Transactions of the Korean Nuclear Society Spring Meeting
Chuncheon, Korea, May 25-26 2006

Simulation of Natural Convection of Air in a Square Cavity Using CFX-10

Churl Yoon, Joo Hwan Park, Meejeong Hwang, Joon-Eon Yang
Korea Atomic Energy Research Institute
150 Dukjin-Dong, Yusong-Gu, Daejeon 305-353, Korea
Phone: +82-42-868-2128, Fax: +82-42-868-8590, E-mail: cyoon@kaeri.re.kr

1. Introduction

For the loss of HVAC(Heating, Ventilation, and Air Condition) system in the NPP's, it is one of the main issues in PSA(Probabilistic Safety Assessment) FT(Fault Tree) model to estimate the transient temperature variations of some component rooms such as CS pump, LPSI room, HPSI room, and AFW room, etc. The air temperature of these component rooms would increase gradually in the case of loss of HVAC. It becomes the main concern to determine whether the component room temperature exceeds the operability condition as shown in Table 1 [1] and which action reduces the room temperature in case of a HVAC function failure. The previous study of the authors[2] gives an example of using CFD method for evaluating the component room temperatures for the loss of HVAC. The key element of this room temperature cases would be the natural convective heating of air in a closed or an open room with some complex geometry. The purpose of this study is to estimate the capability of CFX-10 for the temperature prediction of the CS pump room in the loss of HVAC. As a bench mark problem, the laminar natural convection of air in a square cavity was selected and the results are presented with the previous studies.

Table 1. Operability Condition by the Pump Room

Pump Room	Operable Temp. of Comp. NUMARC87-00[1]
LPSI, CS, Charging, CCW, EDG. AACDG, ESW	180°F (82.2°C)
AFW MDP, AFW TDP	160°F (71.1°C)

2. Methods and Results

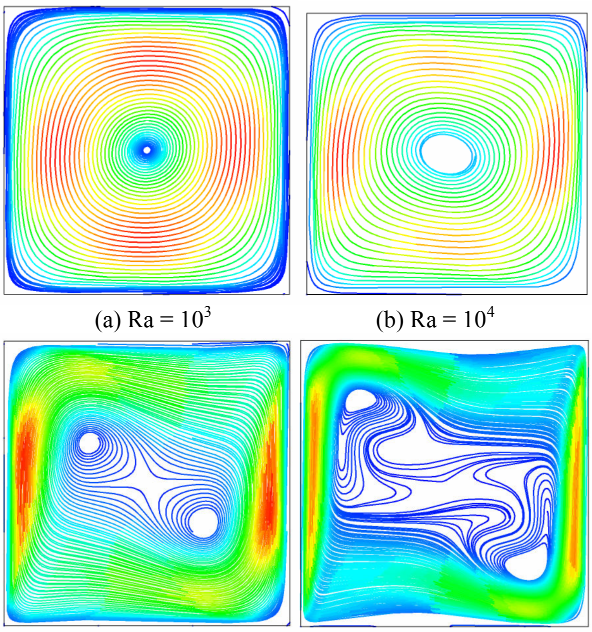
In this section some of the techniques used to simulate the laminar natural convection in a square cavity are described, and the results are presented.

2.1 Problem Definition

The geometry considered is that of a 2-dimensional square cavity with the left and right vertical walls heated to uniform hot and cold temperatures, respectively. The horizontal walls are insulated. In this paper four cases using different Rayleigh numbers are considered: Ra = 10^3, 10^4, 10^5, and 10^6. Benchmark solutions for this range of Rayleigh numbers are provided by de Vahl Davis [3]. For each Rayleigh number, a benchmark solution was obtained by applying Richardson extrapolation to numerical solutions obtained for a number of grid spacing. The extrapolated solutions were reported to be accurate to less than 1% error at the highest Rayleigh number and to less than 0.1% error at the lowest Rayleigh number. M.F. Lightston et al. [4] performed numerical simulation for these natural convection cases by GOTHIC code. They showed the excellent qualitative agreement of the flow and temperature fields between the simulation and the benchmark solution.

2.2 Simulation Method

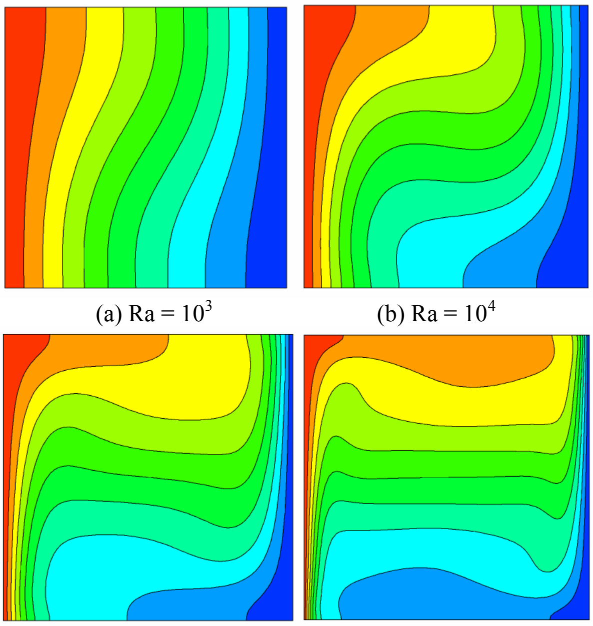
A commercial CFD code, CFX-10(ANSYS Inc.), is used for the simulation. In this study the Rayleigh numbers stay within the laminar flow range. The transition to turbulence occurs at $10^8 < Ra < 10^{10}$ for natural convection flow in a vertical heated plate. The applied numerical scheme is the high resolution scheme. [5] Buoyancy force induced by wall heating and cooling was modeled by Boussineq Approximation. Three uniform meshes of 40X40, 60X60, and 80X80 were generated and used for the simulation.



(a) Ra = 10^3 (b) Ra = 10^4

(c) Ra = 10^5 (d) Ra = 10^6

Figure 1. Streamlines predicted by predicted by using CFX-10, with 80X80 meshes



(a) Ra = 10^3 (b) Ra = 10^4

(c) Ra = 10^5 (d) Ra = 10^6

Figure 2. Contour maps of temperature predicted by using CFX-10, with 80X80 meshes

2.3 Results

Figure 1 shows plots of streamlines for Ra=10^3, 10^4, 10^5, and 10^6 obtained using an 80X80 grid. At the lowest Rayleigh number, the flow is nearly symmetrical about the center point. As the Rayleigh number is increased to 10^4, the recirculation is still about the center point, but the flow streamlines are more elongated into the corners. At Ra=10^5, two distinct circulation zones appear. For the highest Ra number, the recirculation zones penetrate further into the fluid at the top and bottom of the domain with the thinner boundary layers.

Figure 2 presents the contour maps of temperature obtained with an 80X80 grid. For the case of Ra=10^3, this simulation result show slight curvature in the isotherms with the curvature decreasing near the side walls. The increase of the Rayleigh number produces a flattening of the contours with a corresponding larger temperature gradient at the lower left and top right regions of the cavity. At the Ra=10^6, the distinct recirculation zones make a hump in the isotherms near the top left section and a dip near the bottom. Also, a thinning of the thermal boundary layer is seen.

3. Conclusion

The CFX-10 code has been used to simulate the natural convection of air in a square cavity for four values of Rayleigh number. The predicted fluid flow was compared to a benchmark solution. The streamlines are in excellent agreement with the benchmark solution in that the locations of the center point of the recirculation are extremely well predicted. Also, the temperature contours and their evolution with varying Ra number are in excellent agreement with the solution of de Vahl Davis. It is proved that CFX-10 can predict accurately the air circulation and temperature fields in a square cavity for the laminar range of the low Rayleigh numbers. The future works will cover the turbulent natural convection and the complexity of geometry.

Acknowledgement

This project has been carried out under the Nuclear R&D Program by MOST.

REFERENCES

[1] NUMARC 87-00, Guidelines and Technical Bases for NUMARC Initiatives Addressing Station Blackout at LWRs

[2] M. Hwang, C. Yoon, J.-E. Yang, & Joo Hwan Park, Review of the Operability for the Components Under the Loss of the HVAC System of the Pump Room, *Transactions of the Korean Nuclear Society*, Autumn Meeting, Busan, Korea, Oct. 27-28, 2005.

[3] G. De Vahl Davis, Natural Convection of Air in a Square Cavity: A Bench Mark Numerical Solution, *International Journal for Numerical Methods in Fluids*, Vol. 3, p. 249-264, 1983.

[4] M.F. Lightstone and W.M. Collins, Simulation of Natural Convection of Air in a Square Cavity Using the GOTHIC Thermalhydraulic Code, *The 34-th Annual CNS Conference*, Montreal, June 5-8, 1994.

[5] *CFX-5: Solver Theory*, ANSYS Canada Ltd., Canada, 1996.