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A STUDY ON THE OPTIMIZATION OF LEAKAGE AND FRICTION WITH PISTON DIMPLES FOR A COMPRESSOR

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ABSTRACT

Improving compressor efficiency is essential in refrigeration cycles. Some factors leading to poor compressor efficiency are suction and discharge loss, friction, leakage, and heat insulation. This study developed a model capable of predicting leakage and friction, and introduced dimples to pistons. Optimum dimples that minimize leakage and friction were identified.

Keywords: compressor, dimple, leakage, friction, two phase flow.

INTRODUCTION

Refrigeration cycles are used in everyday life and industries due to their high efficiency. Common refrigeration cycles in everyday life include refrigerators and air-conditioners. Since compressors account for the highest portion of energy consumed by refrigerators and air-conditioners, a higher compressor efficiency can save energy and enable more efficient refrigeration cycles [1].

Reciprocating compressors have been utilized for a long time due to their durability and reliability. Similar to reciprocating compressors, linear compressors also consist of pistons and cylinders. Other types of compressors are scroll compressors and screw compressors.

Comprised of pistons and cylinders, both reciprocating compressors and linear compressors have high reliability and efficiency. Because oil is used as a lubricant, frictional loss arises from the friction between pistons and cylinders, as well as the viscous force of the oil. Previous research attempted to reduce friction as well as the leakage that occurs at gaps between pistons and cylinders. Assuming a certain film thickness, Park and Hwang examined friction and leakage in relation to the depth, position, and number of dimples [2, 3, 4]. However, few studies have conducted two phase analysis on friction and leakage with a various number of dimples.

Against this backdrop, this study introduced dimples in pistons and predicted friction and leakage by using three-dimensional numerical analysis that considered the two phase flow in relation to the number of dimples.

Analysis method and conditions

Ansys Fluent [5] was used to analyse the friction and leakage with a various number of dimples. Figure-1 presents the model used in the analysis. The influence of the number of dimples was examined by increasing the number from 0 to 15. Single phase analysis was first performed, followed by two phase analysis using isobutene and oil. A pressure of 3.75 kg_f/cm^2 was applied at the compressor outlet, and atmospheric pressure was assumed at the oil outlet inlet. The isobutene produced leakage through the gap between the piston and cylinder. In addition, piston movement was emulated by applying the moving wall technique. Figure-2 shows the mesh system used in the analysis. The hexahedron mesh had a total of 300,000 meshes.

RESULTS AND DISCUSSIONS

Single phase friction analysis

To examine the decrease in friction in relation to the number of dimples, single phase analysis was conducted with isobutene only. Figure-3 shows the variation of C_f with the number of dimples by pressure and viscous force. During the single phase, C_f decreased linearly with the number of dimples. C_f by pressure offset the C_f by viscous force. The effect of C_f by pressure was found to be less significant compared to that of C_f by viscous force. As such, the piston was more susceptible to friction by pressure than friction by viscous force.

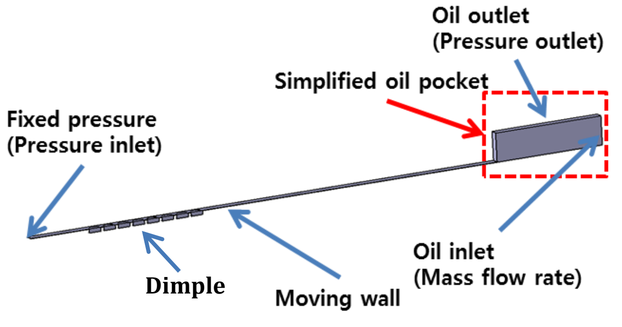

Figure-1. Computational domain with boundary conditions.

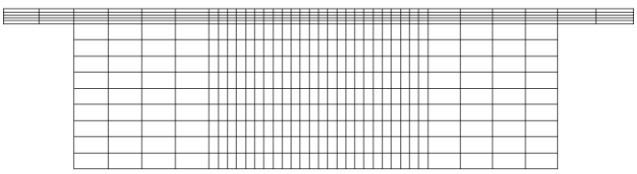

Figure-2. Mesh system of a dimple.

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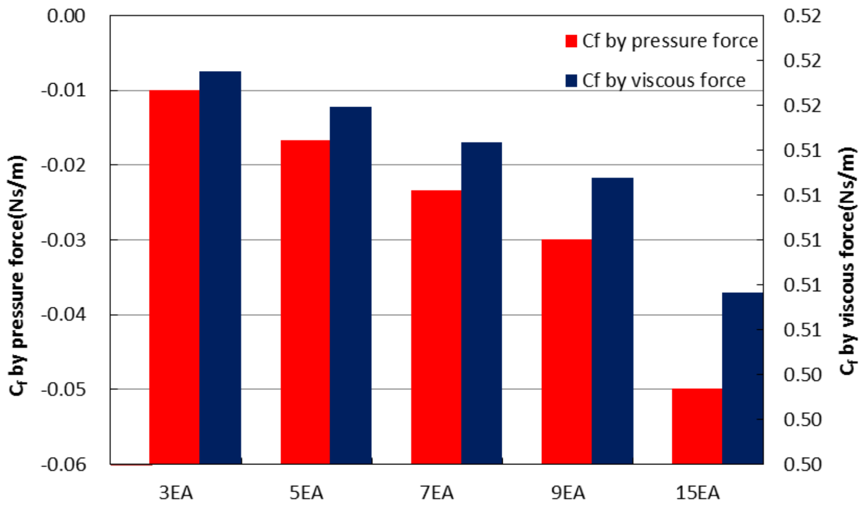

Figure-3. Variation of friction coefficient with number of dimples.

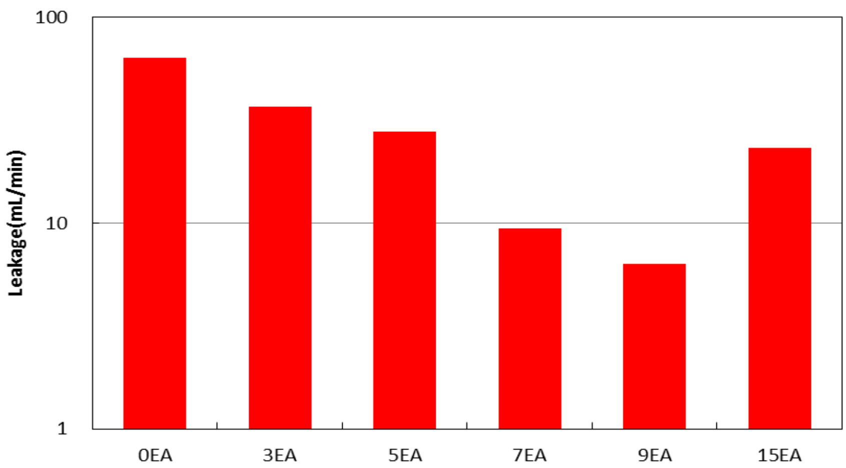

Figure-4. Variation of leakage with number of dimples.

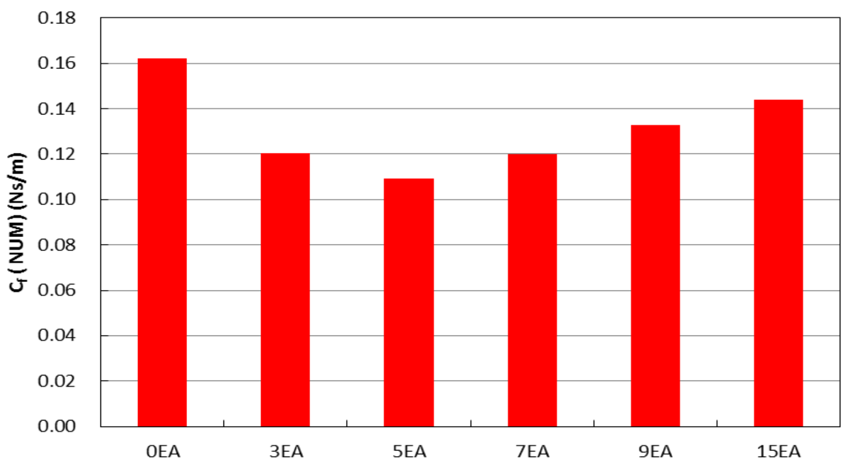

Figure-5. Variation of friction coefficient with number of dimples.

Two phase friction and leakage analysis

The effect of dimples on friction and leakage was examined through two phase flow analysis involving a coolant and oil. Figure-4 shows the variation of leakage with the number of dimples. Instead of increasing linearly with the number of dimples, leakage was found to exhibit

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non-linear behaviour. The variation of leakage was minimal up to five dimples, but decreased significantly for seven dimples. The increase in leakage when the number of dimples was raised to 15 indicates that an optimum number exists. The optimum point for the number of dimples that achieves minimum leakage can be obtained through numerical analysis, and this was 9EA for the present model.

Figure-5 shows the variation of C_f with the number of dimples. Similar to leakage, C_f changes non-linearly with the number of dimples. This is different from the results of single phase analysis, thus suggesting that the two phase flow is more suitable when predicting the leakage and friction of the compressor.

Two phase friction and leakage analysis with consideration of cavitation

To take into account more realistic circumstances, two phase analysis was performed that considered cavitation. Figure-6 shows the variation of leakage with the number of dimples. The overall trend is similar to the case without cavitation, and the amount of leakage was greater when cavitation was applied. This increase in the amount of leakage with cavitation was caused by the coolant melting in oil at high pressure and vaporizing at low pressure.

Figure-7 shows the variation in C_f with the number of dimples. Similar to leakage, the results were the same as the case without cavitation. While leakage increased when cavitation was applied, C_f had an overall decrease. The optimum number of dimples giving the lowest C_f was 5EA. When considering only leakage, the optimum number is 9EA. As such, the number of dimples should be selected in consideration of both leakage and friction.

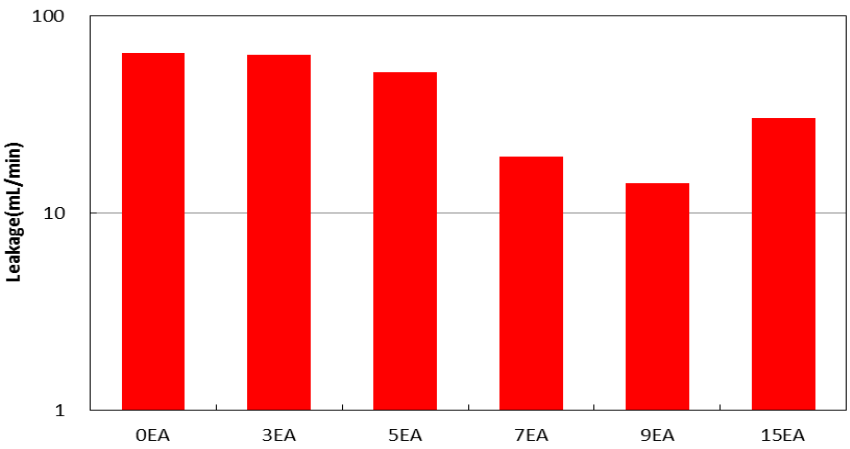

Figure-6. Variation of leakage with number of dimples for a cavitation model.

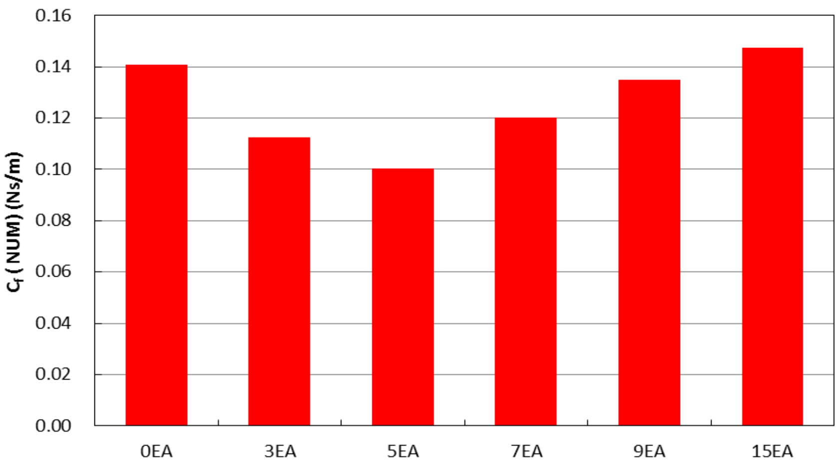

Figure-7. Variation of friction coefficient with number of dimples for a cavitation model.

CONCLUSIONS

To examine the effect of piston dimples in a compressor, this study performed single phase and two phase analysis. The following conclusions were derived.

a) Friction arises due to pressure and viscous force. The results of the single phase analysis showed that the effect of C_f by pressure was less significant compared to that of C_f by viscous force.
b) In two phase flow analysis, the dimples' giving the least leakage and friction was 9EA and 5EA, respectively. Since the two optimum points are different, the number of dimples should be selected based on the various requirements and applications.
c) More realistic predictions of leakage and friction are possible when cavitation is applied.

In the future, models capable of providing quantitative predictions of leakage and friction will be developed.

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