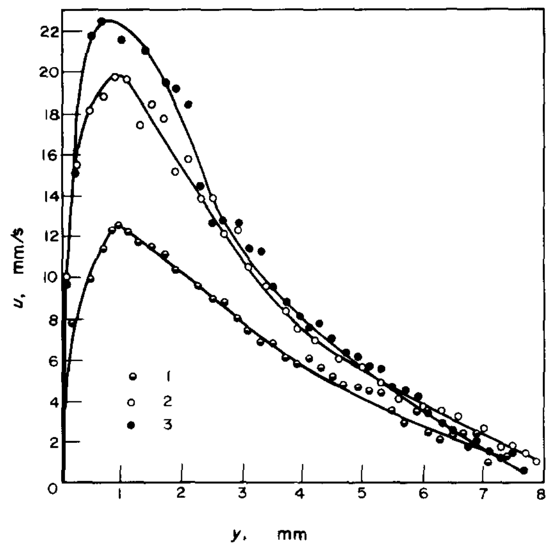



FIG. 10. Mean velocity profile with turbulent free convection in a vertical film;
$H = 395$ mm; $x = 0{\cdot}5H$.
1—$Ra_l = 4{\cdot}76 \,.\, 10^6$; $l = 15$ mm; $\Delta T = 16{\cdot}7$°C; $T_m = 31{\cdot}8$°C.
2—$Ra_l = 8{\cdot}45 \,.\, 10^7$; $l = 30$ mm; $\Delta T = 32{\cdot}0$°C; $T_m = 40{\cdot}2$°C.
3—$Ra_l = 1{\cdot}04 \,.\, 10^7$; $l = 15$ mm; $\Delta T = 31{\cdot}9$°C; $T_m = 40{\cdot}8$°C.

temperature

$$T_m = \frac{T_1 + T_0}{2}$$

As is seen from Fig. 11, the characteristic value of $Re_1$ depends on the relative temperature gradient

$$\left[\frac{\mathrm{d}(T/\Delta T)}{\mathrm{d}x}\right]_{y>\delta}$$

and at the same value of the latter is constant and independent of the Rayleigh number $Ra_l$.

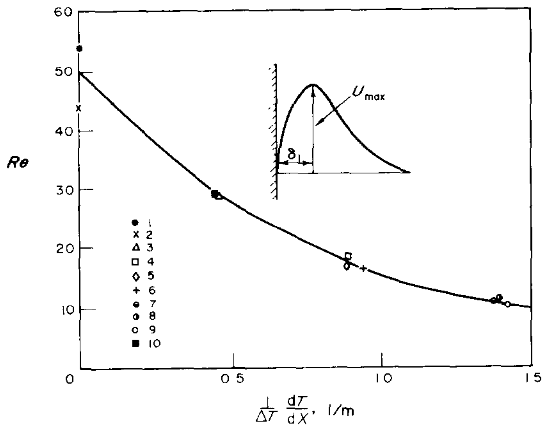



FIG. 11. $Re_1$ vs. relative temperature gradient $\frac{1}{\Delta T}\frac{\mathrm{d}T}{\mathrm{d}x}$ from from experiments presented
1—in Fig. 3 (2).
2—in Fig. 3 (1).
3—in Fig. 8 (1).
4—in Fig. 9 (4).
5—in Fig. 10 (3).
6—in Fig. 10 (2).
7—in Fig. 9 (1).
8—in Fig. 9 (3).
9—in Fig. 10 (1).
10—in Fig. 8 (2).

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## CONVECTION NATURELLE TURBULENTE SUR UN PLAN VERTICAL ET DANS UNE COUCHE VERTICALE

**Résumé**—On mène une recherche expérimentale sur l'hydrodynamique d'une couche limite turbulente de convection libre sur un plan vertical et dans une couche verticale fermée aux extrémités de la face pour de l'acool éthylique. On présente les profils de la composante longitudinale de la vitesse moyenne et le taux de fluctuation de cette même composante de vitesse. Sur la base des résultats présents et des résultats expérimentaux d'autres auteurs, on montre l'existence de la couche à la paroi quasi-stationnaire dans une couche limite turbulente sur un plan vertical dont l'épaisseur et la vitesse maximale satisfont la condition:

$$Re_1 Pr^{\frac{1}{2}} = \frac{U_{max}\delta_1}{(\nu a)^{\frac{1}{2}}} = Cste$$

On montre expérimentalement que pour la section verticale médiane dans la partie centrale de la couche le gradient de température est $dT/dx = Cte$. A l'intérieur de la région de la couche limite turbulente à gradient de température constant il y a une couche pariétale quasi-stationnaire pour laquelle $Re_1 = (U_{max}\delta_1/\nu) = Cte$. Le nombre $Re_1$ est une fonction du gradient de température relative $(1/\Delta T)\cdot(dT/dx)$ dans la couche limite externe.

## TURBULENTE FREIE KONVEKTION AN EINER SENKRECHTEN PLATTE UND IN EINER SENKRECHTEN SCHICHT

**Zusammenfassung**—Mit Äthylalkohol werden experimentelle Untersuchungen durchgeführt über die Strömungsverhältnisse in einer turbulenten Grenzschicht bei freier Konvektion an einer senkrechten Platte und in einer stirnseitig abgeschlossenen senkrechten Schicht. Als Ergebnis werden Profile und Turbulenzgrad der Längskomponente des mittleren Geschwindigkeitsvektors angegeben. Ausgehend von diesen Ergebnissen und den Versuchsergebnissen anderer Autoren wird die Existenz einer quasistationären wandnahen Schicht nachgewiesen in einer turbulenten Grenzschicht an der senkrechten Platte, wobei Dichte und Maximalgeschwindigkeit der Bedingung gehorchen

$$\mathrm{Re}_1\, \mathrm{Pr}^{\frac{1}{2}} = \frac{U_{max}\delta_1}{(\nu a)^{\frac{1}{2}}} = \mathrm{const.}$$

Die Experimente zeigen, dass längs der Mittellinie im zentralen Schichtbereich der Temperaturgradient $dT/dx$ konstant ist. In diesem Bereich mit konstantem Temperaturgradienten in der turbulenten Grenzschicht gibt es eine quasistationäre wandnahe Schicht, für die gilt

$$\mathrm{Re}_1 = \frac{U_{max}\delta_1}{\nu} = \mathrm{const.}$$

Im äusseren Grenzschichtbereich ist $\mathrm{Re}_1$ eine Funktion des relativen Temperaturgradienten

$$\frac{1}{\Delta T}\cdot\frac{dT}{dx}.$$

## ТУРБУЛЕНТНАЯ ЕСТЕСТВЕННАЯ КОНВЕКЦИЯ НА ВЕРТИКАЛЬНОЙ ПЛАСТИНЕ И В ВЕРТИКАЛЬНОМ СЛОЕ

**Аннотация**—Проведено экспериментальное исследование гидродинамики турбулентного пограничного слоя при свободной конвекции на вертикальной пластине и в вертикальном слое, замкнутом по торцам, для этилового спирта. Представлены профили продольной компоненты вектора средней скорости и интенсивность пульсаций той же компоненты вектора скорости. На основании экспериментальных данных настоящей работы и экспериментов других авторов показано существование квази-устойчивого пристенного слоя в турбулентном пограничном слое на вертикальной пластине, толщина и максимальная скорость которого удовлетворяют условию:

$$Re_1 Pr^{1/2} = \frac{u_{max}\,\delta_1}{(\nu a)^{\frac{1}{2}}} = \mathrm{const.}$$

Экспериментально установлено, что в среднем вертикальном сечении в центральной части слоя градиент температуры ($d\tau/d\chi$ = const). В области постоянного градиента температуры в пограничном турбулентном слое существует квазиустойчивый пристенный слой, для которого

$$Re_1 = \frac{u_{max}\,\delta_1}{\nu} = \text{const}.$$

Число $Re_1$ является функцией относительного градиента температуры $(1/\Delta\tau)$ $(d\tau/d\chi)$ во внешней части пограничного слоя.