

## Research on the thermal density current in different incoming depth

Hui Chen<sup>1,a,\*</sup>, Baiquan Chen<sup>1,b</sup>

<sup>1</sup>Nanchang Institute of Technology, Nanchang 330000, China

<sup>a</sup>leisure8651@sina.com, <sup>b</sup>328452678@qq.com

**Abstract:** The thermal density current is researched in different incoming flow depth based on numerical simulation and find there will form a plumping thermal density current if the temperature of incoming flow is lower than the environmental water temperature in the reservoir; the incoming depth has little effect on the thermal density current, in particular, the depth has little effect on the average velocity, the average temperature, and the mixing along in the same section of the reservoir; there is relationship between the mixing coefficient and the Richardson number, and the larger the Richardson number is, the smaller the blending coefficient is.

**Key words:** Incoming depth, Thermal density current, Mixing coefficient, Numerical simulation

### 1. Introduction

Since observing the phenomenon of density current at the entrance of Lake Geneva in 1892, the study of the law on density current is carried out in various countries. At present there is not a unified definition on the density current at home and abroad, Zhang Shannong defines it as the relative movement between two layers of different density and different velocity[1]. In theory, Helmholtz, Kelvin, Boussinesq, etc. laid the foundation for this study, and later there are Harleman[2], Ippen[3], Chia-Shun Yih[4], Ellisen[5] and etc who do a lot, and personal research focus is different. In the experimental study, Huppert and Simpson (1980) found that the Froude number remains unchanged when it was in the self-similar stage[6], Hallworth in the test mainly concerned with the mixing in the interface between the density current and environmental water[7], Ellison and Turner (1959) show that the thickness of the density current increases along the way, and the mixing coefficient is a function of Ri [8], Bournet [9], Chung and Gu [10], Savage and Brimbreg [11], A. Dai and M. Garcia [12], Beckman and Doshier [13] established a mathematical model based on the actual situation, successfully simulated the phenomenon of different density current, the simulation results reflect the actual situation to a certain extent. There are many factors that affect the movement in a reservoirs, this paper mainly studies the motion law under different water depth.

### 2. Mathematical Model

In this paper, the mathematical model is used which is verified by Anastasios.N.G[14], the model includes the continuity equation, the momentum

equation, the RNG turbulence model. The finite volume method is used and employ the structure grid to discrete the equation,

Structure grid, the boussineq assumption is utilized to consider the change of the water density, the PISO method is used to coupling the pressure and the velocity, and ignoring the heat between the water and the external factors.

**3. Test Design**

The reservoir is 11m long, the incoming temperature is 17.5°C, the flow rate is 0.02m<sup>3</sup>/s, the surrounding temperature is 20°C, and the incoming depth is shown in table 1.

Table 1 The test schemes on density current

scheme	A1	A2	A3	A4	A5	A6	A7	A8
depth(m)	0.105	0.115	0.125	0.135	0.145	0.155	0.165	0.175
scheme	A9	A10	A11	A12	A13	A14	A15	A16
depth(m)	0.185	0.195	0.205	0.215	0.225	0.235	0.245	0.255

**4. Analysis of the Influence of Water depth on the Characteristics of Reservoir Density Flow**

**4.1 Analysis of Density Flow Process**

Selecting scheme A2 as a typical scheme to analyze the process, and the velocity and the temperature is shown in figure 1.

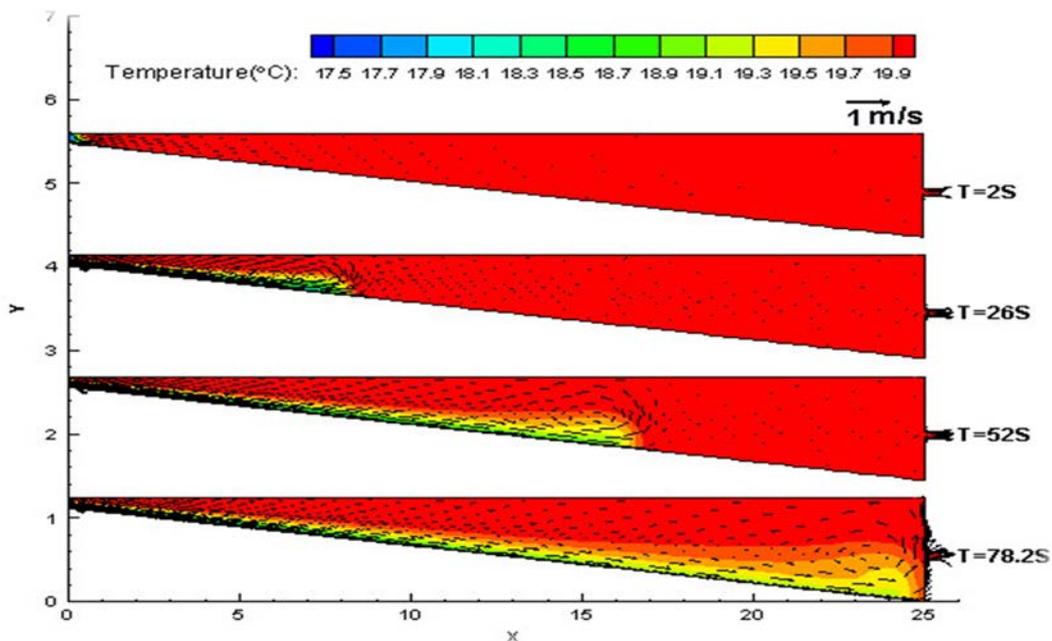


Figure 1. The temperature and the velocity in scheme A2

Figure 1 is the development process of temperature in different time. It is shown

that in the initial time low temperature water flow into the reservoir, the inertia force of the incoming flow occupies the main position, and the reservoir environment water is moved forward. With the movement, the stress of the water pressure and the gravity gradually occupy the main position, and the incoming flow begins to decrease at a position. At initial time the flow accelerates forward under the gravity, buoyancy, drag force between the bottom slope of friction and water environment influence, and distance running in unit time became longer; due to the mixing, thermal diffusion and heat conduction between water environment and incoming flow there is an increase for the density current; and there will form the reverse flow in upper reservoir.

From the thickness we find that the thickness of density current increases with the propagation distance. On one hand, due to the temperature gradient existence inhibit the growth of density current, and the inhibition gradually weaken; On the other hand, water environment mixed effect promote the increase of the thickness of the density current, and gradually increase.

#### 4.2 Analysis of Different Incoming Water Depth on the Influence of Density Flow Movement

##### 4.2.1 Time of Arrival in front of the Dam

Assuming  $t_o$  the time of arrival in front of the dam, and the  $h \sim t_o$  relational curvy can be shown in fig.2.

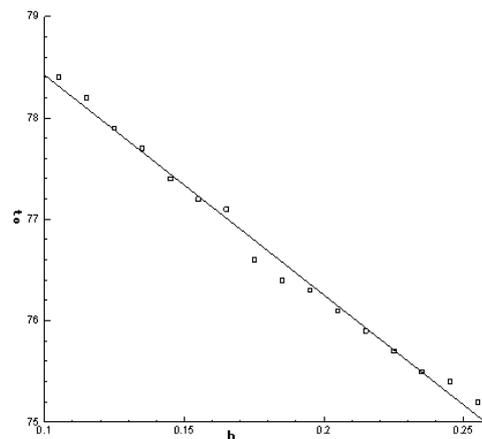


Figure 2. The relationship between the depth and arrival time

As Fig.2 shows, with the incoming flow deep increases gradually, the time of arrival in front of the dam gradually reduced, and they show a linear relationship, in the model test, it is shortest for 78.6s when  $h=0.105m$ , and it is most long for 75.2s when  $h=0.225m$ , to the incoming flow deep increases near 2.5 times, the arrival time in front of the dam has litter changes relatively.

##### 4.2.2 The Variation Law of Density Current along the Average Velocity, Average Temperature and Thickness.

Assuming  $\bar{U}$  is average velocity of density current,  $\bar{T}$  is the average temperature, L is the propagation distance. Choosing schemes A2、 A7、 A11、 A16 as analysis typical scheme and We can get the relation curve of  $L \sim \bar{U}$  ,  $L \sim \bar{T}$  showing at

fig.3 and fig.4.

It shows In fig.3 , the average velocity along in different section drive rapid increases first, the component of the gravity buoyancy and resistance along the slope toward down is the main reason. With the density current propagation, the resistance increases and at a position, the average velocity reduces. Comparing the average velocity in different schemes, it is found in spite of different incoming velocity, the average velocity of density current has a small difference in value when the flow rate is the same, and has the similar law for the propagation.

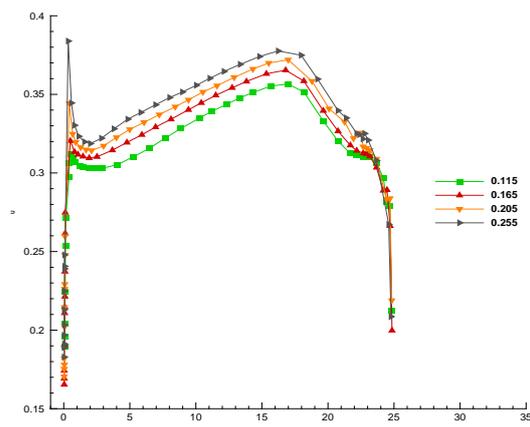


Figure 3. The average velocity

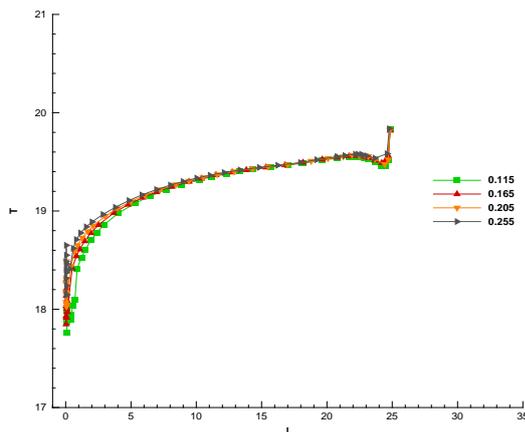


Figure 4. The average temperature

As shown in Fig.4, density current average temperature grows quickly first and then increases slowly, and has a maximum average temperature for 19.8°C. the average temperature of density current also have a small difference and has the similar law for the propagation.

### 4.2.3 The Mixing

Using  $E$  as the mixing between the density current and the environment water, we can get the relation curvy of  $L \sim E$  in fig.5.

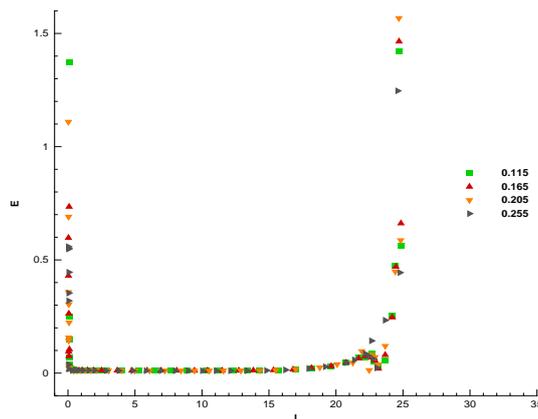


Figure 5. The mixing coefficient in interface changes along

As shown in Fig.5, the mixing coefficient is different in different position which can be divided into three regions: the magnitude is about  $10^{-1}$  when  $L < 0.3m$  where has intense mixing; the magnitude is about  $10^{-2}$  when  $0.3m < L < 22m$  where has small mixing coefficient; and in the third region, it has the same magnitude as first region. Comparing the fig.3 with fig.4, we can find the average velocity and temperature

dramatic change, Therefore we have enough reasons to believe that, there is different the mixing mechanism on the interface in the above three areas along.

Using  $Ri$  as the Richardson number along the way, and the mixing coefficient along and the curvy on  $Ri$  and E in the second area can be shown in fig.6 and fig.7.

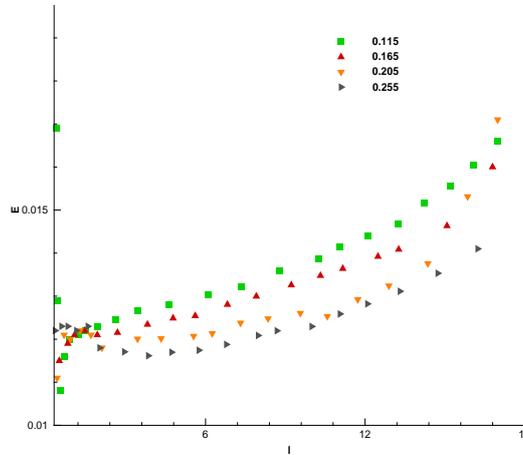


Figure 6. The mixing coefficient changes along

Figure 6 shows that in the area, the mixing coefficient is between 0.01 and 0.02 in value, and increases with the incoming heavy increases, but the numerical difference is small. The mixing coefficient in the interface increases with the propagation distance increase in a scheme, which shows the mixing coefficient increases in the second area. There is litter difference in value for different incoming flow heavy which indicates the similar degree mixing exists.

From fig.7, with  $Ri$  increase, the mixing coefficient in the interface decreases,  $Ri$  is the ratio between buoyancy and momentum, on one hand, the temperature of density current increases gradually for the mixing, and the effect of the buoyancy decreases; on the other hand, due to the buoyancy, the velocity increases gradually along, these two reasons cause  $Ri$  to decrease which reduced inhibitory effect on interface mixing and make the mixing coefficient increase.

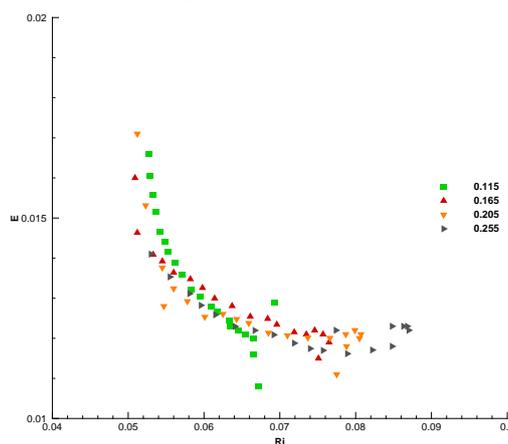


Figure 7. The relationship between mixing coefficient and the Richardson number

## 5. Conclusions

In this paper, we take a research on the thermal density current in a reservoir

based on the numerical simulation, the main conclusions are as follows: there will form a plunging thermal density current if the temperature of incoming flow is lower than the environmental water temperature in the reservoir, and the thermal density current will arrive in front of the dam if the temperature is lower all the way; the incoming depth has little effect on the thermal density current, and the analysis finds that the depth has little effect on the average velocity, the average temperature, and the mixing along in the same section of the reservoir; there is relationship between the mixing coefficient and the Richardson number, in particular, the larger the Richardson number is, the smaller the blending coefficient is.

## 6. References

- [1] Zhang Shunong. Environmental hydraulic[M]. Nanjing: Hohai University Press, 1988,12(1):190.
- [2] Harleman,D.R.F. Stratified flow[M]. Handbook of Hydrodynamics by V.L.Streeter. 1961(21).
- [3] Ippen,A.T. Estuary and coast line hydrodynamics[J]. New York, McGraw Hill,1966.
- [4] Ellison,T.H. Turbulent transport of heat and momentum from an infinite rough plane[J]. Fluid Mech1957(2):456-466.
- [5] Yih. Layered flow[M]. Science press,1983.
- [6] Huppert, H. E., and J. E. Simpson. The slumping of gravity currents[J],J. Fluid Mech., 1980,99, 785– 799.
- [7] Hallworth, M., Huppert,H., Phillips, J. & Sparks, S. Entrainment into two-dimensional and axisymmetric turbulent gravity currents[J]. Fluid Mech,1996(308): 289-311.
- [8] Ellison, T. H., and Turner, J. S. Turbulent entrainment in stratified flows[J]. J. Fluid Mech., 1959,6(3), 423–448.
- [9] Bournet, P. E., Dartus, D., Tassin, B., and Vincon-Leite, B. Numerical investigation of plunging density current[J]. J. Hydraul. Eng., 1999,125(6), 584–594.
- [10] Chung, S. W., and Gu, R. Two-dimensional simulations of contaminant currents in stratified reservoir[J]. J. Hydraul. Eng., 1998,124(7),704–711.
- [11] S.B.Savage and J.Brimberg. Analysis of plunging phenomena in water reservoirs[J]. Journal of Hydraulic Research, 1975, Vol.12, No.2, 187-205.
- [12] A.Dai and M.Garcia, Analysis of plunging phenomena[J].Journal of Hydraulic Research ,2009,Vol. 47, No. 5, 638–642.
- [13] Beckman, A., and Do'sher, R. A method for improved representation of dense water spreading over topography in geopotentialcoordinate models[J]. J. Phys. Oceanogr., 1997, 27(4), 581–591.
- [14]Anastasios.N.G,Kyriakos.L.K,Panagiotis.B.A,Nikolaos.E.K.Numerical investigation of continuous,high density turbidity currents response,in the variation of fundamental flow controlling parameters[J]. Computers and Fluids,2010,vol.60,21-35.