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EFFECT OF FLUID GAP CELL SIZE IN A SUCTION VALVE ON PERFORMANCE OF A LINEAR COMPRESSOR

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ABSTRACT

Fluid gap cell is used for CFD analysis of compressor valve. The effect of the fluid gap cell on compressor performance prediction is still insufficient. Therefore, in this study, the performance change in the compressor was investigated by varying the fluid gap cell size from 100 µm to 10 µm. As the fluid gap cell size decreases, the maximum valve lift increases and the second valve opening lift becomes steeper. Also, the smaller the fluid gap cell size, the more accurately the valve flow rate is predicted when the valve is at closing. However, it has little effect on the PV diagram. In summary, the fluid gap cell size affects valve lift and valve suction flow rate changes but has little effect on CW, CC, and EER. Therefore, a 100um fluid gap cell can be used if you are only interested in overall compressor performance. Otherwise, it would be better to use a fluid gap cell of 25 µm or below.

Keywords: household refrigerator, compressor, suction system, fluid gap cell, computational fluid dynamics, CC, CW, EER

INTRODUCTION

Refrigerant compressors are widely used in various products such as household refrigerators. The refrigerant compressor includes various kinds of compressors such as a reciprocating compressor, a scroll compressor, a screw compressor, and a linear compressor etc. In contrast to the reciprocating compressors, linear compressors have high efficiency because they do not have the effect of converting rotational motion into reciprocating motion [1]. However, it is necessary to secure the competitiveness of linear compressors since reciprocating compressors were improved using variable inverter technology.

Efforts to improve the performance of linear compressors have been made in various fields. Recently, there were many studies on the performance analysis of compressors using CFD (Computational Fluid Dynamics). Park *et al*. predicted the cycle performance of the linear compressor while considering the valve behavior. They compared the valve rigid-body model with the FSI model [2]. Hwang et al. estimated the leakage through the piston clearance of a linear compressor using CFD [3]. Hwang *et al.* analyzed the unsteady flow of a linear compressor using a 1d-CFD coupled model. They proposed a new analytical model for accurate prediction of a compressor superheat [4].

Particularly, studies have been done to describe the valve behavior. Silva *et al.* [5] used a rigid body model to optimize the valve lift with reed valve thickness and verified the enhancement of the COP experimentally. Shiomi *et al*. [6] compared Single-degree-of freedom (SDOF) and Multi-degree-of-freedom (MDOF) models to describe the valve behavior. They showed that the MDOF model was more in agreement with the experimental results although the computation time with the MDOF model was approximately double compared to that of the SDOF model. In addition, Suh et al. [7] performed FSI analysis with suction valve shape and suction muffler of a refrigeration compressor. They verified the accuracy of the FSI analysis with experimental results. Choi *et al.* [8] applied FSI analysis to a linear compressor using R134a and successfully reduced the maximum stress of the suction valve at maximum lift by approximately 4.2 %. Tao *et al.* [9] investigated the delayed closure of the suction valve in the refrigerator compressor by FSI modeling.

Fluid gap cells are usually used for CFD analysis with the opening and closing of the valve. Studies for the effect of the fluid gap cell on compressor performance are still insufficient. Therefore, in this study, the change of the performance of the compressor was investigated by varying the fluid gap cell size from 100 µm to 10 µm. Specifically, the effect of the fluid gap cell size on the valve lift, suction mass flow into the compression chamber, compression work (CW), cooling capacity (CC) and energy efficiency ratio (EER) was investigated.

NUMERICAL ANALYSIS METHODS

Figure-1 shows a schematic view of the suction valve, discharge valve and compression chamber of the compressor. In this paper, five cases were numerically analyzed to predict the performance change of the compressor according to the fluid gap cell. Case 1, a baseline model, represents a 100 µm fluid gap cell model, case 2 a 50 µm model, case 3 a 25 µm model, case 4 a 10µm model, and case 5a 5 µm model. However, if the fluid gap cell of the suction valve is changed, the compression chamber volume will change. Therefore, in this study, the compression chamber length was maintained constant according to the fluid gap cell.

Figure-2 shows the 3D rigid valve model with fluid gap cells. This model is simplified to 1/8 model to shorten the analysis time. The numerical analysis follows the following process. Starting from the BDC, the piston compresses refrigerant gas. When the pressure of the compression chamber becomes higher than that of the

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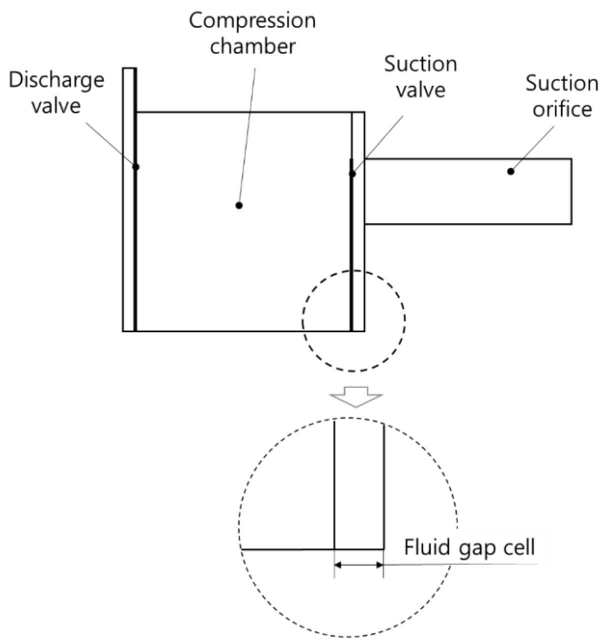

Figure-1. Schematic of the valve models.

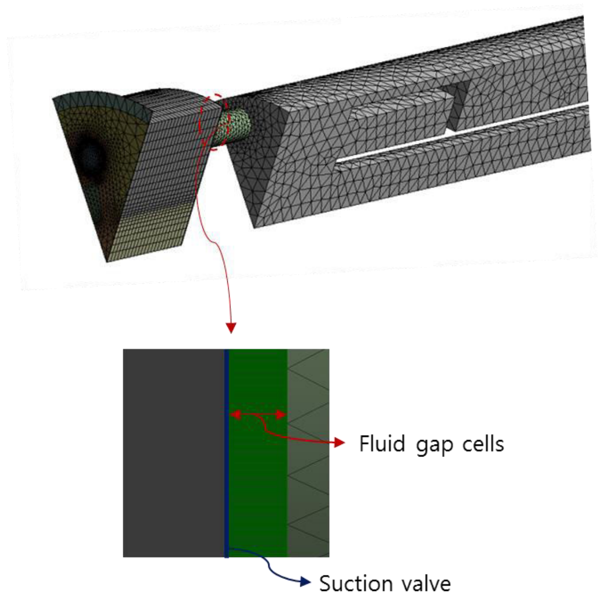

Figure-2. Fluid gap cell of the 3D rigid valve model.

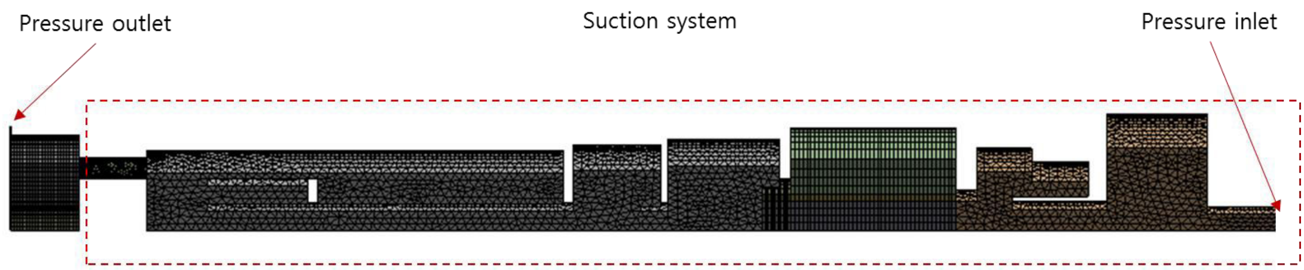

Figure-3. Mesh system of the 3D rigid valve model.

Table-1. Opening and closing conditions of the no-leakage valve model.

Event	Event conditions	Boundary condition change
Opening DV	If compression chamber pressure is greater than discharge chamber pressure	Wall → Pressure outlet
Closing DV	If compression chamber pressure is less than discharge chamber pressure and discharge valve is at the initial position	Pressure outlet → Wall
Opening SV	If suction orifice pressure is greater than compression chamber pressure	Wall → Interior
Closing SV	If suction orifice pressure is less than compression chamber pressure and suction valve is at the initial position	Interior → Wall

discharge chamber, the discharge valve is opened. When the piston expands, the discharge valve is closed again when the compression chamber pressure becomes lower than that of the discharge chamber. The suction valve is opened when the compression chamber pressure becomes lower than that of the suction system. The suction valve becomes closed again when the compression chamber pressure becomes higher than that of the suction system.

Figure-3 shows the mesh system of the 3D rigid valve model. About 17,000 cells were used for the numerical analysis. Ansys Fluent [10] was adopted for CFD analysis. The realizable k-ε model was used for the turbulence model. Fluent UDF (user defined function) was adopted to describe a piston motion. Table-1 shows the opening and closing conditions for the suction valve and discharge valve.

RESULTS AND DISCUSSIONS

Valve lift according to fluid gap cell size

Figure-4 shows the change in valve lift with piston phase angle. At this time, the valve lift was normalized with a fluid gap cell size of 100 μm. The lift of the discharge valve was hardly affected by the fluid gap cell size of the suction valve. In a suction valve, the larger the fluid gap cell size, the greater the maximum lift. This occurs both in the first and second valve openings. However, infinitesimal fluid gap cells do not bring them closer to reality. This is because there is always a certain gap between the suction valve and the valve seat due to the surface roughness and valve deformation etc. Another distinguished feature for small fluid gap cell is that the second valve opening speed is very rapid. As the fluid gap cell becomes smaller, the compression chamber pressure loss becomes smaller, so a smaller fluid gap cell makes the second valve opening speed much faster. Therefore, the fluid gap cell must be less than 25 μm not to cause a large error in the maximum lift size or in the valve opening speed.

Suction mass flow rate and PV diagram according to fluid gap cell size

Figure-5 shows the change of the refrigerant mass flow rate through the suction valve according to the piston phase angle. The mass flow rate of the refrigerant is proportional to that of the valve lift. When the fluid gap cell is 100 μm, the suction mass flow rate at the first valve closing is not close to zero. This is due to the relatively large fluid gap cell. When the fluid gap cell becomes 25 μm or less, the suction mass flow rate approaches zero.

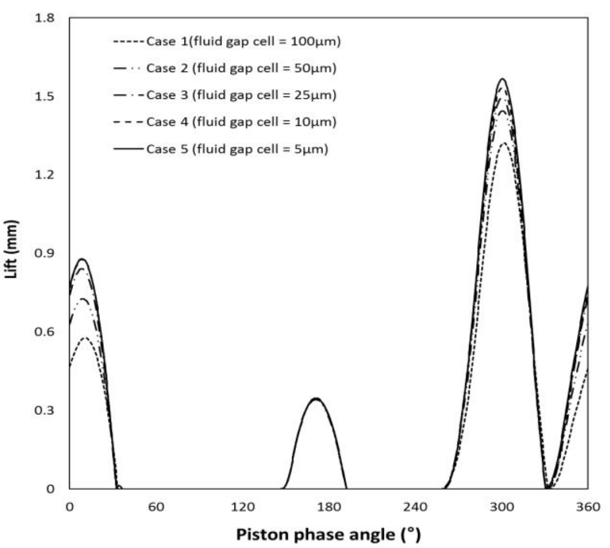

Figure-4. Variation of the valve lifts with piston phase angle.

Furthermore, even at the second valve closing, a 100um fluid gap cell shows a refrigerant flow rate. Therefore, this problem needs to be minimized by using a fluid gap cell of 25 μm or less.

Figure-6 shows a comparison of PV diagrams according to fluid gap cell size. At this time, the pressure was normalized to the evaporation pressure and the compression volume was normalized to the compression chamber volume when the piston is at the BDC. The PV diagram varies little according to the fluid gap cell size overall. However, a slight change exists during the suction process. The smaller the fluid gap cell size, the faster the compression process, the slower the expansion process and the lower the compression chamber pressure.

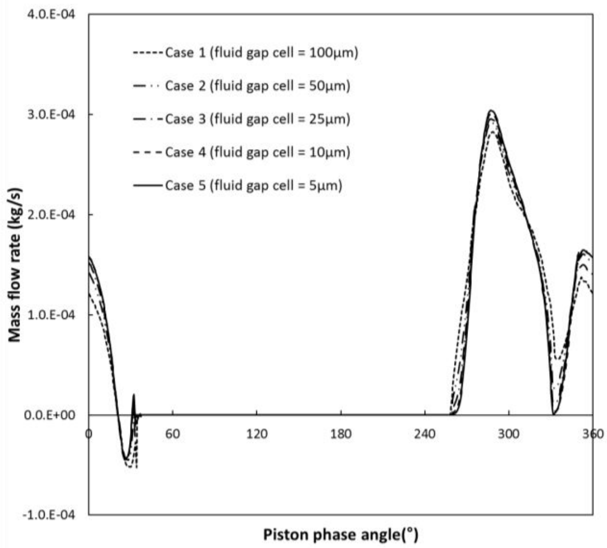

Figure-5. Variation of mass flow rate through the suction valve with piston phase angle.

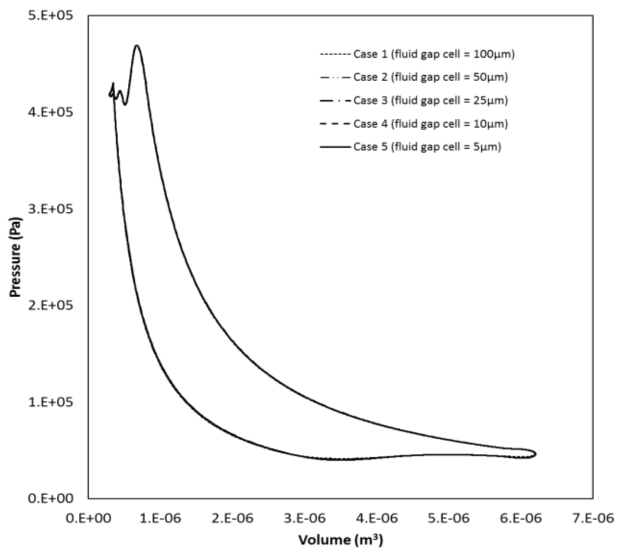

Figure-6. Comparison of the P-V diagrams with fluid gap cell.

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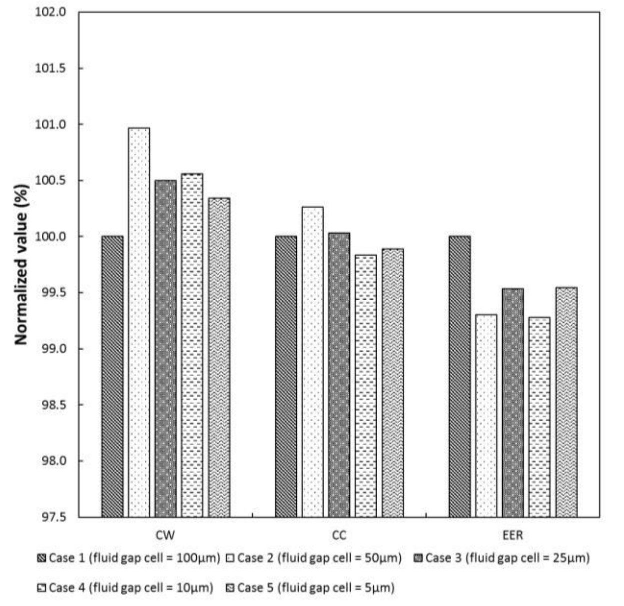

Figure-7. Comparison of CC, CW and EER according to fluid gap cell size.

CC, CW and EER according to fluid gap cell size

Figure-7 shows CC, CW and EER according to fluid gap cell size. At this time, each value was normalized based on case 1. First, CW shows a difference of up to 0.5% depending on the fluid gap cell size. This is because the PV diagrams are relatively unchanged. The CW shows a difference of up to 0.2%. This is a relatively small difference, considering that valve lift and suction mass flow rate change relatively large with fluid gap cell. The EER obtained by the ratio of CW and CC also shows a maximum difference of 0.7% according to the fluid gap cell size. Therefore, fluid gap cell size is not sensitive to CW, CC, and EER predictions. Therefore, 100um fluid gap cell is not a bad choice when predicting only the overall performance of compressors such as CW, CC, and EER. However, fluid gap cell of 25 μm or less needs to be considered when detailed valve lift or suction mass flow rate is necessary.

CONCLUSIONS

In this study, we investigated the effect of fluid gap cell size on the performance of a linear compressor. For this, CFD cycle analysis was performed considering valve behavior with one-dimensional rigid body valve model. The following conclusions were drawn through this study.

a) As the fluid gap cell size decreases, the maximum valve lift increases and the second valve opening speed increases. Therefore, it is recommended to use a fluid gap cell of 25um or less for the compressor considered in this study.

b) The smaller the fluid gap cell size, the more accurately the valve mass flow rate is predicted at valve closing. However, the fluid gap cell size has little effect on the PV diagram.

c) Fluid gap cell size affects valve lift and valve suction flow rate but has little effect on overall CW, CC and EER. Therefore, a 100um fluid gap cell can be used if you are only interested in overall compressor performance.

In the future, the effect of the actual clearance of the suction valve on compressor performance needs to be studied.

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