On the Characteristic Natures on the Helical Vortex

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Abstract

A creation of helical vortex in an agitating tank with the baffled plates was reported in the previous work. This vortex may be found frequently in our usual experiences, but it is remained to be solved. Several of a series of basic experiments will reduce the difficulties to analzye this striking affair.

Another source of helical cone vortex is presented here. It was formed in an unbaffled vessel placed on a usual magnetic stirrer. Some observations of this type of vortex and its simple applications are reported in this paper.

Introduction

The helical cone vortex is produced in the tank with the baffled plates by the agitations of the rotating shaft mounted a turbine impeller. The first observation in an agitating tank with the baffled plates is presented in the last work[1)]. The characteristic vortex is prepared by a relatively slow speed of revolutions of the agitating shaft, and the impeller mounted on the shaft is placed at nearly under the surface of the fluid. At the high speed of revolution of the shaft (more than 400 r.p.m.), the whole fluid in the tank effervesces with the white foams.

Another helical vortex is formed in a beaker on a magnetic stirrer without baffle. It was found in a beaker with a disproportionally large stirring element. At the slow speed of revolution only a slightly hollowed surface is given in a beaker used. Then, it is caved in the fluid by an inceasing of the speed of revolution of the stirring element. The helical vortex caved falls as deep as getting to the stirring element in accompany with an increase in speed of rotation. Simultaneously, the fluid is bursting with the foam by inhaling the air. An interesting attempt was held by means of the helical vortex. A series of examinations was tested by using two immimisible liquid each other. Organic liquids (such as benzene and some peteroleum oils) were placed on the water to examine the relations between the energy comsumed by inhaling the liquid through helical vortex in water and other circumstances.

One of the purposes of this work is to elucidate the conditions of a creation of helical vortex and to find any application to the field of chemical reaction. Another purposes is to pave the way for the future success to analyze completely on the helical cone vortex.

Expermentals

The agitating tank used in the previous work is emploied to get the emulsion in which water takes hold any immiscible liquid through the helical vortex. Fig. 1 shows the

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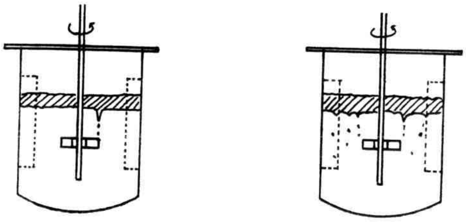
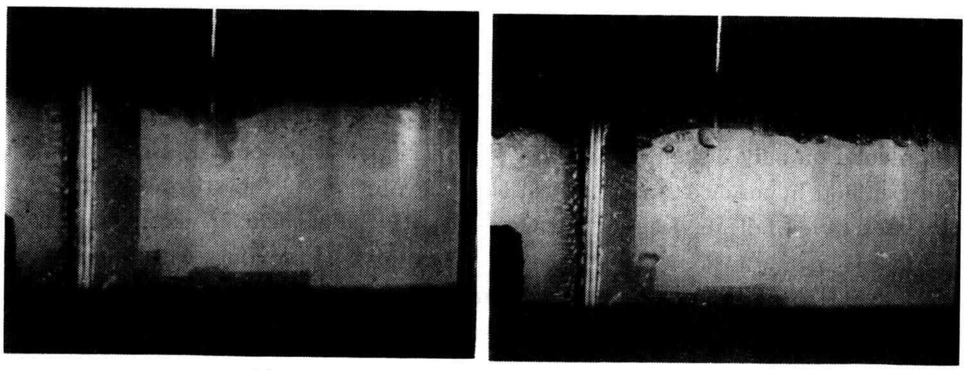
schematic diagram of the agitating tank. An only difference is the presence of an immiscible oil layer upon the surface of water. One of vortex is found near the agitating shaft at low speed of revolution in Fig. 1 (a). Fig. 1 (b) shows a little increased speed of the shaft. Many of small vortices are scattered over the whole surface of water, and then the oil drops are sucked in water at each vortex head. Photo. 1(a) and (b) show these circumstances.



(a) (b)

Fig. 1 The schemaitc diagrams of the agitating tank at oil layer placed on water. (a) is at low speed of agitation (ca. 200 r. p. m.), and (b) that of a faster speed of agitation (ca. 300 r. p. m.).



(a) (b)

Photo. 1 The tank agitation of oil floated on water. (a) is the slow speed of agitation (200 r. p. m.). A small vortex is formed near the agitating shaft. (b) shows the situation of the more speedy agiation (300 r. p. m.). Many of small vortices are found at the whole surface of water.

Another source of the helical vortex is reported in this paper. The most trivial magnetic stirrer found at any chemical laboratory is used to get the helical vortex by an agitating instrument. 1000 *ml* of beaker was used for an agitating vessel. To estimate the energy consumed by the agitation of the contents, a wattmeter was inserted into a circuit of the driving A.C. source. At first, 500, 750 and 1000 *ml* of three volumes of water were put in order in a 1000 *ml* beaker. The same stirring element was used at each trace.

The energy consumed by agitation was measured by the wattmeter. Fig. 2 shows the sizes of the stirring elements in this work.

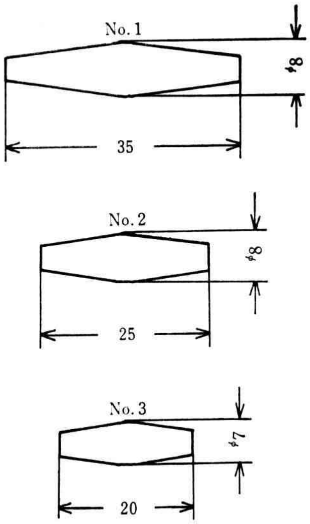


Fig. 2 The size of the stirring elements used in this work.

Subsquent estimations were held by the agitation of mineral oil placed on the surface of water. About 200 *ml* of kerosene (its specific gravity 0.80 at ordinary temperature) was employed to form the water in oil emulsion through the helical vortex.

Results and Discussions

5 l of kerosine was poured onto 45 l of water in the agitating tank. The same baffled tank as shown in Fig. 2(b) in the previous paper[1] is agitated with the curved impeller. The helical vortex could be found at the slow speed of agitation (ca. 200 r.p.m.) in the interfacial surface between oil and water, but it is not shape as shown in the previous paper. Photo. 1 shows these situations. Somewhat different circumstances are found in Photo. 1 (b) which is somewhat speedy revolution of the agitation (ca. 300 r.p.m.). Many of dull-headed vorticies are scattered all over the surface of water, and the suction of oil drops are found at the head of vortices into the water.

Other experiments were made on the formations of the helical vortices by a magnetic stirrer. Some of them may be reported here. The relations between the depth of vortices and the energies corresponding to the agitation were cited in the Table 1.

Fig. 3 is the schematic diagram of the mean depth of the vortex at 40 watts by the No. 2 stirring element shown in Fig. 2 in 500, 750 and 100 *ml* of water put in order in a beaker.

Fig. 4 shows the depth of the vortex corresponding to the each agitating energy by the No. 2 stirring element at 750 *ml* of water in the beaker. The vertical arrows in the figure show the depth of vortex at each agitation. Their correlation are given in the column I of

Table I. The relations between the energy required for agitation and the depth of vortex. The first column is the energy consumed by agitation in watt, the second is the depth of vortex of water and the last is that of the oil floated on the water surface.

Energy [watts]	Depth of vortex [mm]	
	I	II
35	5	20
38	10	35
40	15	50
43	22	61
45	35	75
48	54	—
50	70	—

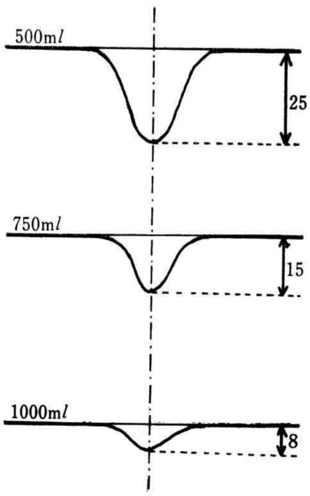


Fig. 3 The schematic diagrams of the depth of vortex by the agitation with the 40 watts of current in the varieties of the volume of water.

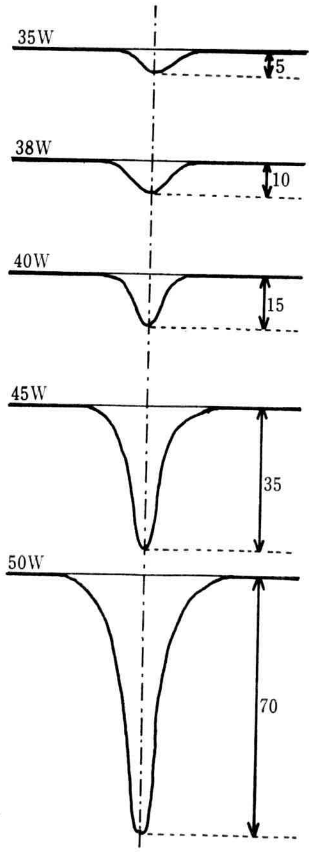
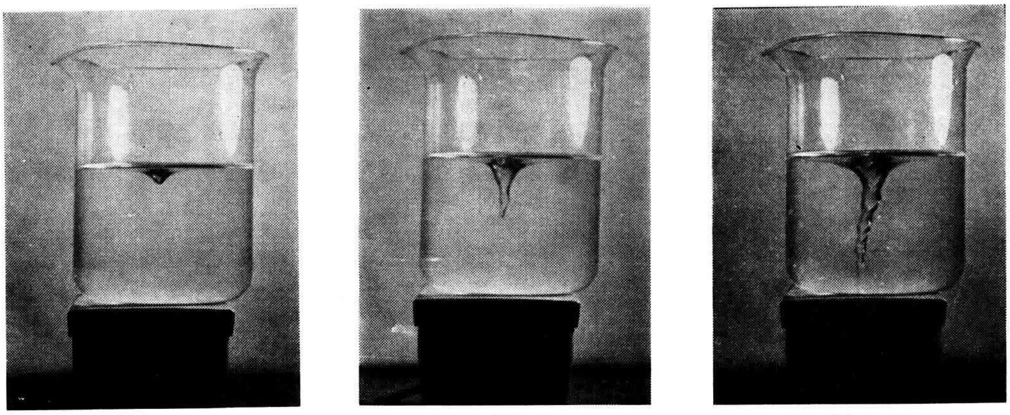


Fig. 4 The schematic diagrams of the depth of the vortex of water. The number of the vertical arrow of each curve expresses its depth and that of upper left hand side of it shows the energy of agitation of electric current in watts.



(a) (b) (c)

Photo. 2 The helical vortex of water in a beaker. (a) is the formation of the vortex at 35 watts of stirring energy. (b) is the elongation of its at 40 watts. (c) is the arrival of the vortex head to the stirring element.

the Table 1. Photo. 2 shows these situations. (a) in the photographs is just created vortex over the surface of water at 35 watts, (b) the elongation of the vortex at 40 watts, (c) the arrival of the elongated vortex head at the stirring element at the bottom of the vessel at 50 watts of agitation.

In Fig. 5, the circumstances of the suction in oil floated on water are given. The depth of vortex is much more greater than that of water alone. These values are cited at the column II in Table 1. Their relations are plotted in Fig. 6. The solid line shows the correlation between the depth of vortex and the energy consumed by agitation by means of the method of averages. The dotted line is that of in the case of the suction in oil through the helical vortex. Photo. 3 shows their situations.

The fact given above is an extremely interesting affair in sicentific sense and in an engineering application.

To analyze the helical cone vortex, we should introduce two of fundamental postulates in here. As a general rule, a steady criculation of liquid necessitate little energy. The law of conservation of circulation[2)] might be held at the surface of liquid, as

$$\frac{d}{dt}\oint \boldsymbol{v}\cdot d\boldsymbol{u}=0 \tag{1}$$

Then, the attraction at a point has to have a definite value at each point on the surface[3)], i.e.,

$$\oint \boldsymbol{F}\cdot d\boldsymbol{u}=\text{constant} \tag{2}$$

Now, we suppose a point O on a caved spherical surface from a horizontal plane S. A plane Q which is parallel to S plane and tangetial to the spherical surface is drawn at O, and then

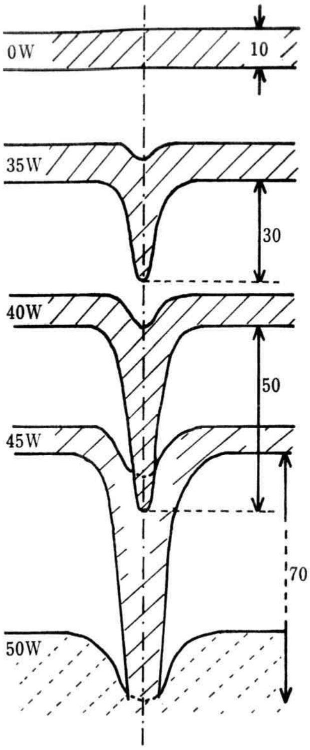


Fig. 5 The situation of the suction of the floating oil layer on water. The top of the figure is no agitation and the number of the right hand side is the depth of oil layer. The bottom of this figure shows the homogeneous oil and water emulsion formed by agitation.

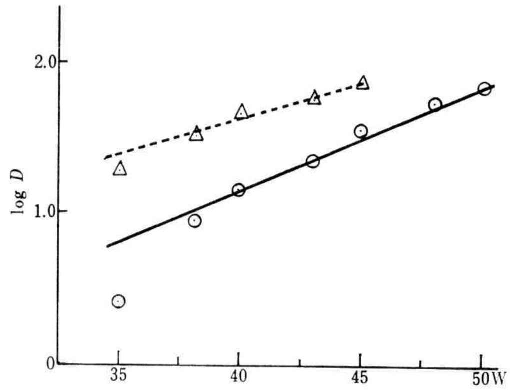


Fig. 6 The relations between the energy required for agitation in watts and the depth of vortex in mm. The abscissa is the reading of the watt-meter and the ordinate is the depth D of vortex.

cut the surface S into two portions by a cylinder whose axis is the normal and its radius is r. The flowline of the stream enclosed in the cylinder is a perfectly steady, since the shape of vortex is relatively stable. The attraction force P on the caved surface S' is led to a little reflection from Eq. (2)

$$P = \int_{S'} \frac{\rho}{r} ds \tag{3}$$

where ρ which is a continuous function of the position, is density of the fluid and ds is the small surface element on the caved surface.

Put S_1 be a point on the caved surface S' at which ds is located, and Q_1 the projection of S_1 on the tagent plane Q. Put α be the angle which the normal at S_1 makes with the normal at O, and β the angle OS_1 makes with OQ_1.

$$ds = r\,dr\,d\theta/\cos\alpha = r \sec\alpha\,dr\,d\theta \tag{4}$$

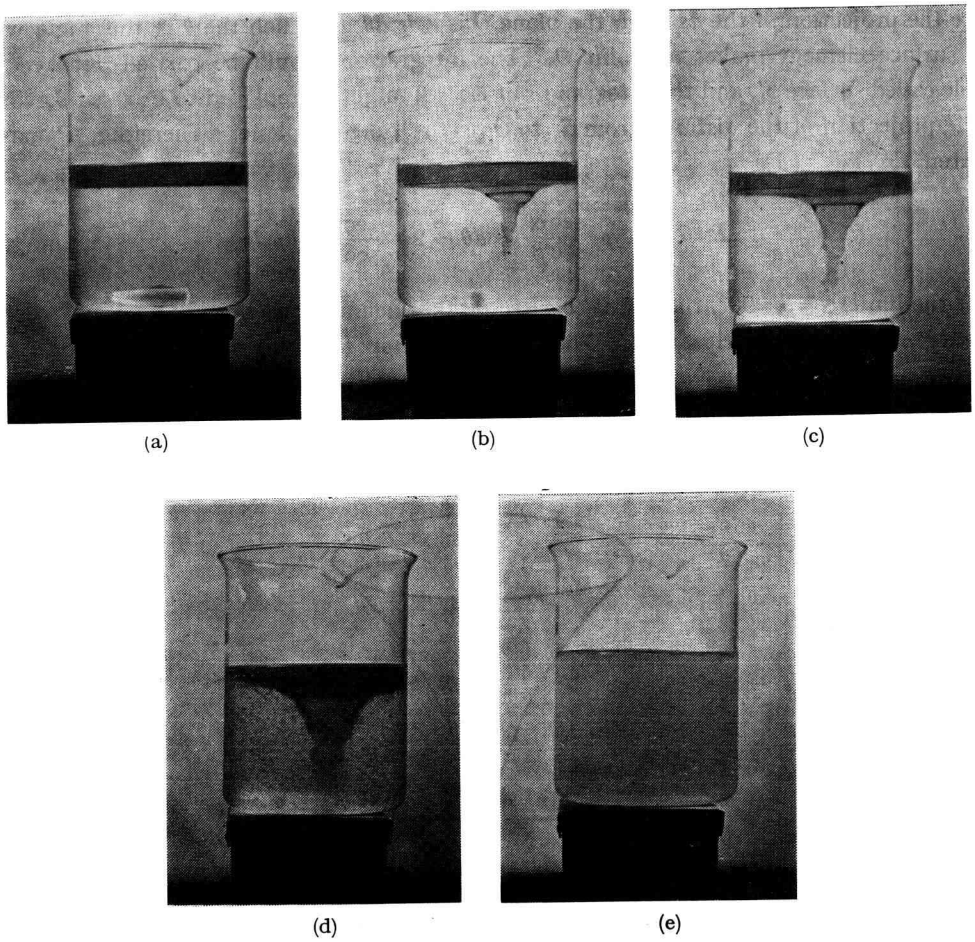


Photo. 3 The situations of oil sucked in water through helical vortex. (a) is no stirring, (b) that of oil sucked into water at 35 W, (c) that of 40 W, (d) that of 45 W. (e) is the formation of a hormogeneous emulsion at 50 W.

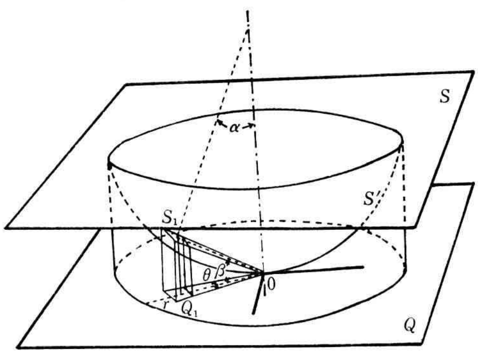


Fig. 7 The schematic diagram of the vortex for analysis.

since the projection of the ds upon the plane Q is $r\,dr\,d\theta$, in which the θ is the angle which the surface element makes at point O. The integration should be carried out over the whole caved surface S', and the integrand r of Eq. (3) might be replaced to be $r \sec \beta$, since r is the projection of the distance from S_1 to O on the tangent plane. Therefore, P may be written

$$P=\int_0^r\int_0^{2\pi}\rho\,\frac{\sec\alpha}{\sec\beta}\,dr\,d\theta=2\pi\,\frac{\sec\alpha}{\sec\beta}\int_0^r\rho\,dr\,. \tag{5}$$

If at the limit, $\alpha=\beta=90°$, the ratio $\sec\alpha/\sec\beta$ takes definite value, and also ρ has a definite density, if r is sufficiently small. Then the attraction force on the caved surface tends to have a certain difinite constant. The Eq. (5) should be realised at the conical point of revolution of the surface, provided the plane is perpendicular to the axis of revolution at the conical point. It is shown schematically as in Fig. 8.

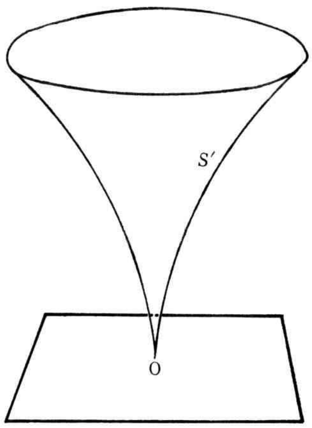


Fig. 8 The schematic diagram of a helical cone vortex.

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Nomenclature

- $\boldsymbol{v}$: The velocity vector of the streamline.
- $\boldsymbol{u}$: The unit vector tangent to the streamline at any point of the surface.
- ρ: The density of the liquid surface.
- $\boldsymbol{S}$: The interfacial surface of liquid concerned.
- Q: The parallel plane to S.
- r: The distance a point from the origin.
- $\boldsymbol{F}$: The force vector at any vortex region.
- P: The potential force at any surface.

Refeernces

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2) L.D. Landau and E.M. Lifshitz, "Fluid Mechanics", Pergaman Press Ltd. (1965).
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