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MEASUREMENTS IN THE THERMAL FIELD OF MERCURY UNDERGOING NATURAL CONVECTION WITH AND WITHOUT ROTATION

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Abstract—An experimental program was carried out to further explore the flow system involved in the natural convection of mercury between two horizontal plates, and spun about a vertical axis. Detailed measurements were made of the temperature distribution, root mean squared temperature distributions, temperature fluctuation behavior, and the effect of radial obstacles. Spin rates of 0 to 60 rpm were used with heat fluxes ranging up to 4400 Btu/hr-ft^2.

The temperature distributions showed a smooth transition with increasing spin that was found to be related to the thickening of the region wherein conduction and convection modes of transfer are equal. At high enough spin values, as measured by the dimensionless Taylor number, conduction predominated throughout.

The root mean squared temperature distributions were found to increase in magnitude with increasing temperature differences between the plates, but to change in the direction of lesser magnitude with spin.

Distributions of temperature fluctuation showed the existence of skewness near the boundaries at low spin. This effect may be explained on the basis of eddy motions. At high spin, the skewness is replaced with quasi-sinusoidal oscillations which tend to definite values as predicted by theory.

Introduction of flow obstacles in the form of radial vanes have no effect on the gross heat-transfer effects, and all previously mentioned temperature effects were found to persist even with their use.

NOMENCLATURE

c_p,	specific heat at constant pressure, Btu/lb degF;
g,	acceleration due to gravity, ft/s^2;
k,	thermal conductivity, Btu/h ft degF;
L,	internal container height, ft;
$T(z)$,	horizontally averaged temperature, °F;
T_B,	time averaged hot surface temperature;
T_T,	time averaged cold surface temperature;
ΔT,	$= T_B - T_T$;
z,	vertical distance from hot surface, ft;
q/A,	heat flux, Btu/h ft^2;
Nu,	Nusselt number $(q/A)(1/\Delta T)(L/k)$;
Ra,	Rayleigh number, $L^3\rho^2 g\beta\Delta T c_p/\mu k$;
Ra_c,	critical Rayleigh number at which convective motion starts;
$NuRa$,	dimensionless heat flux;
Ta,	Taylor number, $4L^4\Omega^2/\nu^2$;
Pr,	Prandtl number, $c_p\mu/k$;
β,	coefficient of volumetric expansion, 1/degF;
μ,	dynamic viscosity, lb/ft h;
ρ,	density, lb/ft^3;
ν,	kinematic viscosity, μ/ρ;
Ω,	spin rate, rads/h;
ζ,	dimensionless height, z/L;
ζ_K,	dimensionless height of thermal layer;
Φ,	dimensionless temperature excess, $[T_B - T(z)]/[T_B - T_T]$.

INTRODUCTION

IN PREVIOUS studies concerning the effects of rotation on natural convection heat transfer, much attention has been focused on either the

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problem of the onset of convection, or experimental programs aimed at predicting the heat-transfer characteristics of a fluid once convection has started [1–7].

These works have indicated that the primary difference between natural convection maintained by a vertical adverse temperature gradient with and without spin, about the vertical axis, lies in the action of Coriolis forces, which by action on fluid motion in the horizontal plane, serve to promote lengthening of streamline paths and thus reduce the heat transport. This effect has been theoretically and experimentally shown in the increase in the driving potential, the Rayleigh number, required for convection to proceed. Chandrasekhar [3], and Chandrasekhar and Elbert [4] were able to relate the Rayleigh number at which convection would start to the Taylor number. Solutions were found for varying Prandtl numbers. The constraint of rigid horizontal boundaries defining the fluid depth led to a result of the form:

$$Ra_c \rightarrow Ta^{2/3}, \text{ as } Pr^2\, Ta \rightarrow \infty$$

It was also noted and later experimentally shown by Fultz and Nakagawa [5] and Nakagawa [6] that the onset of convection in a rotating system is manifested as overstable motions—periodic temperature and velocity histories throughout the fluid—as long as the Prandtl number is less than 0·677. The effect is also shown in the analogous situation of a magnetic field acting on a conducting fluid in which an adverse temperature gradient is maintained [8, 9].

The experiments of Dropkin and Globe [1], and Dropkin and Gelb [2] have shown that the heat transfer in mercury may be reduced by spin. For a constant flux through a volume of mercury, heated on the bottom and cooled at the top, the initial spin effects on heat transfer are small, and may be predicted by expressions derived for static cases. However, with increasing spin (Taylor number for a fixed geometry), a higher Rayleigh number is required to maintain the same heat flux. The transport rate requires a larger driving potential to maintain the constant flux. This may be shown in the relation:

$$Nu = 0{\cdot}095\,(Ra)^{0{\cdot}852}\,(Ta)^{-0{\cdot}463}$$

The critical Taylor number at which this effect starts is given by:

$$Ta_c = 0{\cdot}68\,(Ra)^{1{\cdot}28}$$

In those experiments, Nusselt number values were made to reach unity for sufficiently high (greater than 10^9) Taylor numbers. These observations were taken in the Rayleigh number range (greater than 10^6) where turbulent convection would normally be expected. The clear implication of the unity Nusselt number is that of the absence of the convective mode as a means of energy transfer.

In an effort to further quantitatively describe the influence of rotation on natural convection, an experimental program was undertaken [10]. The program was directed at gathering data on temperature distributions, temperature fluctuations, the spatial extent of fluid motions and the effect of flow obstacles. It was felt that by studying these quantities throughout the complete rotational regime, that is, no-spin up through values at which a unity Nusselt value is achieved, and by comparison with other works [4, 6, 11, 12] a satisfactory picture of rotational influence could be affected.

APPARATUS

The experimental equipment consisted of a turntable which was driven about a vertical axis, a heat-transfer container which housed the mercury, and associated temperature and power measuring and regulating devices. In geometry, the apparatus was similar to the authors' previous equipment, but with several important differences.

The turntable was fastened to a drive shaft which was connected to a variable speed motor through appropriate gear reducers and belts. Turntable speeds in the course of the experiment varied between 0 and about 60 rpm. Rotational speeds were measured by counting the number of rotations in a known time interval.

The heat-transfer container, which was placed on the turntable, may be seen in Fig. 1. It was composed of three sections; a lower heating surface, a cylindrical Lucite wall, and an upper cooled surface. The lower section consisted of two copper plates, Isomica insulators and a

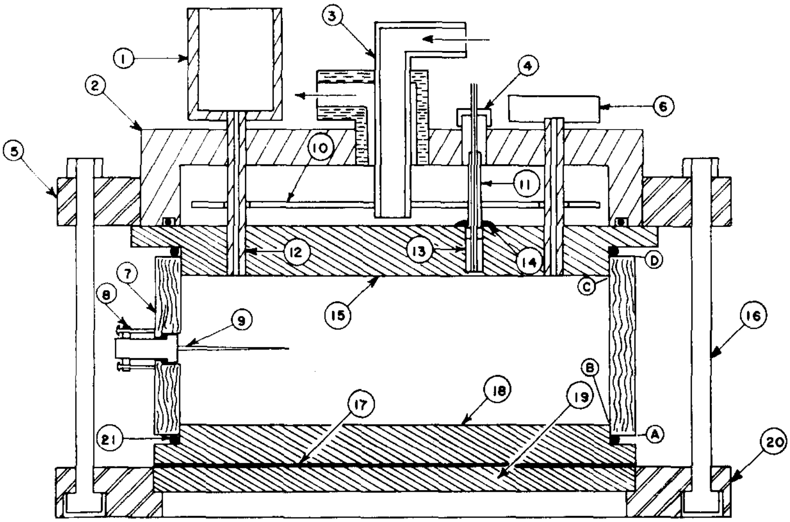

FIG. 1. Heat-transfer container.

1. Mercury overflow chamber; 2. Brass cooling chamber; 3. Rotating water seal; 4. Conax fitting; 5. Micarta clamping ring; 6. Filling port cap; 7. Lucite wall; 8. Probe adjusting nut and screws assembly; 9. Thermocouple probe; 10. Splash deflector plate; 11. Stainless steel tube; 12. Stainless steel filling tube; 13. Plate thermocouple assembly; 14. Epoxy seal; 15. Cold plate, chrome plated copper; 16. Clamping bolt; 17. Heater section; 18. Hot plate, chrome plated copper; 19. Copper backup plate; 20. Micarta clamping ring; 21. O-ring (typical).

nichrome heater element, all arranged in a compact sandwich construction. The assembled heater section was designed to safely dissipate a 2 kW load in still air. The Lucite section was cut from a 6·5 inch I.D., $\frac{1}{4}$ inch wall tube, and was provided with 37 holes through which the appropriate thermocouples could be inserted. The cooling section consisted of a copper plate and a brass chamber through which cold water flowed. Water flow to the rotating system was provided by a rotary joint. Stainless steel nipples extended through the cooling chamber and the upper copper plate, and served as filling ports and sealable openings for air escape during the filling procedure. All copper–mercury interfaces were highly polished, buffed, and chrome plated to prevent mercury attack.

Three thermocouples made of Chromel and Alumel were inserted inside each of the two copper surfaces, at locations representing the center, edge, and midpoint radii of the plates. The location of these junctions was approximately 0·01 in from the mercury surfaces. The Lucite–copper, and copper–brass interfaces were sealed with O-rings. The completed assembly, measuring approximately 1·55 in between plates, was held together by steel bolts drawing on Micarta rings mating on the top and bottom sections. This method of assembly was used to minimize heat conduction across the mercury container height.

The thermocouples used were specially designed to insure a minimum of thermal and hydrodynamic disturbance. They consisted of 0·001 inch diameter Chromel and Alumel wires semi-butt welded and supported in specially drawn Pyrex tubes. The procedures for welding the thermocouples and drawing the glass has been described in another paper [13]. The glass tubes, threaded with either a Chromel or Alumel wire from the junction pair, were epoxy cemented to special phenolic holders which were inserted in the Lucite wall. Location of the thermocouple junctions was accomplished by adjusting three small screws attached to the phenolic holders on the exterior of the Lucite wall.

The probes extended $1\frac{1}{2}$ inches into the interior of the container and were arranged in a spiral pattern about the walls. The actual location of the junctions from the plates varied with each assembly, but in general were arranged as follows. Spacing on the order of 0·01 in was used in the first 0·1 in from either surface. Beyond that the spacing gradually increased to about 0·1 in near the midplane region. The pattern was also designed to maximize spacing between junctions and thus reduce probe interference.

In later measurements, these probes were replaced with another type consisting of 0·005 in diameter Chromel and Alumel wires running through $1\frac{1}{2}$ in × 0·02 in O.D. Pyrex tubes. Four thermocouples were mounted in each phenolic holder, and the junctions separated by a fixed amount. In this manner, the temperature history of two horizontally and vertically displaced points could be measured at the same time.

The thermocouple signals were brought to the various external equipment through a series of spring loaded copper brushes resting on copper slip rings mounted on the drive shaft. Selection of the thermocouples was made by indexing of stepper switches mounted on the rotating system. Heater and stepper switch power were provided through copper slip rings and carbon brushes.

METHOD OF TEST

After sealing the heat-transfer container, the thermocouple probes were positioned and their height within the container was measured by sighting through the Lucite wall with a cathetometer. The error in location was believed to be within ±0·0025 in, a value which was negligible in the computations. This error was also considerably greater than the computed deflection of the Pyrex tubes due to the buoyant effect of the mercury.

The container was then placed under a bell jar and evacuated. Mercury was allowed to flow from an external reservoir into the container. This filling procedure was done very slowly and served to eliminate any erroneous effects due to the inclusion of gases.

After filling, the container was placed on the turntable and the appropriate thermocouple and power connections were made. Finally, the system was well insulated with approximately 10 in of rockwool. Calculations indicated that any heat loss through the insulation was insignificant.

The thermocouple indications could be measured on either a precision potentiometer or a dual pen recorder. The recorder was calibrated using the potentiometer as a voltage source. A sensitivity of 0·1 mV/cm was used consistently throughout the experiments, while the least count readings were taken as 1·0 mm. This led to a least count temperature reading of about 0·5 degF for all the thermocouples.

Power was controlled by a 2 kW autotransformer and was supplied through a voltage regulator to insure constant power. Input energy to the container was measured using precision voltmeters and ammeters.

At the start of a run, power was adjusted to the desired value and the table rotational speed set. The temperatures of the bounding surfaces were monitored at 15 min intervals and equilibrium was assumed when there was no detectable change over a one hour interval. Generally, equilibrium was established in 4 h and the recording of the various thermocouples required an additional 2–3 h. Each recording, using two thermocouples at a time, took approximately 5 min.

RESULTS OF THE TEST

1. *Temperature distributions*

The recorded thermocouple traces were used to determine the mean temperature distributions. The procedure adopted was to sample a trace at 5 s intervals, calculate the mean thermocouple voltage, and hence, the mean temperature. Care was taken that no unfair weighing of the average was caused by any periodic behavior of the thermocouple signals.

In order to place the distributions on scales compatible with the varying temperature differences between the boundaries, all temperatures were non-dimensionalized as Φ, and all heights as ζ. The results of a typical run may be seen in Fig. 2. The distributions are shown only for the lower half of the container as symmetry of the

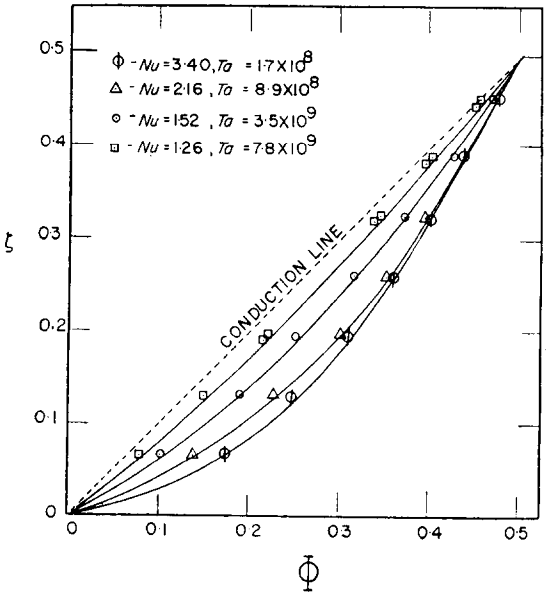

FIG. 2. Variation of dimensionless temperature distributions with spin, at constant $NuRa = 5{\cdot}8 \times 10^6$.

distributions about the half height of the container was evident. It is clear from this curve that with the increase in spin, as given by the Taylor number, the distributions approach a pure conduction situation, as would be expected on the basis of previous works [1, 2].

The dimensionless distributions could be fitted to a bilogarithmic representation of the form:

$$\Phi = f_1 \left[\zeta f_2^{(NuRa,\ Ta)}\right]$$

where the function f_2 was assumed to be of the form:

$$f_2 = C_1\,(NuRa)^y\,(Ta)^x$$

A series of cross plots indicated that the unknowns could be best represented as $C_1 = 0{\cdot}065$, $x = 0{\cdot}18$, $y = -0{\cdot}10$. Together with the condition that all the distributions must coincide at $\Phi = \zeta = 0{\cdot}5$ leads to:

$$\Phi = 0{\cdot}5^{[1-(0\cdot065)(NuRa)^{-0\cdot10}(Ta)^{0\cdot18}]}\,\zeta^{[0\cdot065(NuRa)^{-0\cdot10}(Ta)^{0\cdot18}]} \qquad (1)$$

The results may of course only be applied to the region beyond the breakpoint value of the Taylor number, that is, the value where the heat transfer rapidly decreases with increasing spin.

Using the concept as suggested by Kraichnan [12], the variation of the height ζ_K, the dimensionless height at which the conductive and convective contributions to the total upward flux of heat are equal, was sought. It was found that this layer was about one half of those predicted by the theories of Malkus [11], and Kraichnan for no rotation. This disagreement was assumed to be due, in some part, to the existence of gross motions at no or low spin values. These effects are similar to those observed by Thomas and Townsend [14]. These motions would of course not be compatible with the assumptions of lateral homogeneity of turbulent motions as assumed in those theories, and could be expected to cause a thinning of the thermal layer.

Beyond the critical Taylor number, the thermal layer rapidly thickens, until at Nusselt numbers approaching unity, it completely fills the container height, and conduction predominates throughout. In this region, it was found that the thermal layer thickness could be solely expressed as a function of the Nusselt number. Application of the previous result found by Dropkin and Gelb produces:

$$\zeta_K = 240\,(Ra)^{-1\cdot61}\,(Ta)^{0\cdot875} \qquad (2)$$

2. *Temperature fluctuations*

In order to quantitatively describe the turbulent fluctuations, the temperature traces discussed in the previous section were examined and two distributions formed. The first was the root mean squared temperature distribution; the second was the relative frequency distribution of fluctuations about the mean temperature.

The root mean squared temperature was calculated by measuring the instantaneous deviations of the signals from the computed mean voltage. Using the appropriate squaring, summing and averaging led to the desired result.

The relative frequency of occurrence was determined in order to assign values for comparison of the shapes of the traces. It was observed that near the horizontal surfaces, the traces were not symmetric about the local mean value. The hot boundary showed "spikes" of cold temperature, and the reverse was indicated at the cold side. Description of this effect was accomplished by noting the number of times a thermocouple reached a specific value and dividing this total by the total number of occurrences considered. The values considered were crossings of the traces at 1·0 mm intervals.

A typical result of the root mean squared distributions can be found in Fig. 3. Several interesting effects may be noticed. At a constant Ta value, the RMS temperature everywhere increases with heat flux; while for a constant $NuRa$ value, the initial spin effect ($Ta < Ta_c$) is to increase the RMS level very slightly above the static case. Beyond Ta_c, the levels rapidly decrease with increased spin. While a maximum in the RMS distribution is always found near $\zeta \sim 0{\cdot}1$ for zero spin, this peak is "smoothed" with spin. A comparison of the no-spin RMS values with those predicted by Kraichnan indicated that the experimentally determined values were about one half of the theory. The disagreement with Malkus was about the same. Thomas and Townsend in their experiments in air found similar disagreement, but just as in the present observations, the maximum RMS level fell in a region slightly above the thermal layer, ($\zeta > \zeta_K$).

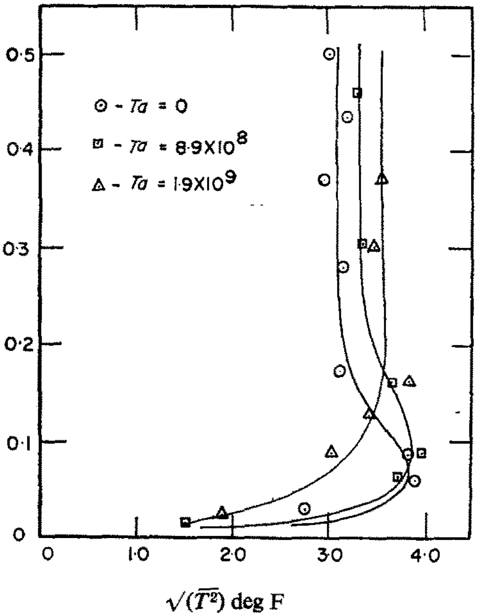

FIG. 3. Distribution of root mean squared fluctuations with spin, at constant $NuRa = 2{\cdot}55 \times 10^6$.

The decrease in the fluctuations agrees well with expectations arising from the mean temperature distributions. As would be expected, the decrease in the Nusselt number with spin implies that the convective mode is being reduced with an associated increase in the conductive mode. This reduction can be presumed to coincide with a reduction in the turbulent mixing process, and hence, a reduction in the magnitude of the temperature fluctuations.

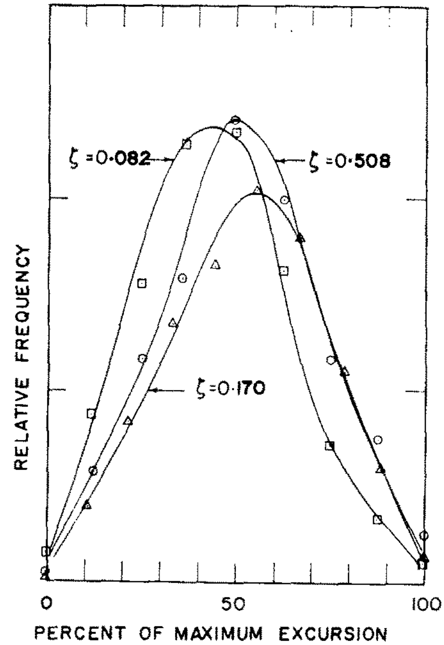

FIG. 4. Temperature fluctuation relative frequency distributions, no-spin, at constant $NuRa = 5{\cdot}8 \times 10^6$.

The results of the relative frequency distributions may be seen in Figs. 4 and 5. The data points have been omitted in some of the curves for the sake of clarity, and absolute numbers omitted as the shapes of the curves are the only meaningful information. Figure 4 shows the symmetry of the turbulent fluctuations at various values of no-spin. Only at very low values of ζ, close to the hot surface, do the cold spikes exist as shown in the traces of Fig. 6. Figure 5 shows the effect of spin at constant flux for two values of ζ, one near the edge of the no-spin thermal layer, the other very close to the half height of the container. The central region consistently shows symmetry in the fluctuations while the thermal layer now exhibits spikes which did not exist in the absence of spin.

The following conclusions may be drawn. At no-spin the existence of spikes is restricted to a thin layer near the surface. With the inception of spin, these spikes grow in magnitude and the region of their existence progresses further into the fluid. At all times the central region of the fluid exhibits symmetry of turbulent fluctuation, but the magnitude is determined by the spin conditions.

A model to account for this effect may be described as follows: Consider a thermocouple which is located near the lower, warm plate (the upper plate results will be the same, but reversed in temperature sense). Fluid in the form of eddies having temperatures and velocities associated with the region from which the eddy has arisen continually cross the thermocouple, constantly changing its temperature. Eddies may be considered to come from three sources: fluid above, below and lateral to the thermocouple. Those coming from below are warm, and are associated with slow-moving, stagnated fluid.

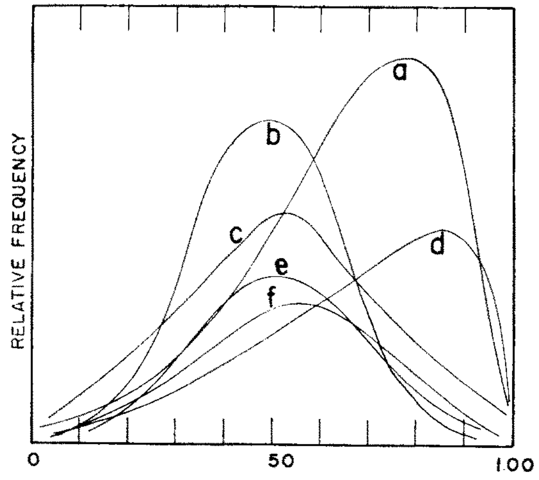

FIG. 5. Temperature fluctuation relative frequency distributions with spin, at constant $NuRa = 5{\cdot}8 \times 10^6$.

(a)—$Ta = 1{\cdot}7 \times 10^8$; $\zeta = 0{\cdot}082$.
(b)—$Ta = 3{\cdot}7 \times 10^9$; $\zeta = 0{\cdot}508$.
(c)—$Ta = 0$; $\zeta = 0{\cdot}508$.
(d)—$Ta = 8{\cdot}2 \times 10^8$; $\zeta = 0{\cdot}082$.
(e)—$Ta = 1{\cdot}7 \times 10^8$; $\zeta = 0{\cdot}508$.
(*f*)—$Ta = 8{\cdot}2 \times 10^8$; $\zeta = 0{\cdot}508$.

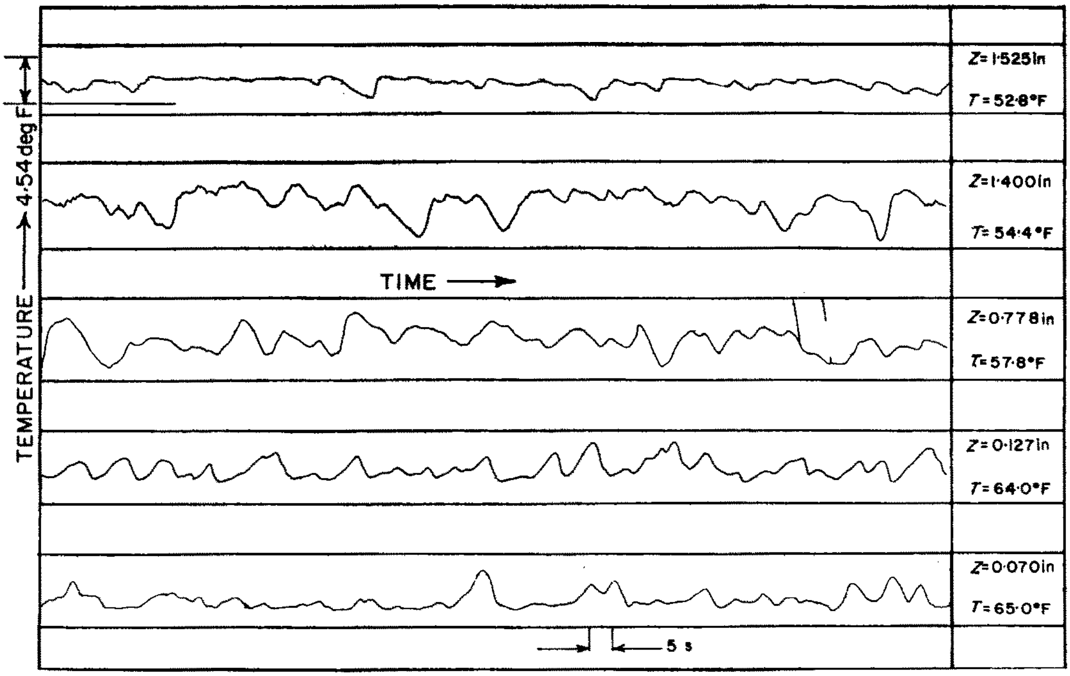

FIG. 6. Sample thermocouple traces showing existence of "spikes" at bounding surfaces, $Ta = 1{\cdot}7 \times 10^8$, $NuRa = 5{\cdot}8 \times 10^6$.

Those from above come from a cooler region, where the action of turbulent mixing has degraded their spatial scale. Lateral eddies will be intermediate to these two. The gross effect will therefore be a superposition of short-time cool bursts of temperature indication on long-time warm fluctuations, thus producing the spike effect. As the increase in spin also produces an increase in the thickness of the thermal layer, it is reasonable that the region of thermal spikes should progress into the fluid volume.

The approach of the unity Nusselt number now brings the natural convection process within the scope of previous investigations on the onset of convection with spin, and the associated characteristic of overstability. Whereas the experiments of other workers [5–7] were conducted by noting the Rayleigh value at which convection would start for a given spin value, the present investigation regards the decrease in convection as spin increases, leading toward the complete absence of convection. The rather random fluctuations may now be expected to be gradually replaced with greater contributions of regular oscillations, whose frequency will depend on the spin frequency and the Rayleigh number. This effect may be seen in the sample trace of Fig. 7. The observed frequency of oscillation was compared with the predictions of references 4 and 6. The observed oscillation frequency was computed

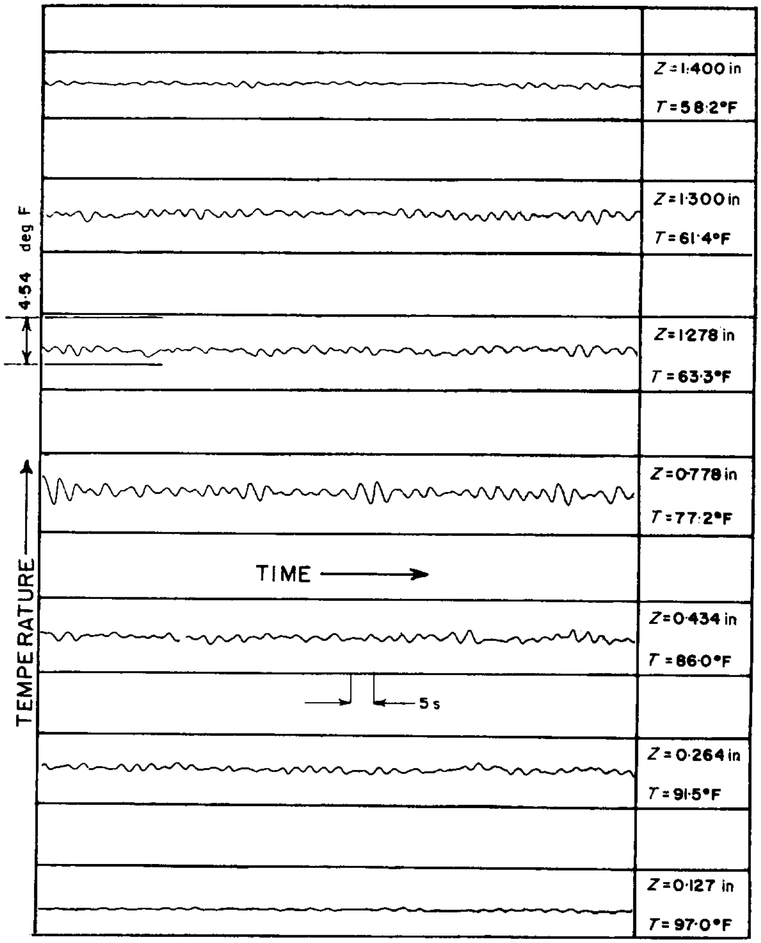

FIG. 7. Sample thermocouple traces showing periodic fluctuations throughout container volume. $Ta = 3{\cdot}1 \times 10^{10}$, $NuRa = 5{\cdot}8 \times 10^{6}$.

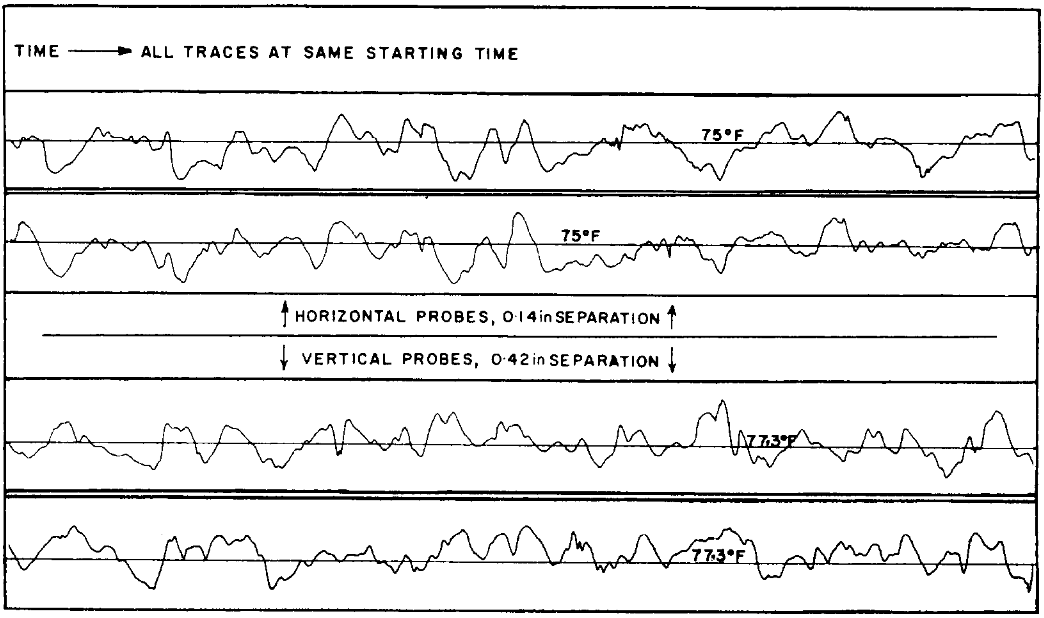

FIG. 8. Thermocouple traces indicating correlation of temperature fluctuations in vertical and horizontal directions, no-spin.

$Ta = 0$, $NuRa = 5{\cdot}8 \times 10^6$, $\zeta = 0{\cdot}50, 4{\cdot}54$ degF/cm.

by counting the number of cycles in a long sample trace and dividing by the total time interval. At values of $Nu = 1{\cdot}03$, $Ta = 3{\cdot}1 \times 10^{10}$ and $Nu = 1{\cdot}04$, $Ta = 7{\cdot}8 \times 10^9$, the ratio of the average oscillation frequency to spin frequency was found to be about twice that predicted. However, the apparent difference could be lessened by noting the problem of determining the exact value of Ta at which $Nu = 1{\cdot}0$. Since it will occur at a higher Taylor value than measured and $Ta \sim \Omega^2$, the frequency ratio would be reduced in the direction of the predicted values.

The experiments using the probes whose thermocouple junctions were a known distance horizontally and vertically apart, served to demonstrate the directionality of fluid motions as the Nusselt number approached unity. The results may be easily observed in Figs. 8 and 9. At no-spin, there is apparently very good correlation between temperature in both the horizontal and vertical directions. Indeed, for these low spin values, the cross correlation between these traces, performed by statistical methods similar to those described previously, indicated values of the cross correlation to be very close to 1·0. This was true up to the maximum separation of thermocouples used, 0·42 in.

With increasing spin, the connection between horizontally spaced thermocouples decreases. At a Nusselt number very close to 1·0 the vertically placed probes show extreme correspondence (trace C), while the closer spaced horizontal probes exhibit a similar signal, but a much lesser correspondence (trace D). This effect implies that motion is now completely restricted to vertical paths. Simple calculation of the possible speed of "conductive" temperature waves would preclude this as a possible explanation. It is also noteworthy to observe that all these effects take place even in the face of continually increasing temperature differences between the plates. One might expect the correspondence in the horizontal to increase with temperature difference; the reverse appears to be the case.

THE EFECT OF FLOW OBSTACLES

Another set of experiments involving flow

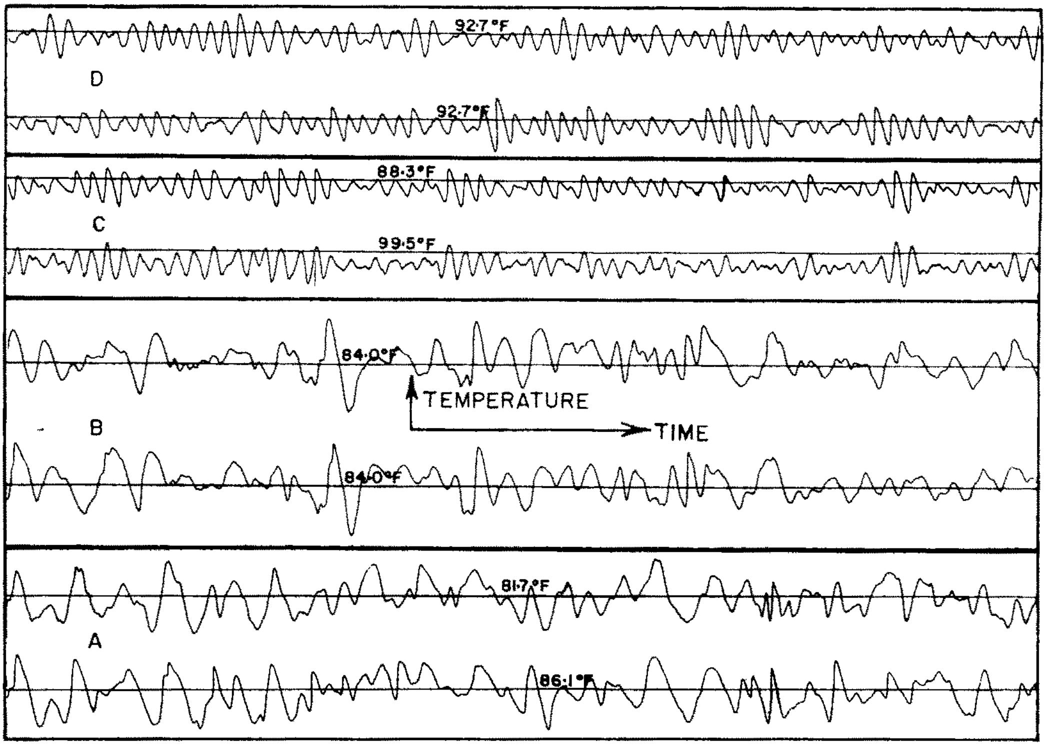

FIG. 9. Thermocouple traces indicating correlation of temperature fluctuations in vertical and horizontal directions, increasing spin.

$NuRa = 5{\cdot}8 \times 10^6$, $\zeta = 0{\cdot}50$.

(a) $Ta = 9{\cdot}0 \times 10^8$; Vertical separation, 0·42 in.
(b) $Ta = 9{\cdot}0 \times 10^8$; Horizontal separation, 0·14 in.
(c) $Ta = 3{\cdot}1 \times 10^{10}$; Vertical separation, 0·42 in.
(d) $Ta = 3{\cdot}1 \times 10^{10}$; Horizontal separation, 0·14 in.

obstacles was peformed in order to grossly establish the scale of horizontal motions caused by the Coriolis effect and evaluate the effect, if any, of restricting these motions.

To produce the obstacles, a series of radial vanes was constructed from 0·060 in thick Lucite sheet. These vanes, spanning the internal height of the container, divided the volume into equal 4, 8, and 16 pie-shaped sectors.

One of the previously measured series of experiments at constant $NuRa = 5{\cdot}8 \times 10^6$ was repeated at values of the Taylor number from 0 to $3{\cdot}1 \times 10^{10}$. Comparison of the Nusselt number vs. Taylor number data with and without vanes was made and the results indicated no differences beyond those attributable to experimental uncertainties. Probe thermocouples of both types indicated there was no difference in either size or frequency of temperature fluctuations, and that all previously described effects continued.

It may be inferred that any horizontal motion is of small effect (in regard to eddy mixing) and that the scale of horizontal motions which are effected by the Coriolis forces are small in comparison to vane separation. The increasing influence of spin on turbulent convection would appear to be a result of forces acting on the eddy or cell surfaces, rather than wholesale motion of these disturbances themselves. Of course at Nusselt values near unity, the previous experiments indicated motion is almost exclusively vertical in direction, and vanes would have no influence.

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Résumé—Un programme expérimental a été conduit pour explorer davantage le système d'écoulement qui se produit dans la convection naturelle du mercure entre deux plaques horizontales, et tournant autour d'un axe vertical. On a fait des mesures détaillées de la distribution de température, des distributions de la racine carée de la moyenne quadratique de la température, du comportement de la fluctuation de température et de l'effet d'obstacles radiaux. Des vitesses de rotation de 0 à 60 tours par minute one été employées avec des flux de chaleur allant jusqu'à 1,38 W/cm^2.

Les distributions de température montraient une transition douce lorsque la rotation augmentait, transition que l'on a trouvé être reliée à l'épaississement de la région où les transports par conduction et par convection sont égaux. A des valeurs de rotation assez élevées, mesurées par le nombre de Taylor sans dimensions, la conduction prédominait entièrement. On a trouvé que les distributions de la racine carrée de la moyenne quadratique de la température augmentaient lorsque les différences de température entre les plaques croissaient, mais que leur direction changeait moins lorsque la rotation augmentait.

Les distributions de fluctuation de température ont montré l'existence d'asymétrie près des parois lorsque la rotation est faible. Cet effet peut être expliqué par des mouvements tourbillonnaires. A rotation élevée, l'asymétrie est remplacée par des oscillations quasi-sinusoïdales qui tendent vers des valeurs définies comme le prédit la théorie.

L'introduction d'obstacles dans l'écoulement sous la forme d'ailettes radiales n'affecte pas les phénoménes de transport de chaleur global, et l'on a trouvé tous les effets de température mentionnés auparavant persistaient même en leur présence.

Zusammenfassung—Um des Strömungssystem, welches bei freier Konvektion von Quecksilber zwischen zwei horizontalen Platten besteht und das sich um eine senkrechte Achse dreht, weiterhin zu untersuchen, wurde ein Versuchsprogramm durchgeführt. Eingehend werden die Temperaturverteilung, die Wurzel aus dem mittleren Quadrat der Temperaturvereilungen, das Verhalten der Temperaturschwankung und der Einflus radialer Hindernisse bestimmt. Es wurden Drehzahlen von 0 bis 60 upm bei Wärmestromdichten bis zu 1,38 W/cm^2 verwendet.

Die Temperaturverteilungen zeigten einen glatten Übergang mit steigender Drehzahl, der sich als Funktion der Zunahme der Dicke in dem Bereich ergab, wo die Erscheinungsformen des Wärmeübergangs, nämlich Leitung und Konvektion, gleich sind. Bei genügend hohen Drehzahlen, wie sie durch die dimensionslose Taylorzahl gemessen wurden, herrscht durchwegs Leitung vor.

Die Wurzel aus dem mittleren Quadrat der Temperaturverteilungen wies einen Anstieg in ihrer Grösse bei zunehmenden Temperaturdifferenzen zwischen den Platten auf, änderte sich aber in Richtung geringerer Grösse mit der Drehzahl.

Die Verteilungen der Temperaturschwankungen zeigten das Vorhandensein von Schrägungen in Nähe der Begrenzungen bei niedriger Drehzahl. Dieser Einfluss kann auf der Basis der Turbulenz erklärt werden. Bei hohen Drehzahlen werden die Schrägungen von sinusähnlichen Schwingungen ersetzt, die sich den definierten Werten, wie sie von der Theorie vorhergesagt werden, annähern.

Das Einführen von Strömungshindernissen in Form radialer Leitbleche hat keine Auswirkung auf die groben Einflüsse des Wärmeüberganges; alle vorher erwähnten Temperatureinflüsse bleiben auch bei Verwendung dieser Hindernisse bestehen.

Аннотация—Экспериментальная программа осуществлялась с тем, чтобы в дальнейшем изучить течения ртути в условиях естественной конвекции между двумя горизонтальными пластинами и при вращении ртути вокруг вертикальной оси. Измерялись: распределение температуры, среднеквадратичные распределения температуры, поведение колебания температуры и влияние радиальных препнствий. Скоротсти вращения изменялись от 0 до 60 об/мин. Тепловые потоки составляли 4400 БТЕ/час. фут^2.

Температурные распределения показали плавный переход с увеличением скорости вращения, что, как было найдено, связано с утолщением области, в которой способы переноса тепла кондукцией и конвекцией одинаковы. При достаточно больших значениях скорости вращения, как измерялось безразмерным числом Тэйлора, кондукция преобладала везде.

Было найдено, что распределения среднеквадратичной температуры увеличиваются по величине с увеличением температурных разностей между пластинами, но меняются в направлении меньшей величины со скоростью вращения.

Распределения колебаний температуры показали существование скоса вблизи границ при малых скоростях вращения. Этот эффект можно объяснить на основе вихревых движений. При больших скоростях вращения скос заменяестя квази-синусоидальными колебаниями, которые стремятся к конечной величине, как предсказано теорией.

Введение в поток препятствий в форме радиальных лопаток не влияет на общий теплообмен, а также найдено, что все ранее упомянутые температурные эффекты существуют при их использовании.