TRANSPORT OF ADMIXTURE IN A STATIONARY VORTEX FLOW

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Abstract

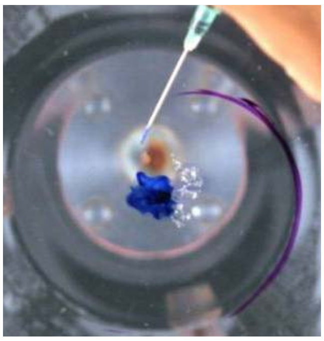
Admixtures transport from a surface patch in a compound vortex was investigated. Vortex was created by a uniformly rotating disk located at the bottom of the cylindrical container. Side and top views of the flow pattern were registered. A round spot of a dye on the liquid surface was transformed in well outlined spiral arms separated by clean water. The orientation of arms was opposite to the direction of general fluid rotation. The dye sunk into the fluid along vertical cylindrical surface in form of helix filaments in a wide range of parameters (diameter and angular velocity of disk, depth of fluid). An oil patch was transformed into surface spiral arms too and formed a body of revolution inside the fluid. Geometrical parameters of surface trough and shapes of admixtures domains were studied for different flow regimes. Comparison with theoretical model and extrapolation on environmental conditions are discussed.

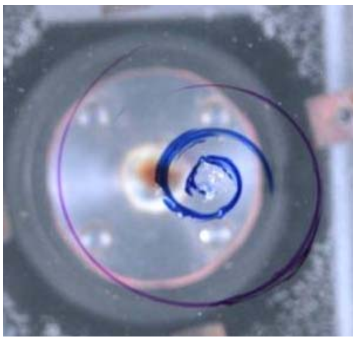
Introduction

Formation of "ink-walls" from a surface dye spot in generally rotating fluid which was firstly observed by G.I. Taylor at the beginning of the last century and thirty years later repeated by R.R. Long [1] now is subject of active theoretical and experimental studies. In supplement to conventional experiments in rotating tanks some experiments are performed in fluids involved in stationary vortex motion in a fixed cylindrical container. Flow is produced by rotating disk located inside the fluid. The advantage of the set-up is fixed geometry of vortex motion and reproducibility of flow parameters. Experiments were performed with a tap water. Distribution of pressure in vortex flow is manifested by the shape of surface trough which was calculated neglecting and taking into account surface tension effects [2]. Transport of solvable and immiscible admixtures from a compact surface patch was studied. Dimensional parameters of the flow are a depth of the water layer H, container radius R_0, angular velocity Ω and radius R of the disk, density and kinematic viscosity of the fluid. Conventional dimensionless parameters that are Reynolds or Ekman and Froude numbers are used for flow parameterization. With increasing of angular velocity of the disk firstly short spiral waves and then inertial waves were formed on the trough surface.

Transport of miscible admixture

A sequence of photographs illustrating an evolution of two separated dye spots is shown in Fig. 1. Firstly introduced at the periphery of flow a drop of purple aniline ink is transformed into spiral arm. The arm is faster extended opposite the direction of general fluid rotation and slower in the direction of fluid motion. The same behaviour demonstrates the patch of blue ink placed near center of the tank. With time both colour fluids are spinning into sharpen spiral filaments where colour strips are separated by clean water. The whole flow pattern rotates in the direction of the disk angular velocity [3].


a


b

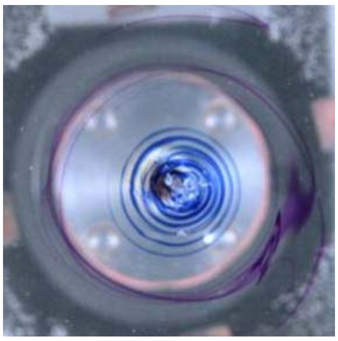
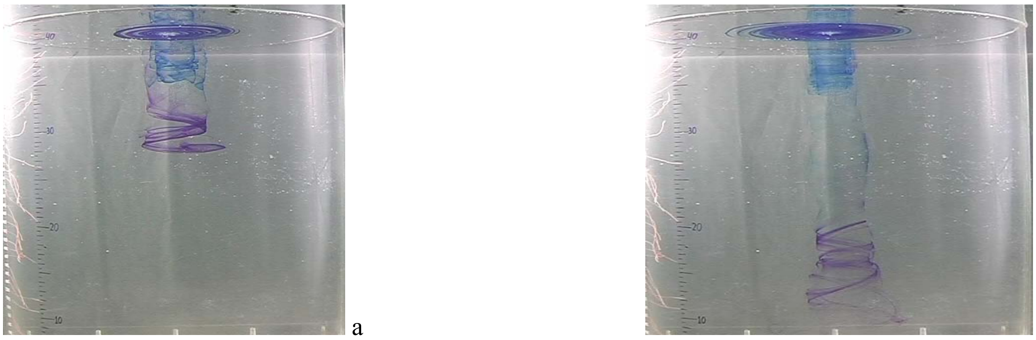

c

Fig. 1. Evolution of dye spots on the surface of compound vortex forming separated spiral arms ($H = 40$ cm, $\Omega = 180$ revo, $R = 5.0$ cm): *a - c*) – $t = 2$, 7, 23 s.

In a quiescent fluid, the spot of the markers was transformed into a slowly sinking cascade of vortices. In the compound vortex the dye sank inside the fluid in form of extended double helix filaments spinning along a vertical surface of revolution. The double filaments were ended by extended dye loops (Fig. 2, *a*). The radius of their surface depends on the initial position of dye patches. The height of colour domains depends on time (Fig. 2, *b*). Geometrical parameters of colour domains in the flow were measured in wind range of flow parameters.

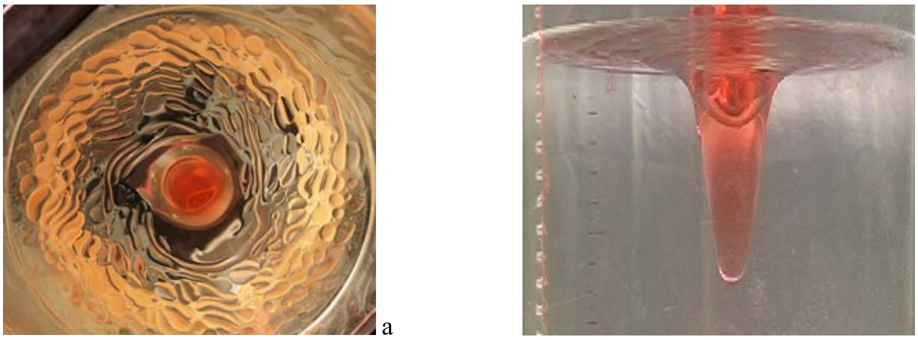


a b

Fig. 2. Transport of blur and purple dyes from surface spots inside compound vortex ($H = 40$ cm, $\Omega = 180$°revo, $R = 5.0$ cm): *a*, *b*) – $t =$ 5, 15 s.

Transport of immiscible admixture

Surface patch of small amount of an oil (30…150 ml of sunflower or castor oil) is transformed on sequence of elongated spots collected along some spiral lines directed opposite to the direction of the main fluid rotation like a miscible dye (Fig. 3, *a*). Inside the vortex the oil is collected into compact central body of revolution (Fig. 3, *b*).



a b

Fig. 3. Top and side view of the compound vortex with sunflower oil ($H = 40$ cm, $R = 7.5$ cm): *a*) – $\Omega = 210$ revo, $V_k = 90$ ml, *b*) – $\Omega = 320$ revo, $V_k =150$ ml.

Geometry of spiral arms and the shape of the oil body were measured in a wide range of the flow parameters [4]. Formation of spiral and inertial waves was observed on the interface between oil and water.

Conclusion

A method is developed for creating and visualization of main structural elements of a reproducible vortex flow. Transformation of a compact spot of the soluble or immiscible admixture into spiral arms on the surface of a compound vortex was observed. The marker is transported into the fluid interior along individual cylindrical surfaces in form of helix filaments. Immiscible oil is collected in a compact fluid body of revolution inside the compound vortex.

Acknowledgment

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References

1. G.K. Batchelor, An Introduction to Fluid Dynamics, Cambridge: CUP. 1970.
2. Chashechkin Y.D., Kistovich A.V., Deformation of the free surface of a fluid in a cylindrical container by the attached compound vortex // Doklady Physics. 2010. Vol. 55, No 5, P. 233–237.
3. Stepanova E. V., Chashechkin Yu. D. Marker transport in a composite vortex // Fluid Dynamics, 2010, Vol. 45, No. 6, P. 843-858.
4. Chaplina T. O., Chashechkin Yu. D., Stepanova E. V. Deformation of a compact oil patch at a compound-vortex surface // Doklady Physics, 2010, Vol. 55, No. 5, P. 238-241.