FLUXES OF HEAT AND SALT ACROSS A DIFFUSIVE INTERFACE IN THE PRESENCE OF GRID GENERATED TURBULENCE

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Abstract—The transport of heat and salt across an interface, which has been stabilized by a salinity contrast and destabilized by a temperature contrast, is investigated when turbulence, produced by vertically oscillating horizontal grids, is imposed on the deeper layers above and below the interface. The fluxes of heat and salt are measured as functions of a non-dimensional parameter λ, which expresses the ratio of the grid-generated velocity to the convective velocity. Both fluxes were found to increase with λ. For $\lambda \ll 1$ the double-diffusive convection process appeared to be the dominant transport mechanism and for $\lambda > 1$ mechanical mixing processes appeared to be dominant. The results were compared with those of Turner [1] which were obtained with only one diffusing component, and for the special case of salt flux the effectiveness of double-diffusive convection can be illustrated by examining the effect of changing the temperature difference between the layers.

NOMENCLATURE

f, frequency of grid oscillation [Hz];
g, gravitational acceleration [cm/s²];
h, layer depth [cm];
l, integral length scale [cm];

Ri_0, $= g \dfrac{\Delta\rho}{\rho} \dfrac{l}{u^2}$ overall Richardson number;

R_ρ, $= \dfrac{\beta\Delta S}{\alpha\Delta T}$ density ratio;

S, salinity [‰];
T, temperature [°C];
t, time [s];
u, horizontal RMS velocity [cm/s];
u_c, vertical convective RMS velocity [cm/s];
u_e, entrainment velocity [cm/s];
u_g, grid-generated horizontal RMS velocity [cm/s];
w, vertical velocity of fluid in fingers [cm/s].

Greek symbols

α, coefficient of volume expansion due to unit temperature change [°C⁻¹];
β, fractional density change produced by unit salinity change;
$\alpha\Delta T$, fractional density difference due to the temperature difference between layers;
$\beta\Delta S$, fractional density difference due to the salinity difference between layers;
αF_T, heat flux [g/cm² s];
βF_S, salt flux [g/cm² s];

λ, $= \dfrac{u_g}{u_c}$ non-dimensional stirring parameter;

$\Delta\rho$, density difference between layers [g/cm³];
ΔS, salinity difference between layers [‰];
ΔT, temperature difference between layers [°C];
ρ, density [g/cm³];
ω, frequency of grid oscillation [cycles/min].

1. INTRODUCTION

FOR MANY years engineers and geophysicists have been interested in the movement of sharp density interfaces between well-mixed weakly turbulent layers and the related problem of heat and mass transport across these interfaces. It is clear that the overall vertical transport of heat, solutes and momentum is controlled by the transport across such interfaces. Thus it would seem worthwhile to study vertical mixing across a single density interface in the presence of weak turbulence within the layers. In the ocean and atmosphere the turbulence within the layers is commonly generated by shear mechanisms, which cannot be easily reproduced in the laboratory. A convenient means of generating turbulence in the laboratory is to use a pair of oscillating grids, one grid being located in the centre of each layer. The structure of the turbulence generated by an oscillating grid has been measured by Thompson and Turner [2]. Their measurements, made with a hot-film probe, showed that the horizontal RMS velocity and the integral lengthscale of the turbulence varied with the frequency and amplitude of oscillation of the grid, the distance from the grid and the shape of the grid.

Turner [1] studied the case where the density difference across the interface is produced by one component. Two separate components, namely heat and salt were considered. Turner measured the entrainment velocity u_e when either one or both layers were stirred. The entrainment velocity u_e was found to be a function of an overall Richardson number. If the subsequent results of Thompson and Turner, obtained with the same

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experimental configuration, are exploited the relationships reduce to

$$\frac{u_e}{u} \propto Ri_0^{-1} \tag{1}$$

when the density difference is produced by temperature and

$$\frac{u_e}{u} \propto Ri_0^{-3/2} \tag{2}$$

when the density difference is produced by salinity. The different functional forms for the rates of mixing imply that molecular effects as well as the overall Richardson number are important. Turner originally argued that equation (1) was the basic relationship, however, more recent evidence (see Linden [3]) tends to support the opposite conclusion. The whole subject has been reviewed in Turner [4] and an overall form for the relationship u_e/u vs Ri_0 has been proposed.

In many situations there are two or more diffusing components present and if one of these components is unstably distributed, then molecular diffusion can act in such a way as to release the potential energy of this component. The most general name which has been given to this phenomenon is double-diffusive convection.

The interface between two convecting layers can take either of two forms depending on whether the component which is unstably distributed has the greater or lesser diffusivity. If the unstably distributed component has the greater diffusivity, then the net result of vertical diffusion is to give an unstable buoyancy flux through the interface and to drive convection in the layers, thus sharpening the interface. This type of interface has been called "diffusive". On the other hand the unstably distributed component may have the lesser diffusivity in which case long narrow convection cells, in which the fluid moves alternatively up and down, are maintained because the heat diffuses horizontally more rapidly than the salinity, thus forming the so-called "finger" interface.

Turner's experiments were performed with only one diffusing component. An obvious next step is to examine the effect of the presence of a second diffusing component on the transports of heat and salt for differing stirring rates.

This problem has, in part, been studied by Linden [5], who examined the case where there is an unstable stratification of salt and a stable temperature stratification (i.e. a finger interface) and found three main features. These results were discussed with reference to a parameter $\lambda = w^2/u^2$, where w is the velocity of the fluid in the fingers in the undisturbed state and u is the horizontal RMS velocity of the turbulence.

(i) The ratio of the heat flux divided by the salt flux became greater than unity when $\lambda \lesssim 1.3$. For the particular geometry of the experiment this corresponds to $f \gtrsim 1$ Hz, where f is the stirring rate.

(ii) The salt flux has a minimum at $\lambda \simeq 0.3$ or $f \simeq 2.2$ Hz but the heat flux has no minimum as a function of stirring frequency.

(iii) The transport is dominated by mechanical mixing for $\lambda \lesssim 0.05$ or $f \gtrsim 5$ Hz.

Linden explained the decrease in the salt flux as due to a disruption of the ordered salt finger motions by the turbulence, the increase is explained by the dominance of mechanical mixing. The fact that the heat flux is an increasing function of stirring frequency is then explained by the shortening of the fingers by the turbulence and, therefore, a subsequent increase in the temperature gradient and thus heat flux.

The complementary problem where heat is the destabilizing component and salt is the stabilizing component (i.e. a diffusive interface) is discussed here. The results will again be discussed in terms of a nondimensional parameter λ, which expresses the ratio of the grid generated velocity to the convective velocity.

2. EXPERIMENTAL DETAILS

The experiments were performed in a plexiglass tank approximately $25 \times 25 \times 45$ cm which contained two oscillating grids. This tank is shown diagrammatically in Fig. 1. Two grids, of 1 cm square plexiglass rods made into a 5×5 array with 5 cm between centres, were mounted on a rod passing vertically through the middle of the tank. A rule was fastened to one of the walls of the tank and this fitted neatly between two grid bars. This rule served the dual purpose of measuring height and preventing axial rotation of the grids. The central rod was connected via a crank to an electric motor and the frequency of oscillation of the grids could be adjusted to a number of discrete frequencies by means of a stroboscopic disk mounted on the driving wheel. A stroke of 1 cm was used throughout these experiments and the oscillating frequency was varied over the range 50 to 300 rpm. This tank is the
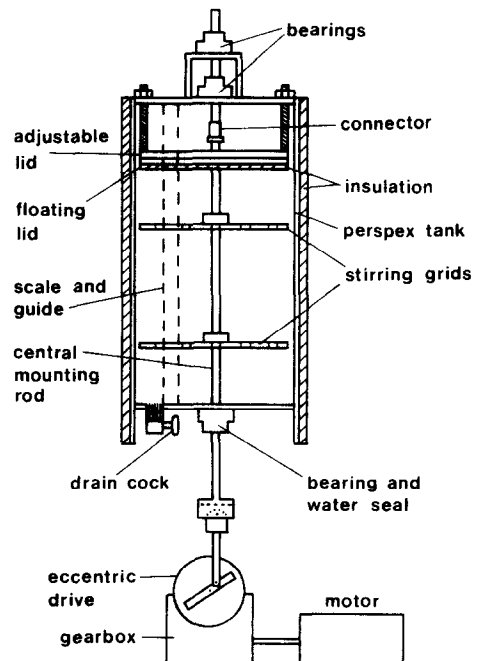

FIG. 1. A sketch of the experimental tank showing the grids and motor drive arrangement.

same as used by Turner [1], Thompson and Turner [2] and Linden [5] and for additional information the reader is referred to these papers.

Each experiment was set up by placing a layer of cold (i.e. ambient temperature) distilled water in the tank and then carefully, but as quickly as possible, adding a layer of warm distilled water, to which a known amount of salt had been added, beneath it. An initial salinity difference, expressed in concentration units (grams of salt per 1000 g of solution), of 7.5‰ was used throughout. The salt solution was preheated until it had the same density as the cold fresh layer, before being syphoned into the oscillating grid tank. During the syphoning the warm salt solution cooled sufficiently for there to be no danger of overturning during the filling operation, although some mixing did occur. In practice the density ratio $R_\rho = \beta\Delta S/\alpha\Delta T$, where $\beta\Delta S$ and $\alpha\Delta T$ are the fractional density differences across the interface produced by the salinity difference and temperature difference respectively, generally increased to approximately 2 before the stirring

by using a single electrode conductivity probe. Variations in the conductance of the solution produced variations in the probe current when a fixed voltage was applied between the single electrode probe and the ground, in this case the metal base of the tank. Variations in the probe current were transformed into amplitude modulations of a high frequency carrier wave, which were then amplified, rectified and filtered to provide a 0–10V signal related to the conductance of the solution. The probe was calibrated directly against temperature, T, and salinity, S, and was found to be accurate to 0.01‰. The 0–10V analogue outputs from the thermistor and conductivity circuitry were then used as the inputs for an experimental computer system. This system controlled the sampling, digitizing, storing and subsequent processing of the data.

In order to calculate ρ, α, β and R_ρ it is necessary to assume an analytic form for the equation of state. Data from the International Critical Tables were fitted, by a least squares fitting technique, to a three-dimensional surface of the form

$$\rho - 1.01350 = \sum_{i=1}^{5} \sum_{j=1}^{4} A_{ij}(T - 29.1667)^{i-1}(S - 26)^{j-1} \tag{3}$$

where

$$10°C < T < 50°C, \qquad 0 < S < 60‰$$

and

$$A_{ij} = \begin{array}{lllll}
5.50539 \times 10^{-4} & -3.30191 \times 10^{-4} & -3.59229 \times 10^{-6} & 2.04738 \times 10^{-8} & 4.88544 \times 10^{-10} \\
7.01408 \times 10^{-4} & -1.29086 \times 10^{-6} & 2.48115 \times 10^{-8} & -2.95243 \times 10^{-10} & 3.73815 \times 10^{-12} \\
1.83461 \times 10^{-7} & 2.87579 \times 10^{-9} & -1.96669 \times 10^{-10} & 1.40960 \times 10^{-12} & 3.33744 \times 10^{-13} \\
5.19488 \times 10^{-10} & -1.12055 \times 10^{-12} & 1.91753 \times 10^{-12} & 6.42775 \times 10^{-15} & -5.37028 \times 10^{-15}.
\end{array}$$

commenced. The sides, top and base of the tank were insulated with $\frac{1}{2}$ in thick sheets of blown polystyrene insulation, and heat losses were allowed for when calculating the heat fluxes. In every case both layers were of equal depth (18 cm) and the grids were located at the centre of each layer.

The stirring was switched on two minutes before any recording was commenced, as Thompson [6] had found that: ... "it takes two minutes for the small scale turbulence and its associated Reynolds stress to fill the tank". The initial salinity difference could be controlled quite accurately. The temperature difference was more difficult to control as it depended critically on the rate at which the lower layer was added and the stirring rate during the preliminary two minute period. The fluxes of heat and salt were determined from measurements of the temperature and salinity of the upper layer. The values of temperature and salinity measured at the mid-point of the lower layer were used as a check as the total heat content (after allowing for heat losses) and the total salt content should be constant.

The temperatures were measured by thermistors calibrated to 0.03°C over the range 15–50°C. The output of the thermistor bridge circuitry was amplified to provide a 0–10V signal. The salinity was determined

As the stirring rate increased the first recorded value of the temperature difference decreased. So in order to standardize the initial conditions the first recorded temperature difference for the 200 rev/min run was selected and then for the other runs all the recorded data up to this temperature difference were discarded. For the lower stirring rates the salinity difference decreased much more slowly than the temperature difference and so the salinity differences corresponding to the selected temperature difference agreed fairly well. For the 250 and 300 rev/min runs it was found to be meaningless to consider anything but values of the heat and salt fluxes averaged over the entire experiment as the 300 rev/min experimental run lasted only 6 min and the 250 rev/min experimental run lasted only 15 min.

3. COMPARISON BETWEEN THE GRID GENERATED TURBULENT VELOCITY AND THE UNSTIRRED CONVECTIVE VELOCITY

The non-dimensional stirring parameter λ will be introduced now so that the experimental results can be discussed without explicit reference to the stirring frequency. The turbulence in the immediate vicinity of the interface effects the transports across the interface and so λ should express the ratio of the grid generated

velocity to the convective velocity immediately adjacent to the interface. Ideally, it would be desirable to relate λ to the overall parameters so that λ could be used in wider contexts. Unfortunately, data relating the grid generated velocity and the convective velocity to the overall parameters is either limited or non-existent. When this information becomes available the present experiments could be re-interpreted as all relevant information is given.

A value of the vertical convective RMS velocity u_c within the layer has been measured by Crapper [7], using the Thymol Blue technique. He performed some two layer experiments in a cylindrical heating tank using an initial density difference of $5^o/_{oo}$ and heating at $1.77\,cal/cm^2$ min. The convective velocity was found to be essentially uniform throughout the layer and to increase as the experiment progressed (or as the density ratio R_ρ decreased). Averaging over each layer and the duration of the experiment u_c was calculated to be $0.24\,cm/s$. Some additional experiments were performed with only the lower layer (i.e. with one homogeneous layer of $5^o/_{oo}$ solution) and the same heating rate in order to determine whether the u_c measured previously was driven essentially by the heating process or by the double-diffusive process. The value of u_c was found to be much less than in the two layer experiments implying that double-diffusive processes were mainly responsible for driving the convection in the two layer experiments and that the heating rate was too low to significantly influence the convective velocity. Thus the value of u_c measured when the double-diffusive convection process was driven by an initial stabilizing density step and heating at $1.77\,cal/cm^2$ min should also be appropriate when the double-diffusive convection is driven by initial steps in both properties provided R_ρ is the same. In both types of double-diffusive convection experiments R_ρ will vary significantly, either a small to a larger value or vice versa, and it is assumed that the averaged value calculated by Crapper [7] is applicable to the present experiment.

The convection velocity measured in the experiments of Crapper [7] is obviously also influenced by the initial density difference. However, the initial density difference is comparable to that used in the present experiments. So, in summary the experiments of Crapper [7], although conducted with a different experimental configuration, should provide an approximate value for the convective velocity in the present experiment.

Thompson and Turner [2] measured the horizontal RMS velocity and integral lengthscale of the turbulence generated by an oscillating grid of bars in a homogeneous fluid. Their measurements showed that the horizontal RMS velocity and lengthscale of the turbulence varied with the frequency and amplitude of oscillation of the grid, the distance from the grid and the shape of the grid. For the particular geometry used in the experiments reported here, their measurements show that the RMS horizontal velocity at the interface u_g is given by

$$u_g = 0.06f \text{ cm/s} \tag{4}$$

where f is the frequency of oscillation in Hz. Although Thompson and Turner's measurements were made in a homogeneous fluid, equation (4) is used as a measure of the imposed turbulence in the homogeneous layers on either side of the interface. Thus the non-dimensional stirring parameter λ is given by

$$\lambda = \frac{0.06f}{0.24}. \tag{5}$$

4. EXPERIMENTAL RESULTS

The density difference $\Delta\rho$ between two layers in a non-stirred double-diffusive experiment, when energy is not being continuously supplied, must initially increase with time. For the case when the two layers are separated by a diffusive interface, this follows because the buoyancy flux ratio, $\beta F_S/\alpha F_T$ where βF_S and αF_T are fluxes of salt and heat expressed in buoyancy units $(g\,cm^{-2}\,s^{-1})$ respectively, must be less than unity, as it is the temperature difference which is driving the motion and thus lifting the salt. There is, however, a maximum value to $\Delta\rho$ as ultimately all the potential energy of the temperature distribution is used. The value of $\Delta\rho$ decreases slowly, once this maximum has been reached, as transport takes place increasingly by pure diffusion until the fluid becomes completely homogeneous, at which time $\Delta\rho = 0$. The whole subject of double-diffusive convection is treated in considerable detail in Turner [4].

Now when the grids within the layers are oscillated continuously, there is another source of energy to drive the motions and hence it is no longer necessary for $\Delta\rho$ to increase initially. In fact, when the transports are driven by a strong mechanical mixing process the flux ratio $\beta F_S/\alpha F_T$ will approach the initial density ratio, R_ρ, which in this case is approximately equal to 2 and $\Delta\rho$ will decrease rapidly. There is no special significance to the numerical value 2.

In between these two extremes in stirring frequency there should exist a frequency at which $\Delta\rho$ is approximately constant. Figure 2 shows graphs of $\Delta\rho$ plotted against time for different values of the stirring parameter, λ. The ordinate scales have been adjusted, by means of an additive constant, so that initially $\Delta\rho$ is the same for all stirring rates. This adjustment was necessary because the initial standardizing procedure produced slight variations in the initial salinity difference.

For $\lambda > 0.83$ $\Delta\rho$ decreases rapidly. For $\lambda \leqslant 0.83$ $\Delta\rho$ increases at first and then decreases, although for the $\lambda = 0.21$ run the experiment was stopped before $\Delta\rho$ started decreasing. The rate of increase and the rate of decrease of $\Delta\rho$ appear to increase with λ.

The values of $\Delta\rho$ vs time for the non-stirred case could not be measured directly using this experimental technique, because there is no mechanism for maintaining homogeneity within each layer. Information about the variation of the fluxes with R_ρ, for the non-stirred case, is contained in Turner [8]. Huppert [9] has fitted equations to Turner's data and these equations can be integrated using the standardized initial
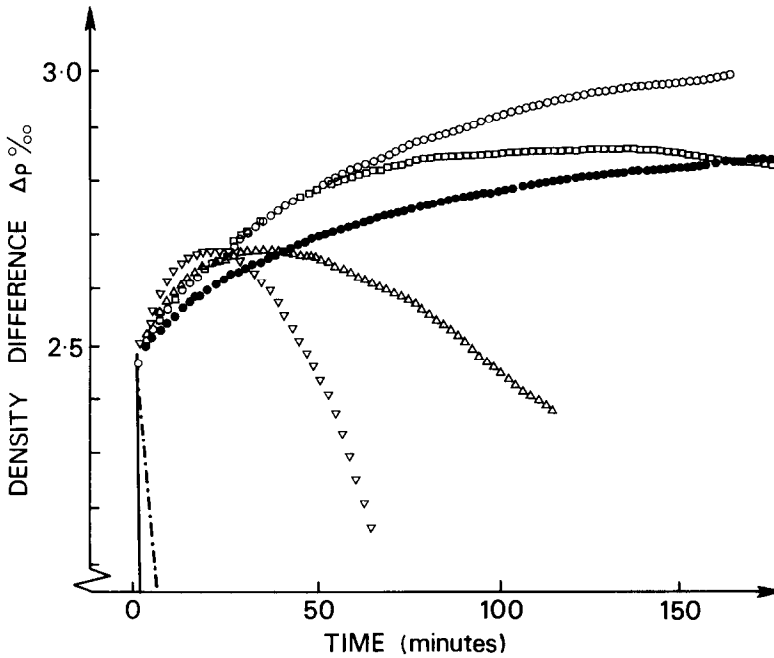
FIG. 2. A plot of the density difference between the layers vs time for varying λ.
●, $\lambda = 0$; ○, $\lambda = 0.21$; □, $\lambda = 0.42$; △, $\lambda = 0.63$; ▽, $\lambda = 0.83$; —·—, $\lambda = 1.04$;
———, $\lambda = 1.25$.

conditions as the starting point, to give the variation of $\Delta\rho$ with time. This variation is plotted on Fig. 2.

Initially, $\Delta\rho$ for the stirred cases increases faster than for the non-stirred case but at a later time there is a cross-over. The time required for this cross-over to occur increases as the stirring parameter decreases and for the $\lambda = 0.21$ run the experiment was stopped before the cross-over occurred.

The density difference $\Delta\rho$ is related to the buoyancy flux ratio $\beta F_S/\alpha F_T$

$$\frac{d\Delta\rho}{dt} = \frac{2\alpha F_T}{h}\left(1 - \frac{\beta F_S}{\alpha F_T}\right), \qquad (6)$$

where h is the layer depth. Thus it is worthwhile discussing the variation of $\beta F_S/\alpha F_T$ with stirring parameter at this time. Figure 3 shows a plot of $\beta F_S/\alpha F_T$ vs R_ρ for varying λ. As R_ρ increases with time for $\lambda \leqslant 0.83$ the abscissa can be thought of as a time axis. Over the experimental period the buoyancy flux ratio $\beta F_S/\alpha F_T$ was found to be always greater than 1 for $\lambda \geqslant 1.04$. For $\lambda = 0.42$, 0.63 and 0.83 the flux ratio was initially less than 1, became equal to 1 at the maximum of $\Delta\rho$ vs time, and then exceeded 1; it was always less than 1 for $\lambda = 0.21$. From equation (6) it is clear that the flux ratio must equal 1 when $d\Delta\rho/dt = 0$.

5. VARIATION OF THE FLUXES WITH STIRRING FREQUENCY

The fluxes of heat and salt for each run were averaged over the time it took the temperature difference to drop from the initial standardized value to half that value. The averaged heat flux and the averaged salt flux are plotted against λ in Fig. 4. Both of these fluxes are expressed in equivalent buoyancy units, which facilitates comparison between the two graphs. The
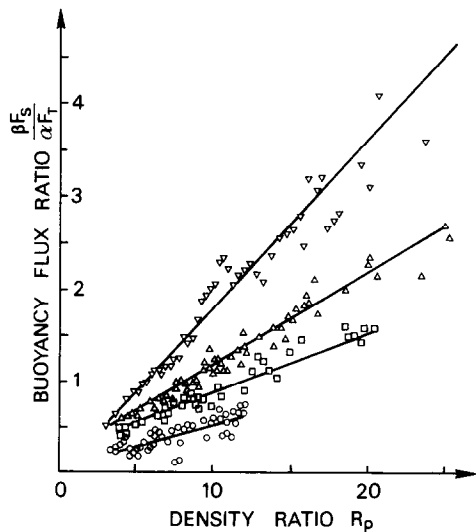

FIG. 3. The buoyancy flux ratio as a function of the density ratio for four different values of λ. The symbols have the same meaning as in Fig. 2.

salt flux and the heat flux were found to increase as λ increases. It is worth remembering at this stage that Linden [5] found that the salt flux has a minimum and the heat flux has no minimum for the case when salt is the destabilizing component and heat is the stabilizing component.

The averaged non-dimensional buoyancy flux ratio, obtained from the averaged fluxes, is plotted against λ in Fig. 5. For each stirring rate this averaged buoyancy flux ratio is equal to the mean of those flux ratios shown on Fig. 3, for which the temperature difference between the layers is less than the initial standardized value and greater than half that value. For $\lambda \ll 1$ the
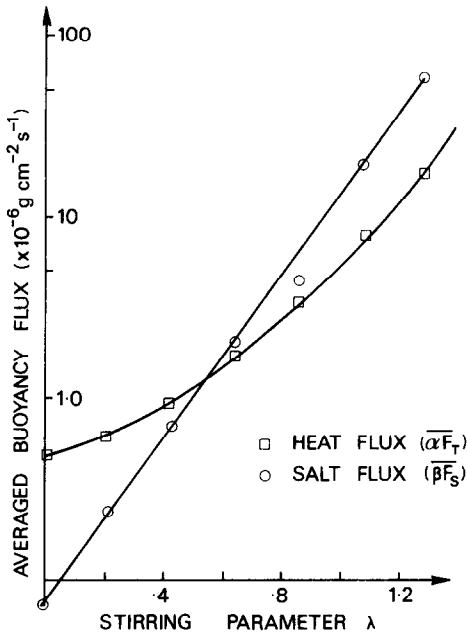
FIG. 4. A plot of the averaged heat flux and salt flux vs λ. The fluxes were averaged over the time it took the temperature difference to fall from its initial standardized value to half that value.
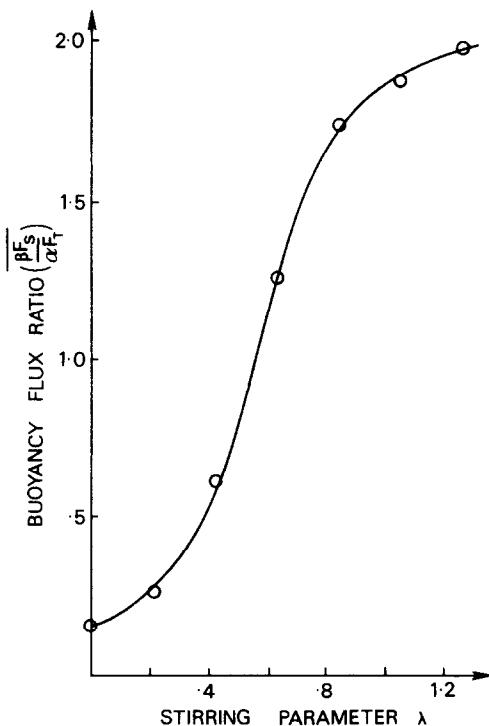

FIG. 5. The ratio of the buoyancy fluxes as a function of λ. These flux ratios were obtained by dividing the averaged salt flux by the averaged heat flux.

flux ratio approaches the value for no stirring (i.e. 0.15), thus suggesting that double-diffusive convection is the dominant transport mechanism and for $\lambda > 1$ the flux ratio approaches the initial density ratio. This feature indicates that for $\lambda > 1$ the transport is dominated by a mechanical mixing process. Linden [5] also observed

the dominance of mechanical mixing at high stirring rates, whilst measuring the fluxes of heat and salt across a finger interface. When $\lambda = 0.54$ the flux ratio equals 1 and hence $\Delta\rho$ should remain constant. An examination of Fig. 2 confirms this constancy.

At this stage Fig. 4 can be explained in greater detail. At low λ the transport is dominated by double-diffusive convection and so from energetic considerations the heat flux must be greater than the salt flux. At high λ the transport is dominated by mechanical mixing and the magnitude of each flux, for given λ, depends on the contrast of that component across the interface. Thus the salt flux will be greater than the heat flux as the initial salinity contrast was greater than the temperature contrast. The heat flux and the salt flux should now increase with λ at the same rate {i.e. $[d(\overline{\alpha F_T})/d\lambda = d(\overline{\beta F_S})/d\lambda]$, as observed} and the ratio of the two fluxes should equal the initial density ratio (2 in this case). So, in summary, there is a smooth transition in transport mechanism from double-diffusive convection to mechanical mixing, implying that the sharpening of the interface by the grid imposed turbulence increases the transport due to the double-diffusive process alone.

6. COMPARISON BETWEEN TRANSPORT IN SINGLE AND DOUBLE COMPONENT OSCILLATING GRID EXPERIMENTS

Experiments on single component transport, performed by Turner [1], have previously been mentioned. For the special case of the salt flux the effectiveness of double-diffusive convection, as a transport mechanism, can be clearly illustrated by including contours of temperature difference between the layers, as there is a stable stratification of salt in both single and double component experiments. In order to include contours of temperature difference on the salt flux plots, it is necessary to plot the actual fluxes for each stirring rate, not the averaged value.

The salt fluxes for the case $\Delta T = 0$ have been calculated from Turner's empirical relationship. The salt fluxes were evaluated using the same initial standardized salinity difference, a temperature of 20°C in each layer and averaging over the same time interval as the corresponding double component experiment. The initial density difference between the layers was different owing to the destabilizing contribution of the temperature step in the double component experiment. However it is possible to take account of the different initial density differences by plotting the salt fluxes against an overall Richardson number. The Richardson number used for the abscissa is the same as that used in Turner [1], from which the single component fluxes were evaluated. As the density difference varies only slightly, the Richardson number is mainly dependent on the stirring rate.

Figure 6 shows a plot of salt flux versus Richardson number in which the lines of constant temperature difference, ΔT, have been drawn in. At large Richardson number, increasing the ΔT increases the salt flux. This clearly shows the effectiveness of double-diffusive pro-
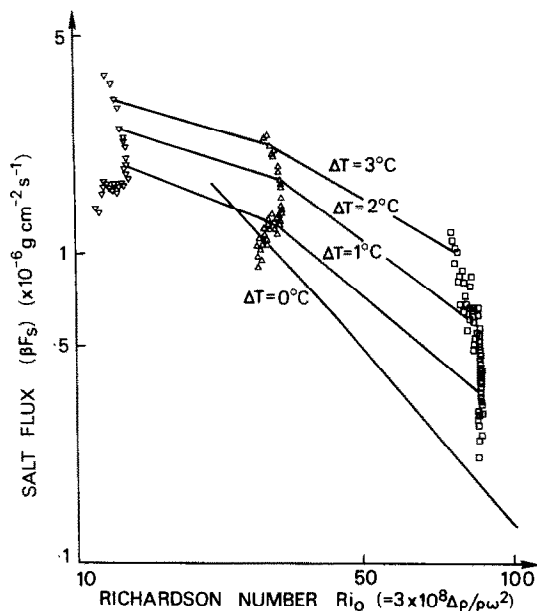
FIG. 6. A plot of the salt flux vs the overall Richardson number for various values of the temperature difference. ω is the stirring rate in rev/min.

gradually from double-diffusive convection processes to mechanical mixing as the stirring rate increased. The salt fluxes in single and double component stirring grid experiments were plotted against an overall Richardson number and it was found that the presence of a temperature difference across the interface increased the salt flux. This figure provides a clear illustration of the effect of variations in the level of turbulence within the layer on the double-diffusive convection mechanism.

The transport mechanism effective across a diffusive interface at high stirring rates has many features in common with the transport mechanism effective across an unstirred diffusive interface when the density ratio is only slightly greater than one. In both cases, the flux ratio approaches the density ratio, thus indicating that the transport mechanism is produced by a mixing process in which both components are transported by the same eddies. However, in the former case the turbulent eddies, which produce the mechanical mixing, are due to the stirring, whilst in the latter case the turbulence is itself produced by the convective transport across the interface.

cesses over normal diffusive transport as a mechanism for the transport of salt, when the stirring rate is low. As the Richardson number decreases the effect of varying ΔT on the salt flux becomes less significant, and in the limit of small Richardson number, it appears that the salt flux may be independent of ΔT. If the salt flux were independent of ΔT it would imply that mechanical mixing is the dominant transport mechanism at low Richardson number.

7. SUMMARY AND CONCLUSIONS

The fluxes of heat and salt across a diffusive interface have been measured in the presence of grid generated turbulence. It was found that the density difference between the layers increases with time for low stirring rates and decreases with time for high stirring rates. The averaged buoyancy flux ratio was found to approach the value for no stirring at low stirring rates and approach the initial density ratio for high stirring rates. The dominant transport mechanism changed

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FLUX DE CHALEUR ET DE SEL AU TRAVERS D'UN INTERFACE DIFFUSIF, EN PRESENCE D'UNE TURBULENCE DE GRILLE

Résumé—Le transfert de la chaleur et du sel au travers d'un interface stabilisé par une différence de température a été étudié lorsqu'une turbulence, produite par des grilles horizontales en mouvement vertical oscillant, est imposée sur les couches éloignées au dessus et au dessous de l'interface. Les flux de chaleur et de sel sont mesurés en fonction d'un paramètre adimensionnel λ, qui exprime le rapport de la vitesse de convection. Chacun des deux flux augmentent avec λ. Pour $\lambda \ll 1$ le processus de convection avec double diffusion apparait comme le mécanisme de transport dominant et pour $\lambda > 1$ le processus de mélange est apparu dominant. Les résultats ont été comparés à ceux de Turner [1] obtenus avec une seule composante de diffusion. Dans le cas particulier d'un flux de sel, l'efficacité de la convection avec double diffusion peut être expliqué en examinant l'effet d'un changement de la différence de température entre les couches fluides.

WÄRMESTROM UND SALZAUSTAUSCH DURCH EINE DURCHLÄSSIGE
GRENZFLÄCHE IN ANWESENHEIT EINER MIT HILFE EINES
GITTERS ERZEUGTEN TURBULENZ

Zusammenfassung—Es wird der Transport von Wärme und Salz durch eine Grenzfläche, welche durch eine Salzkonzentrationsdifferenz stabilisiert wurde und mit Hilfe eines Temperaturgradienten gestört wird, untersucht; dabei wurde durch vertikal oszillierende, horizontale Gitter eine Turbulenz erzeugt, welche in die tieferliegenden Schichten ober- und unterhalb der Grenzfläche eingeführt wurde. Der Wärmestrom und der Salzaustausch wurde in Abhängigkeit eines dimensionslosen Parameters λ gemessen, der das Verhältnis der durch die Gitter erzeugten Geschwindigkeit zur Konvektionsgeschwindigkeit angibt. Beide Ströme zeigten eine Zunahme mit λ. Für $\lambda \ll 1$ war der durch Leitung und Diffusion bedingte Transportmechanismus vorherrschend; für $\lambda > 1$ war der mechanische Mischungsvorgang dominierend. Die Ergebnisse wurden mit denen von Turner [1] verglichen, welche für eine einzige Diffusionskomponente erhalten worden sind. Für den speziellen Fall des Salzaustausches kann die Wirksamkeit der beidseitigen Diffusionskonvektion mit Hilfe der Untersuchung des Effektes einer Aenderung der Temperaturdifferenz zwischen den Schichten klargelegt werden.

ПОТОКИ ТЕПЛА И СОЛИ НА ДИФФУЗИОННОЙ ПОВЕРХНОСТИ РАЗДЕЛА
ПРИ НАЛИЧИИ ВЫЗВАННОЙ РЕШЕТКАМИ ТУРБУЛЕНТНОСТИ

Аннотация — Исследуется перенос тепла и соли на поверхности раздела, стабилизируемый разностью концентрации соли и дестабилизируемый температурной разностью для случая, когда вызванная вертикально осциллирующими горизонтальными решетками турбулентность распространяется в более глубокие слои над и под поверхностью раздела. Потоки тепла и соли измерялись как функции безразмерного параметра λ, представляющего собой отношение скорости, генерируемой решеткой, к конвективной скорости. Найдено, что оба потока увеличиваются с увеличением λ. Оказывается, что при $\lambda \ll 1$ доминирующим механизмом переноса является двухкомпонентный диффузионный процесс, а при $\lambda > 1$, механические процессы смешивания. Проведено сравнение полученных результатов с данными работы [1], в которой исследовалась только однокомпонентная диффузия, а для частного случая потока солености эффективность процесса двухкомпонентного диффузионного переноса можно проиллюстрировать, исследуя изменение температурной разности между слоями.