Zeitschrift: Helvetica Physica Acta
Band: 60 (1987)
Heft: 3

Artikel: A suspension of small metallic plates : a versatile sensor
Autor: Stalder, M. / Lüthy, W.
DOI: https://doi.org/10.5169/seals-115857

Helvetica Physica Acta, Vol. 60 (1987) 464–470
0018–0238/87/030464–07$1.50 + 0.20/0

A suspension of small metallic plates: a versatile sensor

By M. Stalder and W. Lüthy

Institute of Applied Physics, University of Bern, Sidlerstr. 5, 3012 Bern
Switzerland

(4. VI. 1986)

Abstract. Small metallic plates suspended in a liquid are a good medium to generate visible velocity gradients in the convection flow. They tend to align parallel to the flow and lead to anisotropic optical properties of the fluid. Besides Benard and Rayleigh instabilities that can be seen upon heating or cooling of the liquid layer, we present a new type of fluid convection instability based on segregation of the suspension. It is demonstrated that the suspension can be used as a sensitive infrared image converter. Electric and magnetic fields can interact with the metallic plates and lead to similar optical anisotropies without heating of the suspension. It is shown that this allows to construct displays that can be operated with typically 20 Volts applied on a suspension layer of 1 mm thickness.

1. Introduction

The medium under investigation consists of small aluminum plates with typically 5 μm diameter suspended in voladile fluids. Small plates suspended in a fluid align in a inhomogeneous velocity field. The dynamics of the particle orientation has been studied by Peterlin and Stuard [1]. With metallic plates of high specular reflection perpendicular to their surface, and a low reflection parallel to the flat, a change in the orientation of the particles modifies the optical properties of the suspension. This helps to make convection flow visible.

When a thin fluid layer with its surface in contact with air is heated uniformly from below, the disturbed fluid gets out of equilibrium and convection starts. The convection results in a typical cellular structure [2, 3]. According to a theory of Rayleigh [4] similar structures can be observed if the surface of the liquid is in contact with a glass cover. For review articles on Benard- or Rayleigh-convection see Koschmieder [5] or Normand et al. [6].

In our paper we present a new type of convection instability that is not based on thermal effects. We further demonstrate the application of the suspension as an infrared image converter similar to the work of Heintz [7]. We also studied the interaction of electric and magnetic fields with the metallic plates in the suspension. Based on these interactions we built an electrooptical display.

2. Properties of the suspension

In our experiments we used a suspension of aluminum in surgical spirit or penthane. The size of the flat aluminum platelets varies in the range of 1 μm to 20 μm. The suspension has been prepared by diluting one part of commercial aluminum colour with about 10 to 100 parts of the fluid. Before use the mixture has to be shaken. The time for sedimentation range from about 5 minutes to one hour. Since the used fluids evaporate at a temperature of 35–45°C, it is enclosed in sealed off containers.

In a suspension moving with a homogeneous velocity the angular momentum of a small aluminum plate does not change. In an inhomogeneous velocity field, however, any particle experiences a force, that results in an irregular periodic motion around its center of gravity, beside a possible translation. This dynamical behaviour has been studied theoretically for the special case of a rotational ellipsoid by Peterlin and Stuard [1]. They found that these particles stay orientated longest with their largest extension parallel to the direction of the flow, but periodically tumble over. The more the shape of the particles is spheric, the more the motion becomes harmonic.

3. Interactions of thermic radiation with the suspension

If a thin liquid layer is heated uniformly from below, convection flow can be observed leading to characteristic patterns on the surface (Benard cells). These have typically the shape of honeycombs or rolls. This behavior has been studied for a long time. The initial experiments were performed by Benard in 1900 [2]. In Benards fluids the upper surface was in contact with air. In this case the most important driving force for the convection is the temperature dependence of the surface tension (Benard convection).

Rayleigh [4] gave the first fundamental theoretical study for the case of a thin, infinitely extended fluid, with the upper surface covered by a solid layer kept at a constant temperature. When the bottom is heated, the fluid expands and its density decreases. Therefore the density distribution in this liquid layer becomes unstable. The horizontal uniform density distribution in the fluid is disturbed e.g. by the Brownian motion. By this disturbance a small volume of fluid from the bottom may be found in an upper, heavier surrounding and will therefore be accelerated upwards. There are two mechanism, that hinder this fluid convection: the heat transport from the lighter fluid volume to the colder and the viscosity of the liquid. Rayleigh's theory predicts in good agreement with the experiment, that a threshold in the temperature difference between the top and the bottom of the fluid has to be reached to start convection. This type of convection is called Rayleigh convection. An example of the resulting surface patterns is shown in Fig. 1(a).

Block [8] performed experiments, which indicate, that Benard's convection cells are not primarily buoyancy driven. First, he covered a fluid, that shows

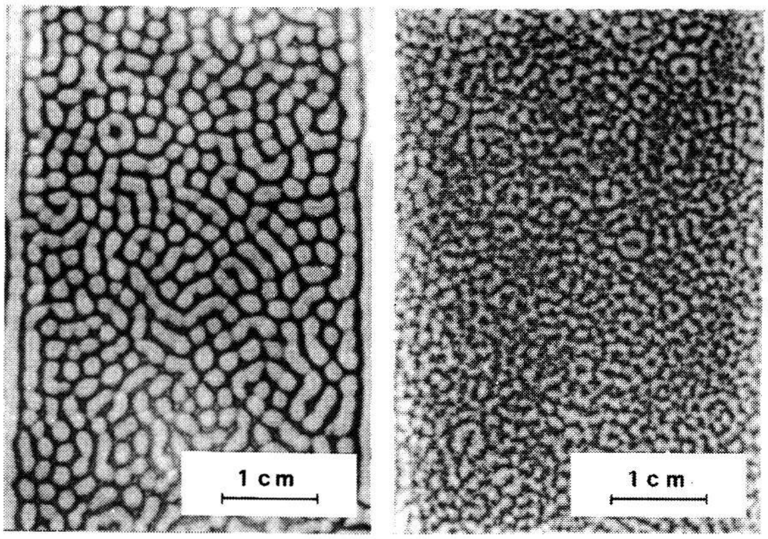

Figure 1
Convection induced by an instable density distribution, performed in a thin (2 mm) fluid cavity. (a) The case of Rayleigh convection, (b) The case of sedimentation.

Benard cells with a monolayer of another fluid and immediately the convection stopped. He also observed convection flow in a liquid layer of 50 μm thickness and a small temperature gradient, that should be stable according to Rayleigh's theory. Finally he cooled the fluid layer from below and even in that case convection cells appeared. So he was lead to the conclusion, that for thin liquid layers the driving mechanism is due to a thermomechanical instability based on the temperature dependence of the surface tension (Marangoni forces). See also [9, 10].

Besides instabilities due to the temperature dependence of surface tension or density we found a new type of instability based on sedimentation. In a suspension where sedimentation has occurred heavy aluminum particles have accumulated at the bottom of the container. If this suspension is carefully turned upside down, an instable density distribution results. Convection arises, but since no energy is supplied further to the system, the flow is limited in time. This first experiment leads to the formation of convection cells as shown in Fig. 1(b). These cells are, however, smaller and not as regular as Rayleigh cells obtained in the same container with identical thickness of 2 mm of the fluid (cf. Fig. 1(a)).

4. An infrared-visible image converter

From the Benard experiments it is known, that suitable liquid layers respond rather sensitively to applied temperature gradients. The fluid reacts even more, if the heating is not uniform but local. Figure 2 shows such a situation. A radiation field *R* heating the area A, produces Marangoni forces that lead to convection in this illuminated region. In the region A the flow is directed upwards and appears dark, whereas the area B of horizontal flow and horizontally orientated particles exibits enhanced brilliance.

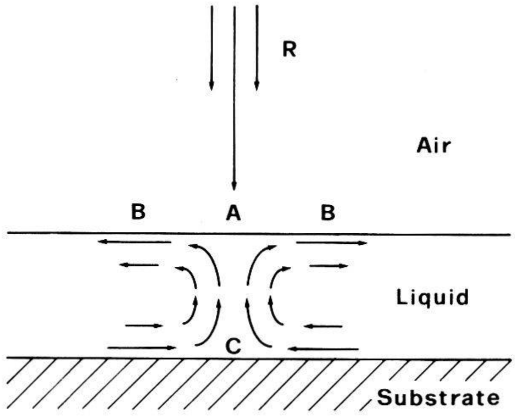

Figure 2
A thin liquid layer, illuminated by the radiation R. The IR absorbing region A is heated and a convection flow starts. Small plates in the liquid align horizontally in the area B and vertically at A.

In a second experiment an infrared-visible image converter based on these mechanisms was constructed. The container with a 2 mm thick suspension of aluminum plates in penthane was covered with a Mylar foil of 2 μm thickness (80% transmission at 10 μm wavelength). The container was kept at ambient temperature (20 °C). A temperature controlled thermal radiator (soldering iron) was imaged with a KCl lens of aperture 0.6 on the surface of the suspension. To obtain an infrared picture after an exposition time of 4 s, a temperature of 41°C was necessary.

Already Heintz [7] performed similar experiments. He used small aluminum plates suspended in amylalcohol. The thermal image was made visible in a different way. The aluminum particles were larger, their concentration was lower with respect to our suspension and therefore sedimentation occurred quite fast. Illuminated from the top, the bottom of the fluid covered with the horizontally lying plates appeared bright and reflecting. Convection induced by the applied temperature field carried the plates into the region C (cf. Fig. 2). The particles are moved towards the surface A, are therefore orientated vertically and in the region below the illuminated surface the reflectivity is reduced.

In order to compare the sensitivity of the apparatus used by Heintz with ours, we estimated the minimum fluence needed to obtain an image. With the assumption, that the radiators are black bodies at a temperature of 41° and neglecting losses in the optics it turns out, that the device of Heintz needs a minimum fluence of about 14 mJ/cm^2 and our suspension one of 3 mJ/cm^2 to form an image.

5. Interactions of electric and magnetic fields with the suspension

If a homogeneous electric field is applied to the suspension the aluminum particles become polarized and align along the electric field. The transmission in the direction parallel to the electric field is increased and perpendicular to the field the reflectivity is enhanced. With the electric field switched off, the particle orientation is destroyed by Brownian motion. For extended investigations of the interaction of electric fields with submicron dipol particles see [11]. Similar experiments with organic pearlescent material have recently been described by Bostwich and Labes 1984.

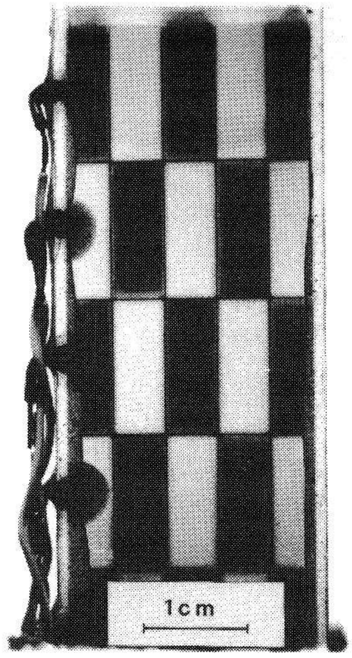

Figure 3
Display based on the aluminum suspension. The fluid depth is 1.0 mm. In the transparent areas a voltage of ±30 V is applied.

In a third experiment we built an electrooptical display. The suspension was filled into a glass cell of 25 by 75 mm and 1 mm thickness. The inner sides of the cell were covered with a semi-transparent gold layer. One side was divided in five horizontal, the other side in five vertical areas. To the resulting ten layers an external voltage could be applied individually. The device with partly applied voltage is shown in Fig. 3. In the area of applied voltage the transmission is enhanced. The area without applied electrical field remains grey. An alternating voltage (±30 V) was used with a frequency of 1 kc. With an applied step of 0 to 30 V the rise time of the transmission is less than 300 ms. Switching the electrical field off, the particle orientation is destroyed within a few seconds. The transmission of the suspension as a function of the applied voltage is given in Fig. 4. It can be seen that at ±40 V the transmission saturates. The contrast between the areas with and without applied electric field might be further improved [11] by using metallic plates with dimensions near the wavelength of visible light.

In a forth experiment we demonstrate the sensitivity of the display to electric charging. A container of 20 cm by 30 cm was filled with a 5 mm deep layer of the fluid and covered with a 0.2 mm thick plastic foil. By touching the plastic foil or by writing on it with a brush or even with a single human hair, enough electric

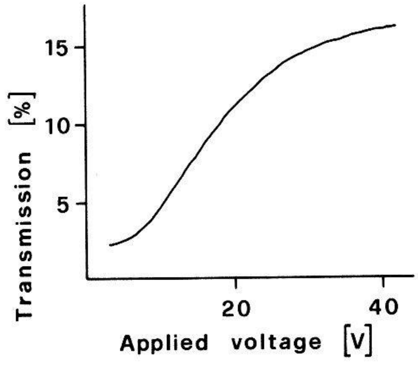

Figure 4
Transmission as a function of the applied voltage (alternating and rectangular at 1 kHz).

Figure 5
The effect of static charging on the suspension. The letter β has been written with a synthetic brush.

charge is left on the foil to produce a picture of high contrast that remains for about a minute. An example is given in Fig. 5. The resolution of the dark traces in the fluid depends on thickness of the foil and was less than 1 mm.

In a last experiment we exposed the suspension to magnetic fields and also observed an alignment of the aluminum particles. In Fig. 6.a the suspension is shown in a magnetic field of linear and circular shape as obtained from ordinary permanent magnets. In Fig. 6.b the two magnetic fields are superposed. The magnetic field strength is in the order of one kG. The bright lines correspond to areas where the magnetic field is perpendicular to the liquid surface.

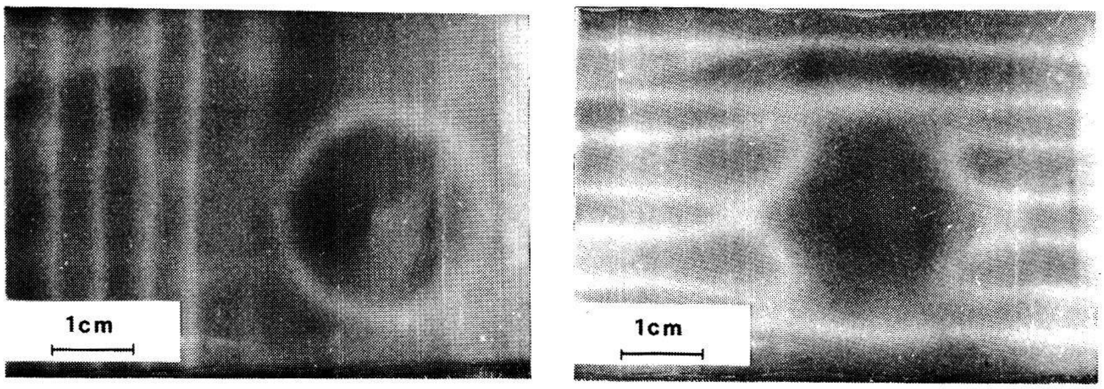

Figure 6
(a) Response of the suspension on a magnetic field of parallel and circular symmetry, (b) Response on the two superposed fields.

6. Conclusion

In conclusion, we have discussed the properties and possible applications of a suspension of small aluminum plates in surgical spirit and penthane. Benard- and

Rayleigh-convection has briefly been reviewed. We have shown that instabilities based on sedimentation lead to a similar behaviour of the liquid as the formation of Rayleigh cells. Experimentally it has been verified that the suspension can be used as a very simple infrared image converter with a threshold sensitivity of $3\,\mathrm{mJ/cm^2}$. The same suspension can also be used as a display or as a sensor of electric and magnetic fields.

Acknowledgments

We would like to thank H. P. Weber for his stimulating interest and B. Wicki for his expert work in the photolaboratory. This work was supported in part by the Swiss Commission for the Encouragement of Scientific Research.

REFERENCES

[1] A. PETERLIN and H. A. STUARD, Z.f. Physik *112*, 1 (1939).
[2] H. BENARD, Rev. Gen. Sci. Pure Appl. *11*, 1261, 1309 (1900).
[3] H. BENARD, Ann. Chim. Phys. *23*, 62 (1901).
[4] LORD RAYLEIGH, Phil. Mag. *32*, 529 (1916).
[5] E. L. KOSCHMIEDER, Adv. Chem. Phys. *26*, 177 (1974).
[6] C. NORMAND, Y. POMEAU and M. G. VELARDE, Rev. Mod. Phys. *49*, 581 (1977).
[7] E. HEINTZ, J. Physique *7*, 293, 336 (1946).
[8] M. J. BLOCK, Nature *178*, 650 (1956).
[9] J. R. PEARSON, J. Fluid. Mech. *4*, 489 (1958).
[10] P. G. GRODZKA and T. C. BANNISTER, Science *176*, 506 (1972).
[11] A. M. MARKS, Applied Optics *8*, 1397 (1969).
[12] B. D. BOSTWICK and M. M. LABES, APL *45*(4), 358 (1984).