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Effect of thermal stratification on interflow travel time in stratified reservoir

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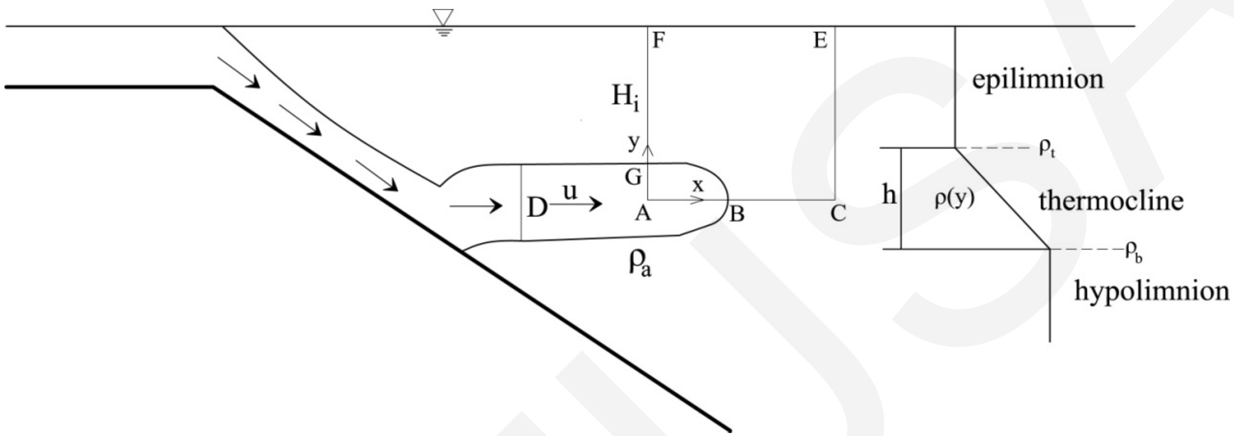
Introduction

Due to the density difference between contaminated inflow and ambient water, a density current forms in the ambient water. An overflow, as shown in Fig. 1, moves forward on the surface of water forms if the density of inflow is lighter than that of the ambient water. While the denser inflow moves along the bed slope as an underflow. If the ambient water is thermal stratified, the inflow separates from the bottom slope and penetrates horizontally into ambient water as an interflow when it becomes neutrally buoyant.

To help better understand the influence of thermal stratification on interflow travel time from physic background, a model from energy conservation is developed to predict the velocity of interflow in thermally stratified environment in this paper. The results help to analyze the relation between buoyancy frequency as a reflection for the thermal stratification and interflow travel time. Experiments and a 2D numerical model are implemented as well to verify this relation. The results could help understand the effect of thermal stratification on behavior of interflow.

Analytic modea

The fig illustrates the schematic process for the movement of interflow in stratified surroundings.

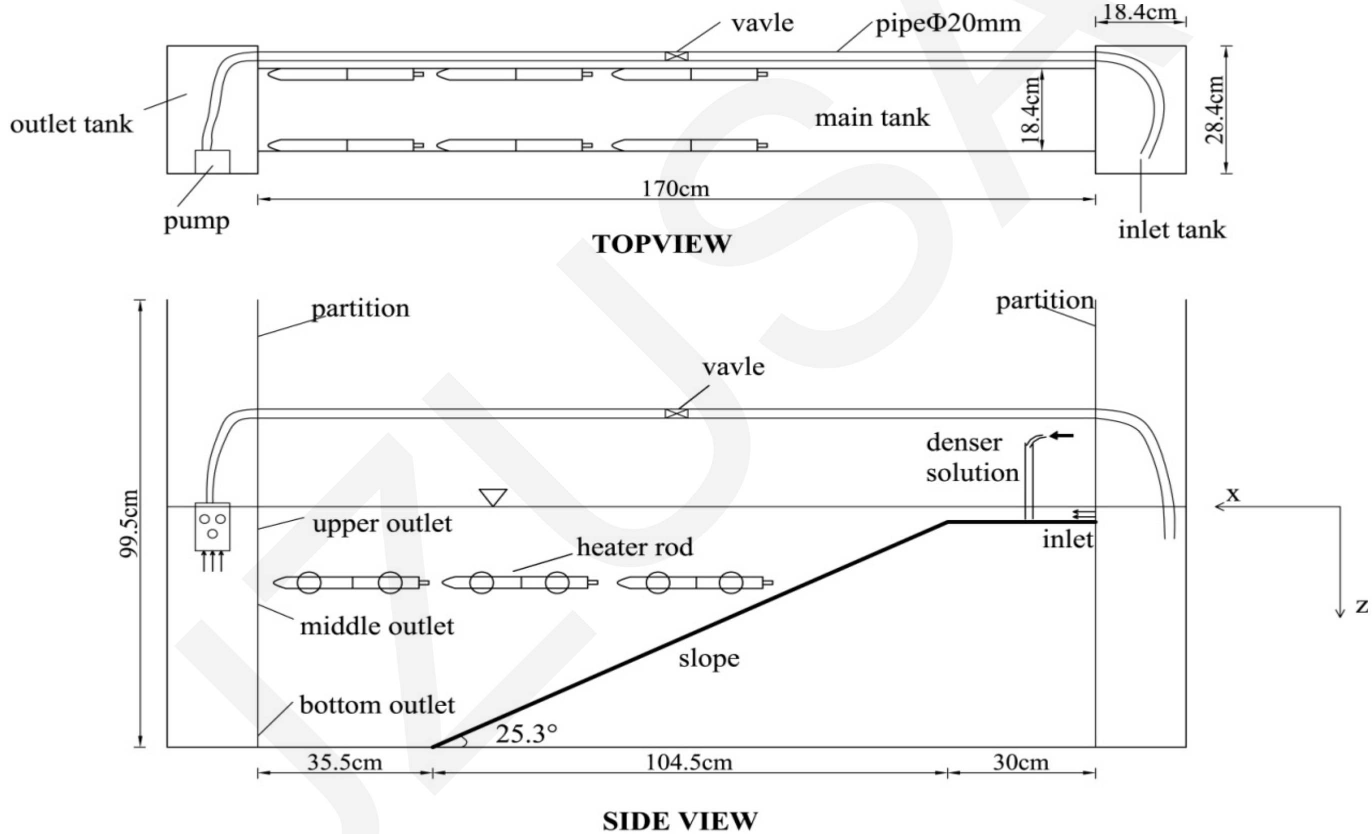


We can get an inverse relation between travel time of interflow (t_i) and thermal stratification defined as buoyancy frequency (N) through the Bernoulli's principle of energy conservation as follow:

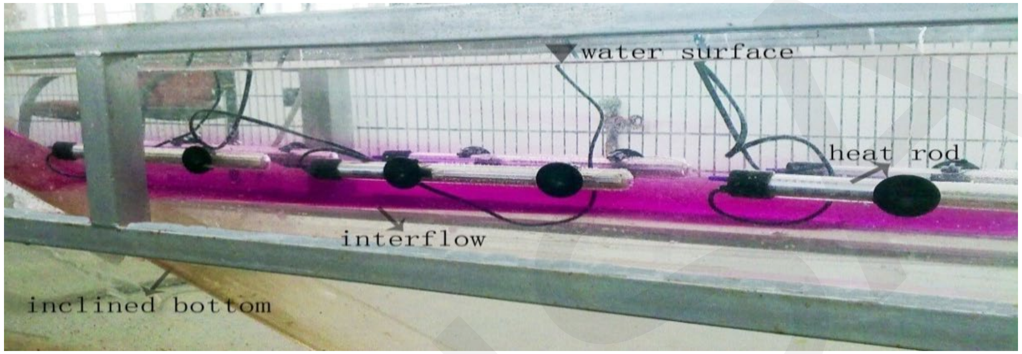
$$t_i = \frac{L}{U} = \frac{2L}{DN}$$

Experimental evidence

The schematic diagram of experimental apparatus and the formation of an interflow are shown as follow,



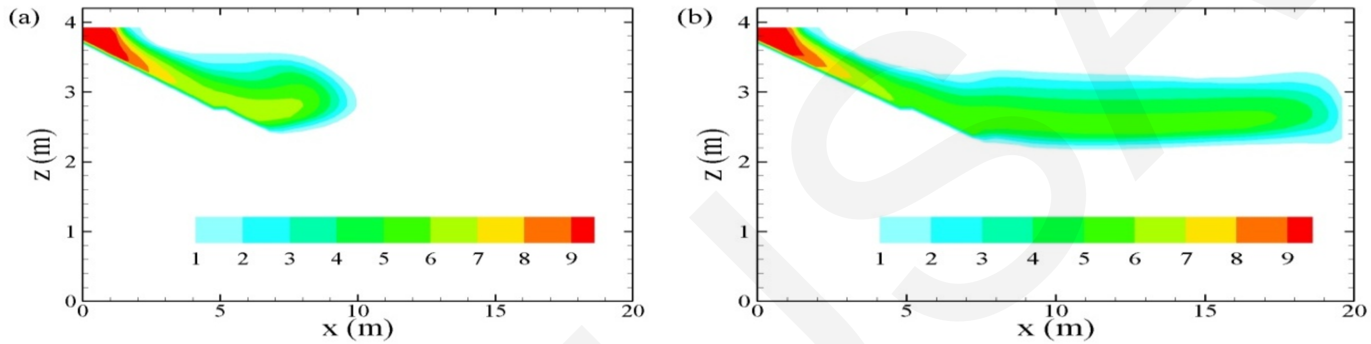
Experimental evidence



Run	Q_0 (cm²/s)	ρ_0 (kg/m³)	Outlet position	N (s^{-1})	t_i (s)
A	1.80	1002.21	middle	0.24	511
B	1.80	1002.23	middle	0.29	491
C	1.80	1002.21	middle	0.30	462
D	1.80	1002.20	middle	0.35	445
E	1.80	1002.20	middle	0.37	410

Numerical evidence

A vertical 2D RNG k-ε model is developed to simulate the interflow. The simulation results are shown,



Parameters for numerical simulations of interflow under various stratification conditions

Cases	Inflow conditions		Stratified condition		N (s^{-1})	t_i (s)
	Q_0 (m^3/s)	T_0 (℃)	T_t (℃)	T_b (℃)		
1	0.005	18	19	21	0.071	980
2	0.005	18	18	22	0.101	860
3	0.005	18	17	23	0.123	810
4	0.005	18	16	24	0.142	740
5	0.005	18	15	25	0.159	690
6	0.005	18	14	26	0.174	670
7	0.005	18	13	27	0.188	630
8	0.005	18	12	28	0.200	590
9	0.005	18	11	29	0.212	540
10	0.005	18	10	30	0.223	530

Conclusions

The effect of thermal stratification on the travel time of contaminant as an interflow was investigated in this paper. The velocity of interflow in thermally stratified was predicted through analytical analysis from the view of energy conservation. As a result, a linear relation between interflow travel time and buoyancy frequency was found.

The interflow was investigated by suddenly releasing denser fluid at the top of the slope in the experiments. As the density of denser inflow decreased by dilution and mixing with ambient water, the interflow formed when the inflow travelled at its equal buoyancy level. Through experiments that inflow moved into ambient water with different stratification intensity, a nearly linear relation between buoyancy frequency and travel time of interflow was found. This confirmed the prediction from the analytical analysis.

A two-dimensional RNG k-ε model was used to simulate the interflow in thermal stratified reservoir. In the numerical simulation, constant inflow discharge and contaminant concentration are used at the inlet, which simulated the tributary inflow form upstream river to reservoir. The numerical results also verified the near-linear between travel time and buoyancy frequency. This result helps to better understand the reason of interflow travel time decreased with vertical temperature difference increasing in previous study. What's more, in spite of the interflow formed from the different inflow patterns, the impact of buoyancy frequency on the travel time of interflow is not influenced.