A Hydrothermal Convective Flow at Extremely High Temperature*

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Abstract: To investigate the flow structure of a hydrothermal convection in the deep sea, a thermal convective flow is simulated, where the temperature of the heated water and the environmental pressure are very high above its critical point. The compressible Navier-Stokes equations are solved incompressibly using multidirectional finite difference method. Numerical results clearly show differences in the flow field depending on the temperature of the heated water.

Keywords: Hydrothermal Convection, Supercritical Water, Incompressible Flow Computation, Flow Structure.

1 Introduction

Hydrothermal convective flows are found in geothermally heated water issued from hydrothermal vents. They are found in deep oceans of depth over 2,000 m where the hydrostatic pressure is over 20 MPa, and the temperature of the heated water is sometimes more than 300°C. Under these conditions, water emerging from these vents can be in a supercritical state that is a condition between liquid and gas.

In order to deepen the understanding of the oceanic crust that possesses abundant resources, it is also important to investigate the advection and diffusion of materials which are issued from hydrothermal vents accompanying the heated water.

2 Computational Method

The compressible Navier-Stokes equations are solved on the assumption that pressure difference from environmental pressure is sufficiently small and does not affect the density change. And also the flow velocity is assumed to be much smaller than its sound velocity. The environmental water pressure is taken as 23 MPa which is above its critical pressure of 22.064 MPa. The temperature of the heated water T_h in this computation is 670 K which is above its critical temperature of 647.096 K. Since the emitted heated water is quickly cooled by the environmental water whose temperature T_e is approximately 2 °C, water changing to a gas phase is not assumed.

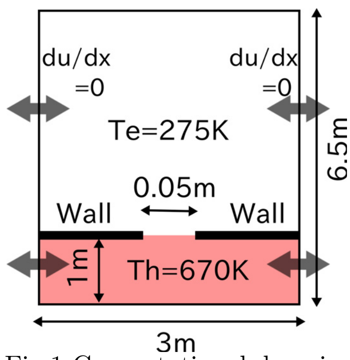

Fig.1 Computational domain.

The basic equations are approximated by the multidirectional finite difference method. To stabilize the calculation, a third-order upwind scheme is employed for the advection terms. These equations are solved numerically using the method for an incompressible flow, where Poisson's equation is solved to obtain pressure. The flow is simulated in a 2D domain (see Fig.1) which is partitioned into regions of the heated water and the environmental water by walls. The opening in the wall is likened to the hydrothermal vent.

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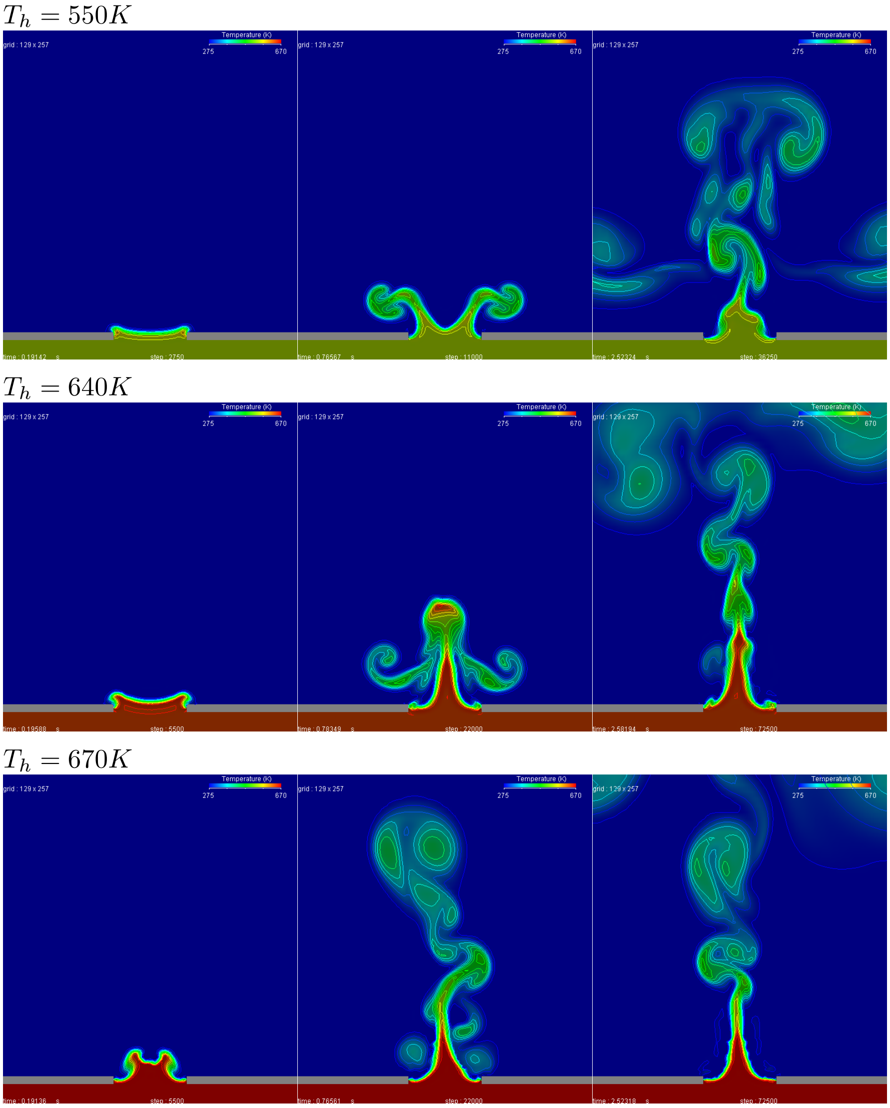
3 Computational Results

Flow simulations are carried out at three kinds of heated water temperature T_h of 550 K, 640 K and 670 K. Fig.2 shows time development of temperature fields visualized using the same level ranging between 275 K and 670 K. On the other hand, in Fig.3, the averaged temperature fields are expressed in the range between T_e and T_h.



$t = 0.19$ s $t = 0.76$ s $t = 2.9$ s

Fig.2 Time development of temperature field at each T_h.

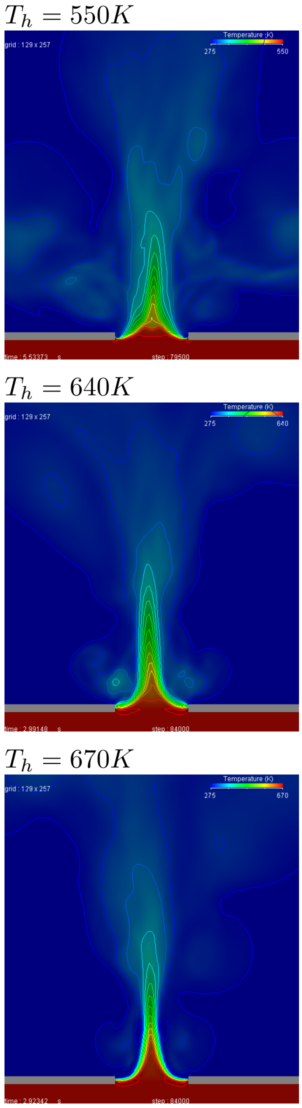


Fig.3 Time averaged temperature field.

4 Conclusion

Hydrothermal convective flows of various temperatures including values near the critical temperature were simulated using the numerical method same as an incompressible flow. Under conditions closed to the critical temperature, the flow was sensitive to the temperature of the heated water and large difference in the flow field was observed. At a temperature above the critical temperature, the thermal convection developed faster and explosively. Also in this case,the rising flow was fast and narrow. The phenomenon may be due to the large changes in density accompanying the small changes in temperature.