Experimental studies of differential heating for artificial upwelling

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Abstract

PIV experiments were carried out to study the mechanism and characteristics of a new artificial upwelling technology via differential heating named "Differential- Heating-Liquid-Upwelling" (DHLU). Results show that there is a small scaled area with high temperature around the modelling heat point source in DHLU system. The existence of this high temperature area is suggested as the power source of upwelling. Obvious upwelling flows upon the heating source were observed in DHLU system. The stream tube of upwelling for DHLU system is just like an upside-down cone. The max ascending velocity of horizontal layer increases firstly and decreases then as the height increases. A few of fluid masses with high ascend velocities were observed and the mechanism of the DHLU is revealed.

Keywords: artificial upwelling, differential heating, mechanism

1 Introduction

Upwelling is one of the most important conditions for rich marine fish stocks [1]. Upwelling can bring the nutrients which is rich in deep seas to the top and euphotic layer of the ocean. Therefore the phytoplankton which is at the bottom of most marine food chains can be fed. So the areas with natural upwelling are the most productive ocean fishing grounds in the world.

In recent years, only 75% of the world's commercial fish stocks are being fished at or above mean sustainable levels [1]. This situation is likely to get worse as the world's population grows. Artificial upwelling is considered as a promising technique for the enhancement of productivity in a sustainable way, as artificial upwelling can make up for the deficiencies of nature upwelling which has a restriction of time and space [1, 2].

Many studies were carried out for artificial upwelling technologies over the past few decades. McClimans et al. [3, 4] realized artificial upwelling with a freshwater source firstly, and then a combined method of fresh water and bubble curtain, with which significant amounts of nutrient-rich seawater could be lift to the light zone and provide an environment in which useful algae can survive at a large-scale fjord-experiment.

Kazuyuki et al. [5, 6] described an ocean nutrient enhancer named "TAKUMI" to upwelling deep ocean water with a pump which is powered by a diesel generator. The prototype of the machine was manufactured and set-up at the centre of Sagami Bay in Japan. However, the deep seawater flow rate is only about 1.2 m^3/s.

Isaacs et al. [7] proposed to use wave energy to invert the density structure of the ocean and therefore the deep, nutrient-rich water can be pumped into the euphotic layers. Liu et al. [8, 9] also described a similar wave-driven artificial upwelling device which consists of a buoy and a long pipe with a one-way valve. The main principle of the wave driving device is that the valve is only open on the down slope of a wave and close on the up slope. An estimated flow rate is about 0.45 to 0.95m^3/s for a wave height of 1.90m and a wave period of 12s.

Tsubaki et al. [10] proposed an artificial upwelling technology based on the concept of "perpetual salt fountain" which is initiated by Stommel et al. In many areas of the tropical and subtropical ocean, warm salty water overlies colder fresher water. And that causes a famous vertical convective motion calling "salt finger". The salt fingers occur because of the difference in the diffusivities of heat and salt. When a pipe is inserted to connect deep sea and the surface and the pipe is filled with the low salinity deep sea water, the salinity of the water inside the pipe is lower than that outside. The upwelled deep sea water becomes almost the same temperature as the surrounding water. Hence buoyancy occurs in the pipe. The upwelling flow can be continues as long as the differences of the temperature and salinity exist. The flow rate with a single pipe was estimated as approximately 45m^3/day [10]. The results would suggest that if such a perpetual salt fountain were to be viable for an ocean farming project, a large number of upwelling pipes would be necessary [11].

Liang et al. [12] proposed an air-lift pump for upwelling deep ocean water. For the air-lift pump the air is compressed into a vertical pipe, dipped in water. Bubbles ascend and the water level in the pipe rises due to the density decrease in the air–water mixture. Once the water level reaches the top of the pipe and the water flows out, the water flows continuously from the lower

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end. For the air-lift pump the seawater flow rate ratio could be hundred times higher when compared to the air flow rate [12]. McClimans et al. [4] and Fan et al. [2] studied the air-lift pump experimentally and the effect of the air-lift upwelling method was confirmed.

In this paper, a new technology of artificial upwelling via differential heating is proposed. This renovation technology is bases on the phenomena that the vertical temperature gradient of fluid, which is hot at bottom and cold at top, can cause the vertical density gradient inside the fluid, which will cause the inner vertical convection of the fluid for the reason of buoyancy. In this paper, PIV experiments were carried out to study the mechanism and characteristics of this new technology which we named “Differential- Heating-Liquid-Upwelling” (DHLU for short in follows).

2 Experimental setup

A schematic view of the experimental apparatus is shown in Figure 1. Heat source of the DHLU system was modelled by a self-made heating system. The heating system consisted of a heating stick, a quartz fibre tube and a temperature & power controller. The heating stick with a diameter of 10 mm and a length of 25 mm was placed inside the heat-insulated quartz fibre tube with an inner diameter of 30 mm and a length of 400 mm. And at the top, a length of 20 mm of the heating stick was kept outside of the quartz fibre to simulate a point heat source. The heating temperature and the power of heating stick can be controlled by the Temperature & Power Controller separately.

The environment of the upwelling was modelled by a glass tank of 700×400×550 mm. The tank was filled with water. The water depth was kept at 420 mm. At the top of the tank where was a water cooler. The water cooler was immerged into water to keep the temperature of the top water layer at a constant lever. The heating system was fixed vertically at the bottom centre of the glass tank, as Figure 1 shows. The height of the heating stick’s head from the bottom of tank was fixed at 100 mm to avoid the influence of the tank bottom. Rubber seals were used to seal the heating system.

A group of nine K-type thermocouples was arranged with its testing points placed nearly equidistantly upon the heating system along the central axis of heating stick, as shown in Figure 1 and Table 1. The No.1 to No.8 thermocouples were used to measure the vertical temperature variation in steady upwelling with height along the central axis of heating stick. The No. 9 thermocouple was placed in air to measure the room temperature. Temperatures measured by thermocouples were collected by a data logger of HP34970A with 34901A Armature Multiplexer Module (Agilent Technologies, Inc.)

The fluid field of the upwelling was measured by the V3V-2D PIV system (produced by TSI, USA). The PIV system includes a laser (Nd:YAG laser, 350mJ, 15 Hz), three cameras (PowerView Plus 4MP, 2K × 2K pixels), a synchronizer and Insight4G software. This system can measure a three-dimensional flow field with a max area of 140×140×100 mm. Figure 1 shows the positions of the laser and cameras of PIV system in experiment.

In Experiments, the power of heating stick was set at 200W. And then the fluid field was measured by PIV system when a steady upwelling could be observed.

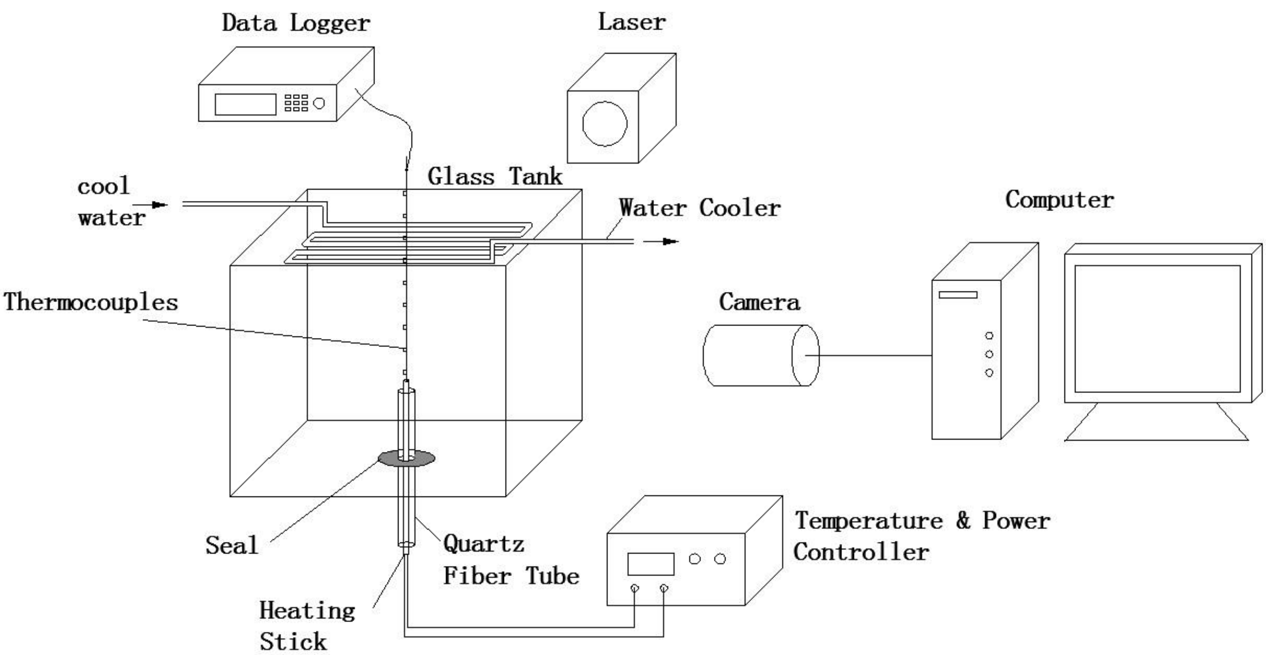


FIGURE 1 Schematic diagram of the experimental system

TABLE 1 Heights of the test points of thermocouples from the top of the heating stick

No.	Height (cm)
1	0
2	1
3	5
4	10
5	15
6	20
7	25
8	30
9	35

3 Results and discussion

Experiments were carried out on DHLU system. In steady case, the vertical temperature distribution in upwelling along the central axis of heating stick was shown in Figure 2. The temperature of heat source could be kept at about 61℃ when the power of heating stick was set as 200 W in experiment. As the height increased from 0, the temperature dropped quickly firstly. And the temperature dropped to 26℃ when the height rose only 5 cm from the top of heating stick. And then as the height increased again the drop of temperature became slowly. And finally the temperature of water reached an environmental water temperature of about 20℃. The room temperature measured in experiments was 17.5℃. Above all, we can see that there is a small scaled area with high temperature around the modelling heat point source in DHLU system. The existence of this high temperature area is suggested as the power source of upwelling.

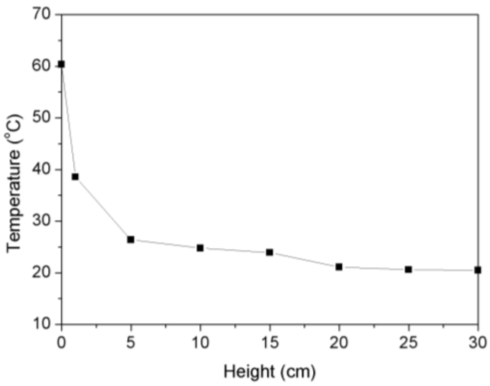
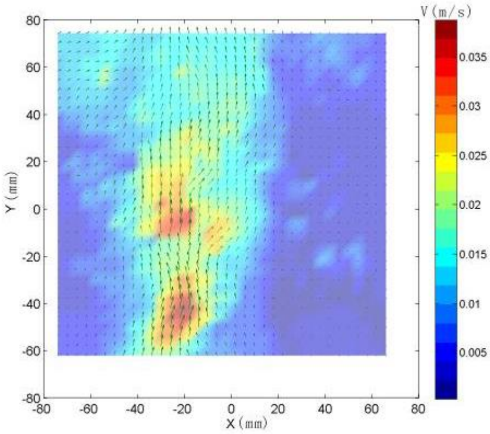


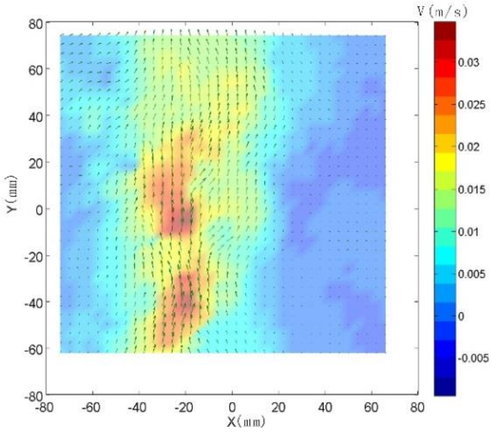
FIGURE 2 Variations of vertical temperature in steady upwelling vs. the height of test point from top of heating stick (P=200 W)

The fluid field of upwelling was measured by PIV in steady case via V3V technology. The measure area was set as X=140 mm, Y=140mm, Z=100mm. X and Z are horizontal coordinates. Y is vertical coordinate. The position of modelling heat point source was set at X=-20, Y=-70, Z=-650 mm.

Figure 3 shows the velocity field at a XY plane across the centre of heating stick in a steady case. Both the full velocity and the vertical velocity(Y-direction velocity) were figured out. It is shown that the temperature difference caused by the heating at bottom can cause obvious upwelling. There were obvious upwelling flows with up velocity upon the heating source. The stream filament of upwelling appeared narrow at bottom and wide at top. More studies were carried out to analysed the three dimensional shape of the upwelling boundary with V3V technology. The 3D iso-surfaces of the velocity of 0.019 m/s was figured out, as Figure 4 shows. From the Figure we can see the explicit shape and distribution area of upwelling. The stream tube of upwelling for DHLU system is just like an upside-down cone.



(a) Velocity



(b) Vertical velocity

FIGURE 3 The velocity field at a XY plane across the centre of heating stick (Z= -650 mm)

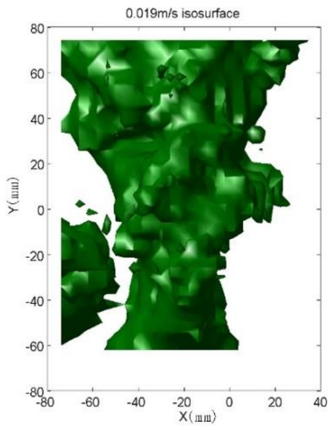


FIGURE 4 Iso-surfaces of velocity equals 0.019m/s in upwelling

Furthermore, several water masses with high speed were observed in upwelling. Speeds of those water masses are obviously higher than the fluid around. A string of those water masses appeared and floated up in steady case. This suggests that the mechanism of the DHLU may be as follows: The heating at bottom of the heat source produces a series of fluid masses with relative higher temperature and lower density. And those fluid masses ascend due to the density decrease and bring the fluid around ascend together. And a continuous steady upwelling is formed as the heating at bottom continuous.

We also analysed the vertical velocity field of horizontal layers at different heights from the modelling heat point sources, as shown in Figure 5 to Figure 7. Totally speaking, in steady case the max ascending velocity of horizontal layer increases firstly and decreases then as the height increases. The area of upwelling increases as the height increases.

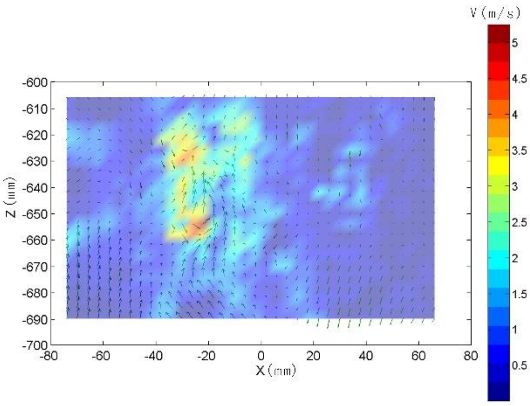


FIGURE 5 The vertical velocity field at a horizontal XZ plane with a height of 40 mm(Y= -30 mm)

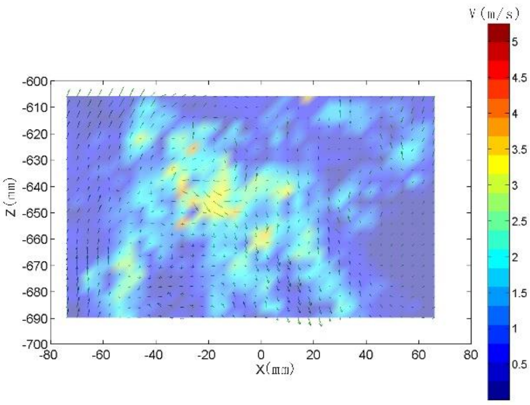


FIGURE 6 The vertical velocity field at a horizontal XZ plane with a height of 80 mm(Y= 10 mm)

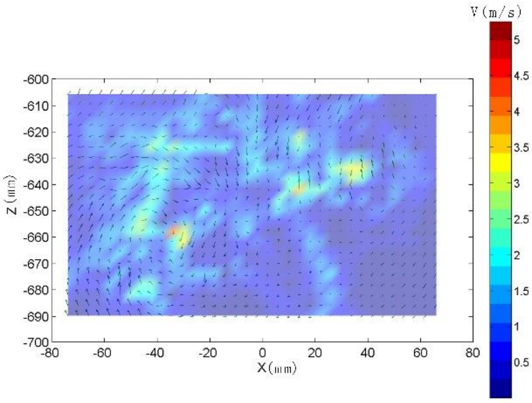


FIGURE 7 The vertical velocity field at a horizontal XZ plane with a height of 120 mm(Y= 50 mm)

4 Conclusions

PIV experiments were carried out to study the mechanism and characteristics of a new artificial upwelling technology via differential heating named “Differential-Heating-Liquid-Upwelling” (DHLU).

Results show that there is a small scaled area with high temperature around the modelling heat point source in DHLU system. The existence of this high temperature area is suggested as the power source of upwelling. Obvious upwelling flows upon the heating source were observed in DHLU system. The stream tube of upwelling for DHLU system is just like an upside-down cone. The max ascending velocity of horizontal layer increases firstly and decreases then as the height increases. A few of fluid masses with high ascend velocity was observed and the mechanism of the DHLU is suggested as follows: The heating at bottom of the heat source produces a series of fluid masses with relative higher temperature and lower density. And those fluid masses ascend due to the density decrease and bring the fluid around ascend together. And a continuous steady upwelling is formed as the heating at bottom continuous.

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