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# THERMAL CONVECTION OVERLAPPED BY VELOCITY SHEAR: FLUID EXPERIMENT

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**Abstract.** Complexity of plasma dynamics restricts usual considerations to relatively simple elementary processes. Not only the processes itself but and interactions between the processes are interesting too. Many analogies between plasma and fluid dynamics are known, partly, convective processes. Here we present our first results of laboratory observation of fluid thermal convection overlapped by velocity shear. The velocity shear was orientated perpendicular to the temperature gradient. The fluid used is oil with aluminum dust. The fluid motion has been recorded by digital HD video camera. The structure of the convective cells has been extracted by gradient filter. Visco-elastic features of the convection structure in the region of reconfiguration of thermal convection cells to shear motion have been considered. Gradual decrease of the fluid temperature gave us possibility to follow an increase of the shear motion zone with increase of viscosity. Possible analogies of observed structure with events in the auroral ionosphere are discussed.

## 1. Introduction

A numerous different instabilities strongly complicate an analysis of plasma dynamics [1,2]. Some of these instabilities were analyzed separately; however interactions between the processes occurring simultaneously in a system are not obvious. There are many analogies between plasma and flow dynamics, partly, convective processes [3,4]. Therefore by fluid laboratory experiment it is possible to study relatively simple situation when we have two independent source of the fluid perturbation. Here we present our first results of laboratory observation of fluid thermal convection overlapped by velocity shear.

## 2. Equipments and observations

The measured temperature dependence of viscosity of the used oil is presented in Fig.1. The tabulated dependence for similar oil is shown to compare. The measured values are 4-10 times higher than tabulated ones, however typical decrease of the viscosity with temperature is observed. The oil was heated up to 70$^o$C by bottom plate in a cylinder tank. Then the heater was turn off and the oil temperature was gradually decreasing due to coupling with environment. The coaxial central cylinder can be rotated.

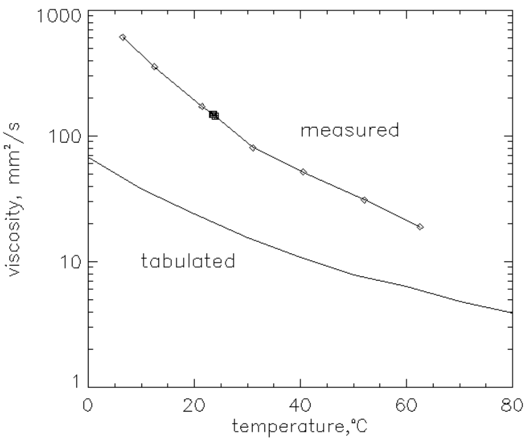


**Fig.1.** Temperature dependence of oil viscosity.

It is known that in case of a free liquid surface in contact with air also surface tension effects will play a role in formation of the convection pattern, besides buoyancy. It is known that liquids flow from places of lower surface tension to places of higher surface tension. This is called the Marangoni effect [5].

Convection experiments have been provided for temperature range 30-70$^o$C. The corresponded range of Reynolds number is from ~3 to ~15, taking into account diameter of rotation cylinder (10 cm) and rotation velocity (2.5 mHz). The height of the oil layer was ~1.7 cm.

The aluminum dust has been admixed to the oil to visualize a structure of the fluid motion. Fig.2 presents images of the experimental tank from the top. The images were recorded by digital HD video camera (resolution 1440x1080 pixels, 25 frames/s). The record has been digitized with resolution 720x576 pixels. Boundaries between convection cells are seen in the images as darker lines due to different orientation of aluminum dust particles in vertical flow. Structure of the boundaries was considered in coordinates of angle - radial distance, see Fig.3. The radial distance has been normalized by diameter of rotation cylinder.

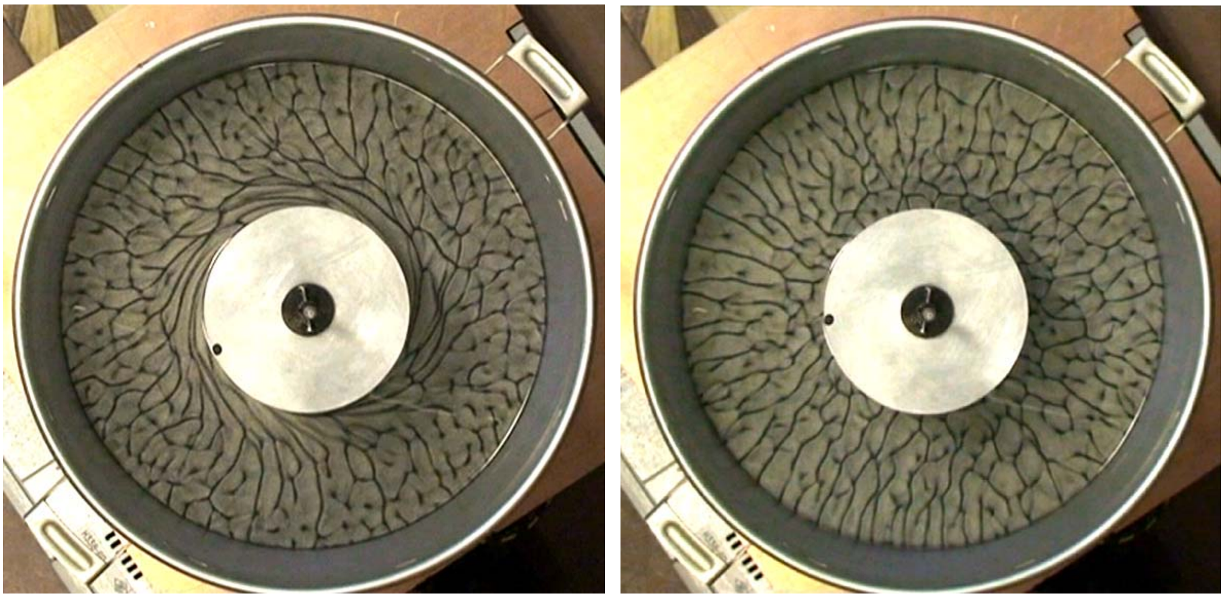

**Fig. 2**. Thermal convection with velocity shear due to CW rotation of central cylinder (left). Structure of the convection without shear (right). Boundaries between convection cells are seen as darker lines due to different orientation of aluminum dust particles.

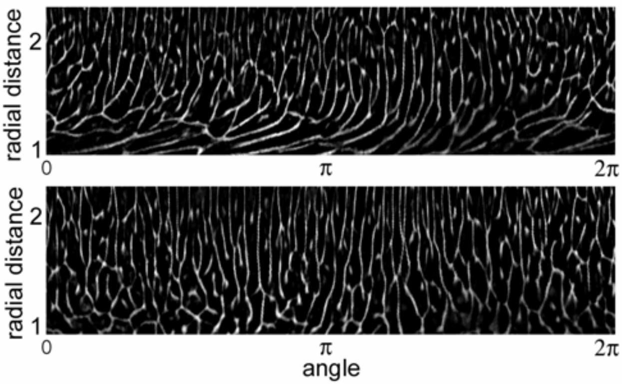


**Fig.3.** Structure of convection cells with (top) and without (bottom) shear in angle-radius coordinates.

One can see that the convection structure distortion was mainly located in the limited range of radial distances near the rotated cylinder. This is a region of shear flow.

Here we analyzed a short interval (~5 min) of observation. Each 10-th frame was extracted for analysis, so we have 930 frames. The dependence of number *n* of boundaries between convective cells on radial distance has been calculated for each frame.

Fig.4 illustrates the normalized deviation of the boundaries number, $(n-\langle n \rangle)/\langle n \rangle$, as a function of time and radial distance. Here $\langle n \rangle$ is mean value of the number over considered time interval. One can see that the strongest normalized deviations were observed in the shear flow region.

## 3. Discussion

To analyze the radial dependence of the convection cells structure it was calculated the statistical moments: mean value, standard deviation, skewness and kurtosis of the number of boundary cells as a function of radial distance. These dependences are shown in Fig.4.

The mean value of the boundaries number is gradually increasing with the radial distance. The only deviation observed near the tank boundaries.

The standard deviation is varying near 4 in full range of radial distances. So the strong normalized deviations in shear region (seen in Fig.4) are mainly result of the mean value decrease.

The most interesting features were observed for skewness and kurtosis. At large radial distances (>1.5) we have regular variation of both characteristics on distance due to regular structure of convection cells. The experimental tank is relatively small, so only a few cells fit into the range of the radial distances. These regular structure is better seen in smoothed curves presented in Fig.5-c,d. In average the skewness is varying near zero value, the kurtosis value is mainly less than 3.

At smaller distances the skewness and kurtosis are larger. The skewness is mainly positive; the kurnosis is rising to 3. The qualitative difference of the convective and shear regions is more obvious if we plot the kurtosis vs. skewness, Fig.6. One can see on Fig.6 two different groups of points, corresponded to the regions.

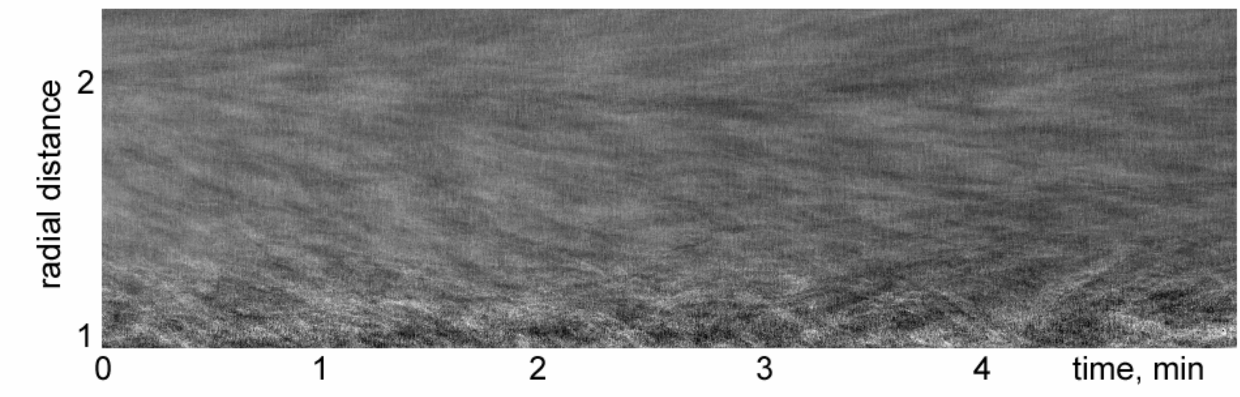


**Fig.4.** Normalized deviation of the boundaries number, (*n*-<*n*>)/<*n*>, as a function of time and radial distance. Here <*n*> is mean value of the number over considered time interval (~5 min).

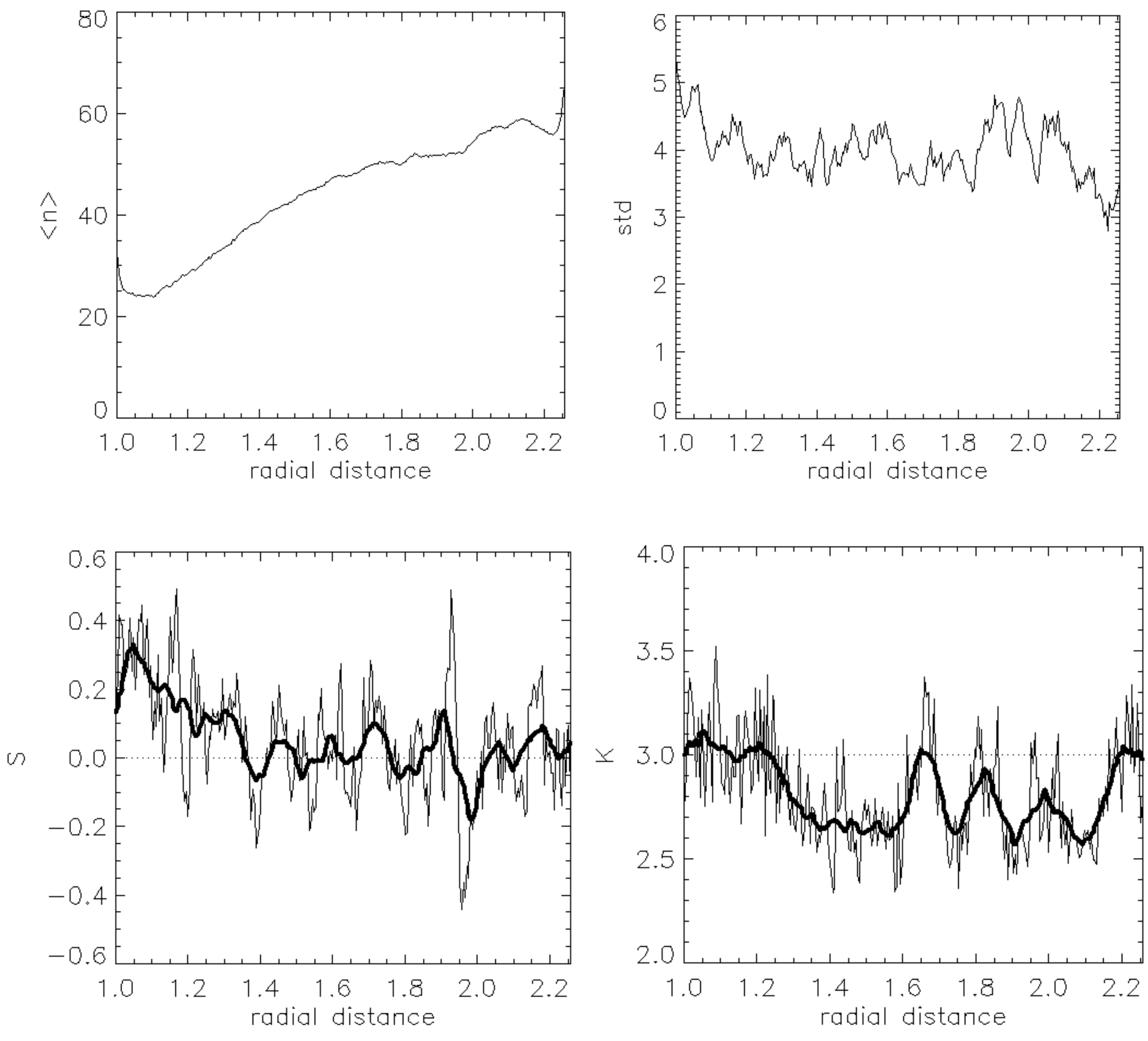


**Fig.5.** Radial dependences of the moments of the boundaries number distribution. Skewness and kurtosis values for Gaussian distribution are shown by dotted line, thick lines are smoothed over 0.1 radial distances.

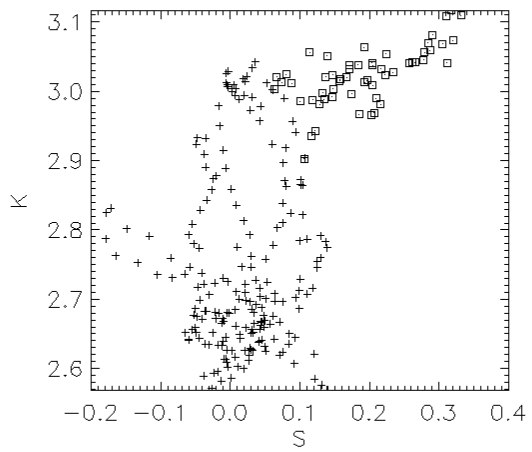


**Fig.6.** Two populations observed in S-K plot: pluses are corresponded to region of undisturbed thermal convection, squares – the shear region.

Fig.7 presents a direct comparison of the normalized probability density functions (PDF) of the cell number in these two regions. The PDF is nearly symmetric one for the convection region, but skewed one for the shear region.

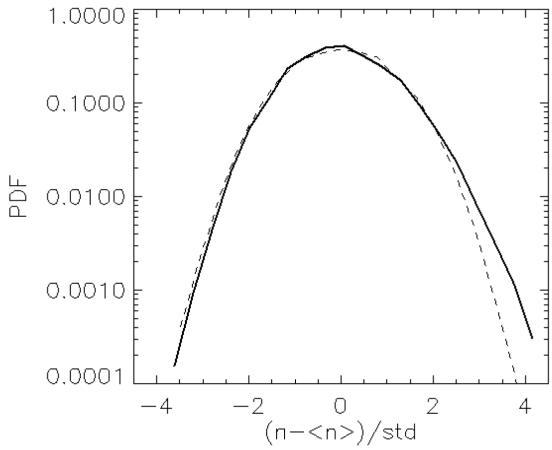


**Fig.7.** Normalized PDF of the cell number for two regions: dashed line - undisturbed thermal convection, solid line – the shear region.

We can assume that the thermal convection structure should tend to survive and, therefore, to suppress the shear motion at large distances. At small distances, where shear velocity is comparable with the convection velocity, the stretching of the convection cells should lead, firstly, to decreasing of total number of cells and, secondary, to their disruptions. Relatively small mean number of cells in the shear region (Fig.5-a) and positive skewness (Fig.5-c) supports this assumption.

More detailed analysis of the fluid experiments with different velocities of the central cylinder rotation, as well as relations with similar experimental and numerical treatments [6,7], will be provided in future works.

## 4. Summary

The laboratory equipments have been realized to observe the motion structure of liquid forced by two reasons: thermal gradient and velocity shear. The velocity shear gradient was directed perpendicular to the thermal gradient. The structure of convective cells in horizontal plain has been extracted. The number of convective cells as a function of radial distance has been analyzed. We found that the PDF of the number of convective cells is different for shear and for non-shear region. Probability of large positive deviations of cells number from mean value is larger in the shear region. This is probable manifestation of disruptions of the convection cells forced by velocity shear.

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