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Design of The Suction Muffler of a Reciprocating Compressor Using DOE (Theoretical and Experimental Approach)

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Contents

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Introduction

- A hermetic reciprocating compressor is used widely to household refrigerator and they consist of suction, discharge, electronic system.
- Volumetric efficiency of a reciprocating compressor is influenced by the design of suction system greatly.
- Until now, most research have observed a phenomenon of flow in a structure of suction (Suction tube, Inlet of suction muffler)
- In this research, calculated flow loss in suction muffler using CFD and DOE, and verified CFD results through a experiment.

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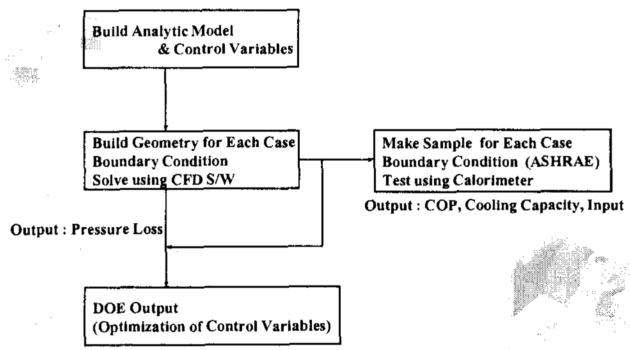
Introduction



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Selection of Control Factors

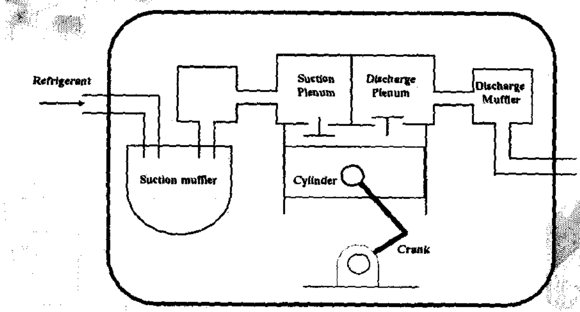
- Control factor is standard
  that is good and bad to evaluate special quality.

- In the suction muffler, control factor is *(In CFD's point of view)*
  Pressure Drop → Flow rate is fixed
  If this is small, it is good characteristic in efficiency of suction process.
  Flow Rate → Pressure is fixed
  If this is large, it is good characteristic

- The reduction of pressure loss is main issue in suction muffler design of a reciprocating compressor.
  In this study, we selected "pressure drop" as control factor.

Geometry of The Analytic Model

Figure 1: Schematic diagram of hermetic reciprocating compressor



Geometry of The Analytic Model

Table 1: Control variables and their levels

Control variables		A	B	C	D
		Section area of tube	Throat width	Tube length	Tube offset
Level	Hi	5.8 [mm^2]	7.7 [mm]	74 [mm]	1.0 [mm]
	Lo	5.5 [mm^2]	11.7 [mm]	70 [mm]	0.0 [mm]
Design		Full Factorial (Variable : 4, Level : 2)			

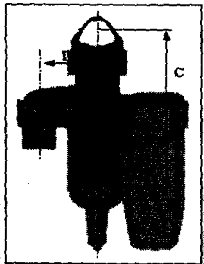


Figure 2: Geometry of the analytic model and control variables

Govern Equation

In this research, we supposed that suction muffler's flow is *incompressible*, *3-dimensional turbulent flows.*

Continuity Equation

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = S_m \qquad \text{------------ (1)}$$

Momentum Conservation Equation

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j} + \rho g_i = F_i \qquad \text{------ (2)}$$

$$\tau_{ij} = \left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] - \frac{2}{3}\mu\frac{\partial u_l}{\partial x_l}\delta_{ij}$$

Govern Equation

We tried approximative method to solve answer. Standardized momentum equation is used in most engineering problems, because we need equalized value.

Energy Conservation Equation

$$\frac{\partial}{\partial t}(\rho E) + \frac{\partial}{\partial x_i}(u_i(\rho E + p))$$
$$= \frac{\partial}{\partial x_i}\left(k_{eff}\frac{\partial T}{\partial x_i} - \sum_j h_j J_j + u_j(\tau_{ij})_{eff}\right) + S_h \quad \text{------------ (3)}$$

Transport Equation for Standard k-e model

$$\rho\frac{Dk}{Dt} = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right] + G_k + G_b - \rho\varepsilon - Y_M \quad \text{------------ (4)}$$
$$\rho\frac{D\varepsilon}{Dt} = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_i}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}(G_k + C_{3\varepsilon}G_b) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}$$

where $\mu_t = \rho C_\mu \frac{k^2}{\varepsilon}$, $C_{1\varepsilon} = 1.44$, $C_{2\varepsilon} = 1.92$, $C_\mu = 0.09$, $\sigma_k = 1.0$, $\sigma_\varepsilon = 1.3$

Boundary Conditions

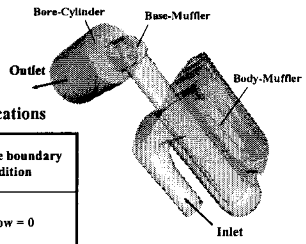


Table 2: Boundary conditions at the various locations

INLET (Suction muffler inlet)	$V_{in} = V_{ave}$	Flow rate boundary condition
OUTLET (Suction muffler base)	$P_{out} = 0Pa$	Inflow = 0
INTERIOR (Suction muffler interior)	$\frac{\partial T}{\partial t} = 0$	Incompressible flow 3-dimensional turbulent flow
Wall (Suction muffler's wall)	Porosity = 0, No-slip	Volume = 0

Calculation and Experimental Results

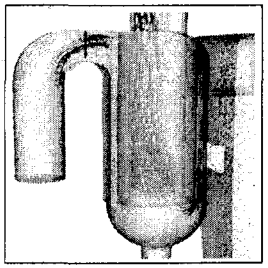


Figure 3 : CFD Result of Throat width (B) 7.68

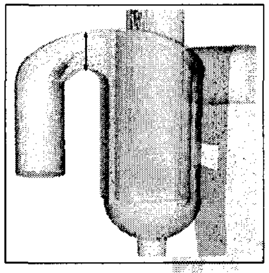
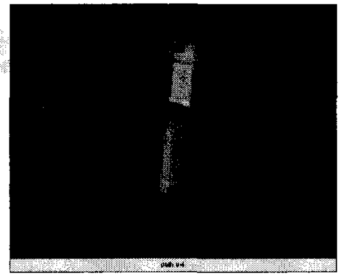


Figure 4 : CFD Result of Throat width (B) 11.68

Calculation and Experimental Results



Calculation and Experimental Results

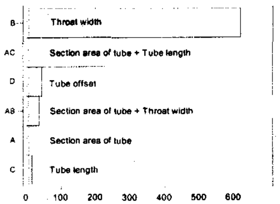


Figure 3: The standardized effects of control variables (Before Polling)

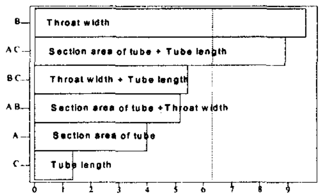


Figure 4: The standardized effects of control variables (After Polling)

Calculation and Experimental Results

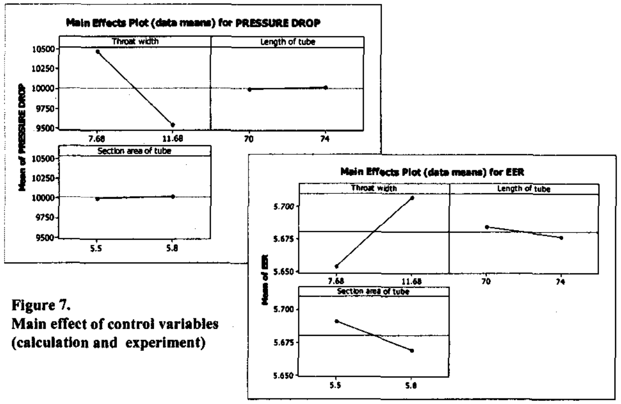


Figure 7.
Main effect of control variables (calculation and experiment)

Calculation and Experimental Results

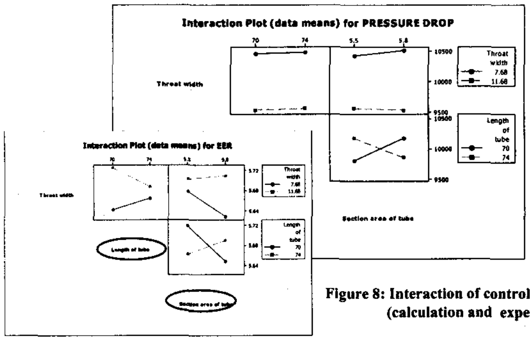


Figure 8: Interaction of control variable (calculation and experiment)

Conclusions

- To improve performance of reciprocating compressor, we did DOE using CFD about analytic model of suction muffler, and confirmed each main effect and interaction effect. And through an experiment, we could make sure of the control variables' effect.
- Actually, we applied results in design of the compressor, and got result that improve performance of compressor.
- At the process of noise control using suction muffler, we could consider correlation with performance and noise and achieved design optimization.