An Experimental Study of "Siwome" or Current Rip as a Train of Horizontal Vortices.

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The narrow stretched band, which appears on the sea surface with singular rippling and is commonly accompanied by foams and other drifting bodies of various kinds, is called "Siwome" by fishermen and navigators of our country[1, 2, 3]. It is equivalent to the "current rip" in English, "Stromkabbelung" in German, "Clapotis" in French and "Stromrafeling" in Dutch. It is already noticed that "Siwome" appears in many cases in coincidence with the zones to which planktons, fish shoals, whales, etc. are accumulated and is consequently an important indicator for fishing-grounds.[4]

In order to study the mechanism of "Siwome," which is originated from simply dynamical causes*, and to apply the results to fisheries problems in future, the writer undertook experiments in the physical laboratory of the Imperial Fisheries Institute from the summer of 1927 to the winter of 1929 under the guidance of Dr. M. TAUTI and the late Dr. T. TERADA.

Arrangements. A water-tight glass tank, 1 meter long, 30cm. wide and 30cm. deep was filled up with fresh water to the depth of 13 to 25 cm. A wooden cylinder, A in Fig. 1, of 3cm. in diameter was horizontally hung in and across the tank, was rotated with variable frequency N_A by 3-stranded cotton ropes on the two side pulleys, D and D', the shaft of the pulleys having been driven by an electric motor with another belt. The position of the axial line of the cylinder (x_0, y_0) was made variable in both horizontal, or x-, and vertical, or y- directions by shifting the sides pedestals and vertical supports of the cylinder. To prevent the disturbance due to the running of the driving ropes, vertical glass plates, E and E', were inserted in the neighbourhood of both ends of the cylinder. In such a way we should obtain a circulation nearly two-dimensional in $x\,y$-plane.

With the aim to produce "Siwome," the tank was equipped with another bar of copper, B, of semicircular section suspended horizontally in and across the tank. The diametral plane of the bar, 1·5 cm. broad and 19 cm. long, was made to face upward, and at its centre the bar was fixed to the lower end of a vertical piston-rod, which was set in motion by the rotation of an eccentric disc, F, the shaft of which was driven by another electric

* As an example of the studies on this line we can quote the famous experiments made by J. W. SANDSTRÖM[5], while as examples of the experiments on "Siwome" of thermal causes those made by Dr. T. TERADA and others[6] or that by Dr. S. K. BANERJI and others[7].

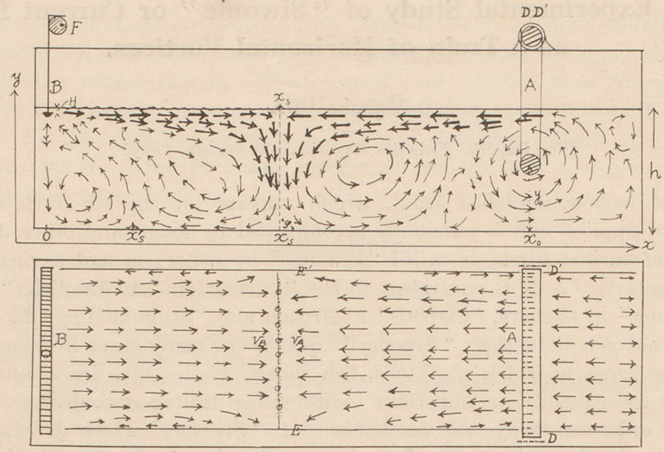

Fig. 1. Showing the arrangements and an example of the sketches of "Siwome." h 20 cm., x_0 81 cm., y_0 11·2 cm., H 0·5 cm., N_A 39 sec^{-1}., N_B 5·8 sec^{-1}., medium 60,000c.c. of water and 250c.c. of glycerine at 7°C.

motor with a belt. The bar was, thus, made to oscillate vertically with a variable frequency N_B, and an effective current, as well as progressive waves, was sent on the surface against the first current from the rotating cylinder A.*

In course of the experiments, the stream lines were inspected by illuminating aluminium powder, suspended in water, with a bundle of light sent in the median plane of the tank vertically from below. The effect of thermal convection due to the heating by the light source beneath the tank was ascertained to be of the negligible order.

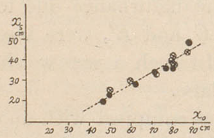

Fig. 2.

⊗h 20 cm., y_0 11·2 cm. N_A 39, N_B 5·8, H 0·5 cm., (Jan. 24, 1929), medium: water.

●h 19 cm., y_0 11 cm., N_A 43·7, N_B 10, H 1·5 cm., (Feb. 4, 1929), water at 5°∼8°C

$x_s = 0{\cdot}6x_0 - 6.\ u_{B0} < -u_{A0}.$

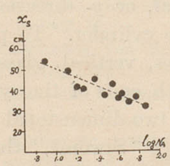

Fig. 3 a.

h 19 cm., x_0 81 cm., y_0 11 cm., N_B 10, H 1·5 cm., (Feb. 5, 1929), water at 6°·5C.

$x_s = -21 \times \log_{10} N_A + 72.$

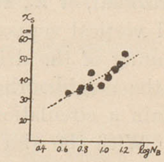

Fig. 3 b

h 19 cm., x_0 80 cm., y_0 11 cm., N_A 43·7, H 1·5cm., (Feb. 6. 1929), water at 5°∼7°C

$x_s = 29 \times \log_{10} N_B + 14.$

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* See the postscript on p. 11.

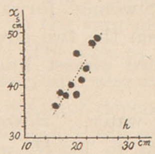

Fig. 4.
x_0 81 cm., y_0 11·2 cm., N_A 39, N_B 5·8, H 0·5 cm., (Jan. 24–26, 1929), water at 5°∼6°C.
$x_s = 1{\cdot}6h + 8$.

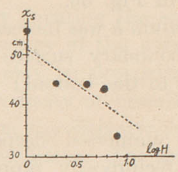

Fig. 5.
h 19 cm., x_0 80 cm., y_0 11 cm., N_A 43·7, N_B 43·7, (Feb. 6, 1929), water at 5°∼7°C.
$x_s = -14 \times \log_{10} H + 51$.

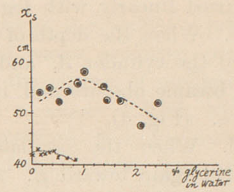

Fig. 6.
⊙h 19 cm., x_0 80 cm., y_0 11 cm., N_A 43·7, N_B 43·7, H 1·5 cm., (Feb. 6, 1929) medium at 5°∼6°C.
×h 20 cm., x_0 81 cm., y_0 11·2 cm., N_A 39, N_B 35·8, (Jan. 28, 1929).

The direction of motion was sketched in various conditions, while the velocity was measured at several points by means of a scale attached on the front wall and with a stop-watch.

Experiments and results. In the first preliminary experiment, when the cylinder A only was rotated, it was observed that the cellular vortices, usually 5 to 7 in number, were produced in the tank. They diminished in number and became more stable as the depth of water was increased. When the medium was made more and more viscous by mixing glycerine, the current, of course, became slower, but vortices, more stable and more clearly distinguishable. Finally when the number of revolution N_A was increased, the vortices became gradually unstable.

Next, both the cylinder A and oscillator B were put in action simultaneously, a modelled "Siwome" was clearly recognized on the line of convergence between two opposite currents. The aluminium powder and saw-dusts floated on the water surface were accumulated in a peculiar band on that line x_s. On the bottom of tank, another band was formed by wetted aluminium powder and saw-dusts, which were accumulated to the line of convergence at x_s'. This seems to suggest us some mechanism of sand-drift, which is important from the point of harbour engineering. Though appeared macroscopically as a zone of no current, "Siwome" on the surface was microscopically a train of minute vortices of vertical axes[8].

The following series of experiments were carried out :—

a. The position of "Siwome" x_s was examined when the cylinder A was shifted horizontally. In both of two cases, a linear relation was found between x_s and x_0 as in Fig. 2.

b. When N_A was increased, while N_B was kept constant, x_s diminished nearly exponentially as shown in Fig. 3a. On the other hand, when N_B was increased, while N_A was kept constant, x_s became larger also exponentially, i.e. varied linearly with log N_B as in Fig. 3b.

c. When the depth of the medium h was increased, "Siwome" forwarded toward the cylinder A, and the boundary surface between the two circulations became obscure and inclined to the bottom; x_s varied almost linearly with h. (Fig. 4).

d. When the oscillator was immersed deeper in water, "Siwome" retarded again toward B. x_s was reciprocally proportional to log H, where H is the depth below the water surface of the diametral plane of the oscillator. (Fig. 5).

e. Finally, the viscosity of the medium was changed by mixing glycerine. As the medium became more and more viscous, "Siwome" was forwarded at first a little to A and then continually retarded toward B. At the same time the inclination of the boundary surface to the vertical became less and less.

Discussions. When the circulations in the tank are always in a stationary state, it is necessary that the component of velocity normal to the boundary surface between two circulations is nill, while the pressure must be equal on both sides of that surface. These are respectively the kinematical and dynamical boundary conditions[9]. It follows at once that on both sides of the zone of "Siwome" the velocity normal to the line of "Siwome" must be equal in speed and opposite in direction.

Since the stream lines in $x\,y$-plane, as shown by thick arrows in Fig. 1, diverge in the form of nearly exponential curves with the distance from the point just above A or B toward the boundary at x_s, the velocity of the surface currents u may also be diminished nearly exponentially with the distance of travel. Denoting the quantities on both sides of "Siwome" with suffixes A and B respectively, we have, for the velocity in x-direction, or u.

$$-u_A = -u_{A0}e^{-\lambda_A(x_0-x_s)} = u_B = u_{B0}e^{-\lambda_B x_s} \quad \dots\dots\dots (1)$$

where the second suffix 0 is referred to the quantities immediately above the centre of A or B, and λ_A and λ_B are constants depending on the viscosity of the medium μ. From (1), we have

$$x_s = \frac{\lambda_A}{\lambda_A+\lambda_B}x_0 + \frac{1}{\lambda_A+\lambda_B}\log\frac{u_{B0}}{-u_{A0}} \quad \dots\dots\dots (2)$$

Now, the velocity $-u_{A0}$ is nearly proportional to N_A and d, the diameter of the cylinder, and may be considered to diminish exponentially with the depth of the cylinder. Hence, we can put

$$-u_{A0} = \xi d N_A e^{-k(h-y_0)} \quad \dots\dots\dots (3)$$

where ξ and k are constants. On the other hand, the relation between

u_{B0} and N_B will be got by equating the energy loss of the oscillator per unit time to the sum of the energy of the current and waves produced per unit time. The first of them may be proportional to the energy of oscillation of the bar, and also to the velocity of circulation, i. e. $\eta u_{B0} 4\pi^2 A^2 M N_B^2$, where η is a constant depending on the viscosity of the medium, M is the mass and A the amplitude of the oscillator. The amount of water which flows out per unit time from the space above the oscillator is $Hl\rho u_{B0}$, of which the part carrying the wave is practically $\varepsilon l \rho u_{B0}$, ρ being the density of the medium, l the length of the oscillator and ε a small thickness. Consequently, if a be the amplitude of the wave, We have

$$\eta 4\pi^2 A^2 M N_B^2 u_{B0} = 4\pi^2 a^2 N_B^2 \varepsilon l \rho u_{B0} + \frac{1}{2}(Hl\rho u_{B0}) u_{B0}^2,$$

or putting $m = M/l$,

$$u_{B0} = 2\pi N_B \sqrt{2(\eta A^2 m - \varepsilon a^2 \rho)/H\rho} \quad \dots\dots\dots\dots\dots (4)$$

From (3) and (4), we get, putting $C = 8\pi^2(\eta A^2 m - \varepsilon a^2 \rho)/(\xi^2 d^2 \rho)$,

$$\log \frac{u_{B0}}{-u_{A0}} = \log \frac{N_B}{N_A} + k(h - y_0) + \frac{1}{2} \log \frac{C}{H} \quad \dots\dots\dots\dots\dots (5)$$

Putting (5) into (2), we obtain the relations of x_s to the various quantities under different circumstances :—

(a) If N_A, N_B, h, H, y_0 and μ are constant, $x_s = a_1 x_0 + b_1$, where

$$a_1 = \frac{\lambda_A}{\lambda_A + \lambda_B} \text{ and } b_1 = \frac{1}{\lambda_A + \lambda_B} \left\{ \log \frac{N_B}{N_A} + k(h - y_0) + \frac{1}{2} \log \frac{C}{H} \right\} \text{ are constant.}$$

(b) If N_B, h, H, x_0, y_0 and μ are constant, $x_s = -a_2 \log N_A + b_2$, where

$$a_2 = \frac{1}{\lambda_A + \lambda_B} \text{ and } b_2 = \frac{1}{\lambda_A + \lambda_B} \left\{ \lambda_A x_0 + k(h - y_0) + \frac{1}{2} \log \frac{N_B^2 C}{H} \right\} \text{ are constant,}$$

and if N_A, h, H, x_0, y_0 and μ are constant, $x_s = a_2 \log N_B + c_2$, where

$$a_2 = \frac{1}{\lambda_A + \lambda_B} \text{ and } c_2 = \frac{1}{\lambda_A + \lambda_B} \left\{ \lambda_A x_0 + k(h - y_0) + \frac{1}{2} \log \frac{C}{H N_A^2} \right\} \text{ are constant.}$$

(c) If N_A, N_B, H, x_0, y_0 and μ are constant, $x_s = a_3 h + b_3$, where

$$a_3 = \frac{k}{\lambda_A + \lambda_B} \text{ and } b_3 = \frac{1}{\lambda_A + \lambda_B} \left\{ \lambda_A x_0 - k y_0 + \log \frac{N_B}{N_A} + \frac{1}{2} \log \frac{C}{H} \right\} \text{ are constant.}$$

(d) If N_A, N_B, h, x_0, y_0 and μ are constant, $x_s = -\frac{a_4}{2} \log H + b_4$, where

$$a_4 = \frac{1}{\lambda_A + \lambda_B} \text{ aud } b_4 = \frac{1}{\lambda_A + \lambda_B} \left\{ \lambda_A x_0 + k(h - y_0) + \log \frac{N_B}{N_A} + \frac{1}{2} \log C \right\} \text{ are constant.}$$

(e) Finally, when μ is variable, we may consider, for the first approximation, that λ_A, λ_B, k, η and ε vary as μ, and put

$$\lambda_A = \alpha\mu, \quad \lambda_B = \beta\mu, \quad k = \kappa\mu, \quad \eta = n\mu, \quad \varepsilon = \delta\mu \text{ and } C = c\mu.$$

Then we have $x_s=\frac{a_5}{2\mu}\log\mu+\frac{b_5}{2\mu}+c_5$, where $a_5=\frac{1}{\alpha+\beta}$, $b_5=\frac{1}{\alpha+\beta}\log\frac{N_B^2C}{N_A^2H}$ and $c_5=\frac{1}{\alpha+\beta}\left\{\alpha x_0+\kappa(h-y_0)\right\}$ are constant. x_s attains a maximum value of $\frac{a_5}{2}e^{-\frac{a_5-b_5}{a_5}}+c_5$ when $\mu=e^{\frac{a_5-b_5}{a_5}}$, and then tends to an asymptotical value of c_5 at greater viscosity.

These relations (a) to (e) agree, at least qualitatively, with the results of experiments mentioned already. Further we can compare the values of coefficients by fitting the results in Figs. 2 to 6 with these relations. From Figs. 3a, 3b and 5, we obtain 9cm, 13cm and 12cm respectively for $1/(\lambda_A+\lambda_B)$, while from Fig. 2, it is known that $\lambda_A/(\lambda_A+\lambda_B)=4/7$ i.e. $\lambda_A:\lambda_B=4:3$, and from Fig. 4, $k/(\lambda_A+\lambda_B)=1{\cdot}6$. Using these values and putting other observed values in the expressions of b_1, b_2, c_2, b_3 and b_4 we can get the values for $\log C$ from $-2{\cdot}1$ to $+0{\cdot}2$, which are nearly equal when the experiments were carried out under similar circumstances.

Denote the x- and y-components of the velocity by u and v respectively, and the corresponding components of the resultant force per unit mass of the medium by X and Y respectively. Then the variation of the pressure p along the boundary surface between two circulations is

$$dp=\rho(X-\dot{u})\ dx+\rho\,(Y-\dot{v})\ dy.$$

But, since $p_A=p_B$ on the boundary, $dp_A=dp_B$, and since $\dot{u}_A=\dot{u}_B=\dot{v}_A=\dot{v}_B=0$, we have

$$\tan\varphi=\frac{dy}{dx}=-\frac{X_A-X_B}{Y_A-Y_B}.$$

In almost all the cases in the present experiments, $Y_A\fallingdotseq Y_B\fallingdotseq g$, and the slope of the boundary φ is $\frac{\pi}{2}$. But, when h was great, φ became less than $\frac{\pi}{2}$, suggesting that X_A-X_B and Y_A-Y_B have different signs.

By the present experiments, it was ascertained that "Siwome" can appear from simply dynamical causes as a train of small vertical vortices. It was also justified that the position of "Siwome" is determined by the kinematical and dynamical boundary conditions. In practical case, such kind of "Siwome" is supposedly observable at the margin of upwelling and diverging region on the sea surface. In this connection, the effects of the topographical conditions or of the difference in density between the water masses on both sides of "Siwome" may raise interesting problems to be studied in future.

In concluding this report, the writer wishes to state his sincere thanks to Dr. M. Tauti and the late Dr. T. Terada for their kind guidance through-

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P.S. Lately T. TSUTUI has shown experimentally that a progressive motion is produced in fluid by an osillating plate in it. The reader is referred to the following:—

TSUTUI, T.: Liquid motion produced by oscillating bodies. Part I: Tuning fork and surface circulation. Bull. of the Inst. Phys. & Chem. Res. Vol. 14. No. 8, 1935, pp. 694～703.