2022

Simulation technology of Oil circulation rate with Moving particle for Scroll Compressors

Tsutomu Nozaki

Kazuyuki Matsunaga

Simulation Technology of Evaluating Oil Circulation Rate with Particle Motion Analysis

Tsutomu NOZAKI[1]*, Kazuyuki MATSUNAGA[2]

[1]Center for Technology Innovation-Mechanical Engineering, Hitachi, Ltd.,
Hitachinaka-shi, Ibaraki, Japan
(Phone: +81-70-4209-3746, Fax: +81-29-353-3876, E-mail:tsutomu.nozaki.hq@hitachi.com)

[2]Compressor technology, Hitachi-Johnson Controls Air Conditioning, Inc.,
Minato-ku, Tokyo, Japan
(Phone: +81-70-1587-1861, E-mail: kazuyuki.matsunaga@jci-hitachi.com)

ABSTRACT

We developed an oil circulation rate (OCR) simulation technology with particle motion analysis that can quantitatively evaluate the influence of the shape and structure in the scroll compressors. It became clear that particle moving analysis was good for analyzing oil mist behavior. The analysis consists of three simulations. These simulations have three different injectors that define particles starting positions. The first one is at the discharge port of the fixed scroll, and another is on the oil pool in the bottom of scroll compressor. And the last injector is on the motor top, and these three simulations calculate number of particles that discharge out from the compressor to the cycle unit. The mechanism of the oil mist behavior inside the scroll compressor was clarified, and these simulations made it possible to be calculated mostly within ± 1wt% to the measured OCR in various model's case.

1. INTRODUCTION

In the global market of compressors for refrigeration and air-conditioning, demand for lower cost and wider operating range is increasing due to the expansion of the air-conditioning market and the energy efficiency evaluation based on partial load performance. To achieve lower cost, a more compact and lightweight compressor is directly effective, and to achieve a wider range, a compressor must be operated at higher speeds. High speed operation often causes oil circulation rate (hereinafter referred to as "OCR") deterioration. It is because oil mist is discharged from the discharge pipe into the refrigeration cycle due to increased flow velocity near the discharge pipe when the internal space of the compressor becomes smaller due to downsizing. Similarly, as the flow velocity near the discharge pipe increases due to high-speed operation, the OCR performance tends to deteriorate, resulting in lower heat transfer performance and higher-pressure loss in the refrigeration cycle. For this reason, compressor development must address these issues by understanding the flow conditions inside the compressor. The balancer, discharge tube, motor, and oil pool have a wide variety of shapes and they have positional relationships. To solve OCR problems, many evaluation periods are required.

The flow state inside a compressor has been elucidated by visualizing the interior of the compressor using a sight glass attached to the casing[1][2]. However, the center of the compressor is not visible and quantitative evaluation of the oil-mist mixture ratio is difficult. To address this issue, fluid analysis of compressor internals has also been conducted[3]. But for scroll compressors, for example, it is limited to analyzing the behavior of oil mist released from the discharge port of a fixed scroll and the detachment of oil mist from the liquid film.

In this study, complex phenomena inside a scroll compressor were clarified by particle analysis method, and the behavior of oil mist and OCR prediction method were investigated.

2. ANALYSIS METHOD

2.1 Compression Mechanism Structure and Refrigerant Flow in Compressor

Fig. 1 shows a scroll compressor for which refrigerant flow was simulated in this study. This scroll compressor requires balancer components that balance the centrifugal force exerted by the orbital scroll. The shape and position of the balancer, discharge pipe, motor, and oil reservoir have a significant influence on the OCR.

Fig. 2 shows the results of a steady-state fluid analysis of the single-phase refrigerant flow inside the compressor. The refrigerant discharged from the fixed scroll passes through the notched channel around the periphery of the fixed scroll and flows almost vertically downward toward the motor, then swirls as if caught in the rotation of the balancer. The balancer shape differs from compressor model to compressor model. In some models, it causes large shear forces, the refrigerant is stirred, and a stronger swirling flow is generated. Therefore, the velocity and turbulence intensity of the swirl flow have often been partially evaluated for the characteristics of the refrigerant flow caused by the balancer shape, but the entire flow state inside the compressor has not yet been clarified. In this report, we utilize simulation technology to elucidate the mechanism of the flow state inside a compressor and investigate how to improve the prediction accuracy of OCR by focusing on the process of oil mist accumulating in the balancer.

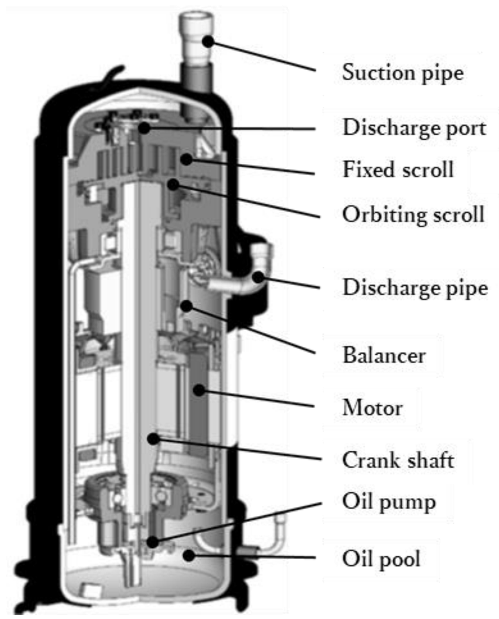


Fig. 1: Cross section of the scroll compressor

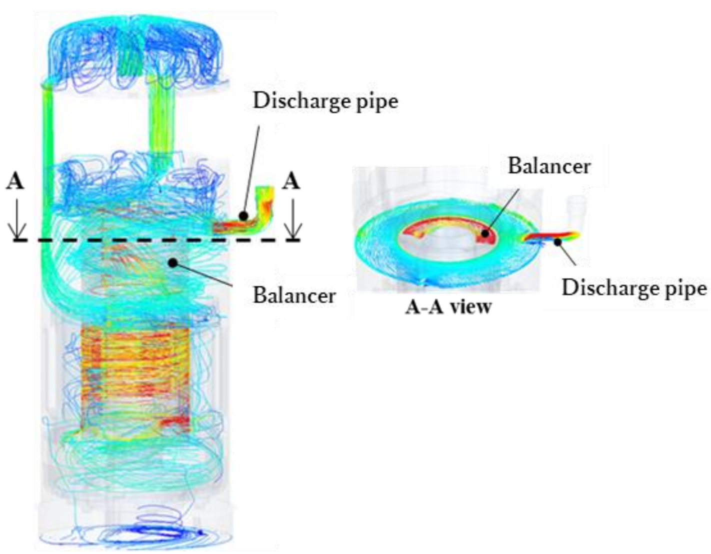


Fig. 2: Refrigerant flow in the scroll compressor at 130[rps]

2.2 Overview of Particle Analysis Methods

Oil mist behavior analysis is classified as multiphase flow analysis, which in this case is analysis of a system consisting mainly of discrete particles, droplets, and bubbles carried by a single continuous phase. In this study, we decided to conduct the analysis using a Lagrangian multiphase flow model, which is a particle method analysis. The analysis consists of two steps: a first step to calculate the continuous phase flow and a second step to calculate the dispersed phase on the continuous phase flow. In the analysis presented in this report, 5,000 parcels of oil mist were calculated at various locations in the compressor, treating oil mist as a group. The locations where parcels were placed in the particle analysis were selected where oil mist was generated in the compressor. Specifically, based on previous observations of a compressor with a sight glass. It was assumed that oil mist was generated at the top and bottom of the motor, and the discharge port of the fixed scroll was added to the other two locations where the parcels were installed. Each of the parcel trajectories was analyzed individually to evaluate the trajectory of the parcel. Table 1 shows the main boundary conditions used.

Table 1: Boundary conditions

Case	1	2	3
Injector position	Discharge port	Motor top	Oil pool
Number of parcels	5000	5000	5000
Oil mist diameter	8 micrometers	8 micrometers	8 micrometers

3. ANALYSIS RESULTS

3.1 Trajectory of oil mist leaving the discharge port of a fixed scroll

Fig. 3 shows the distribution of the arrival position of oil mist at the discharge port of a fixed scroll. The left side of the figure plots the arrival position in the compressor, and the right side shows the height distribution as a percentage. Focusing on the amount of oil mist that accumulates around the balancer, approximately 73% of the mist accumulates around the balancer, indicating that more than 70% of the oil mist accumulates around the balance weight.

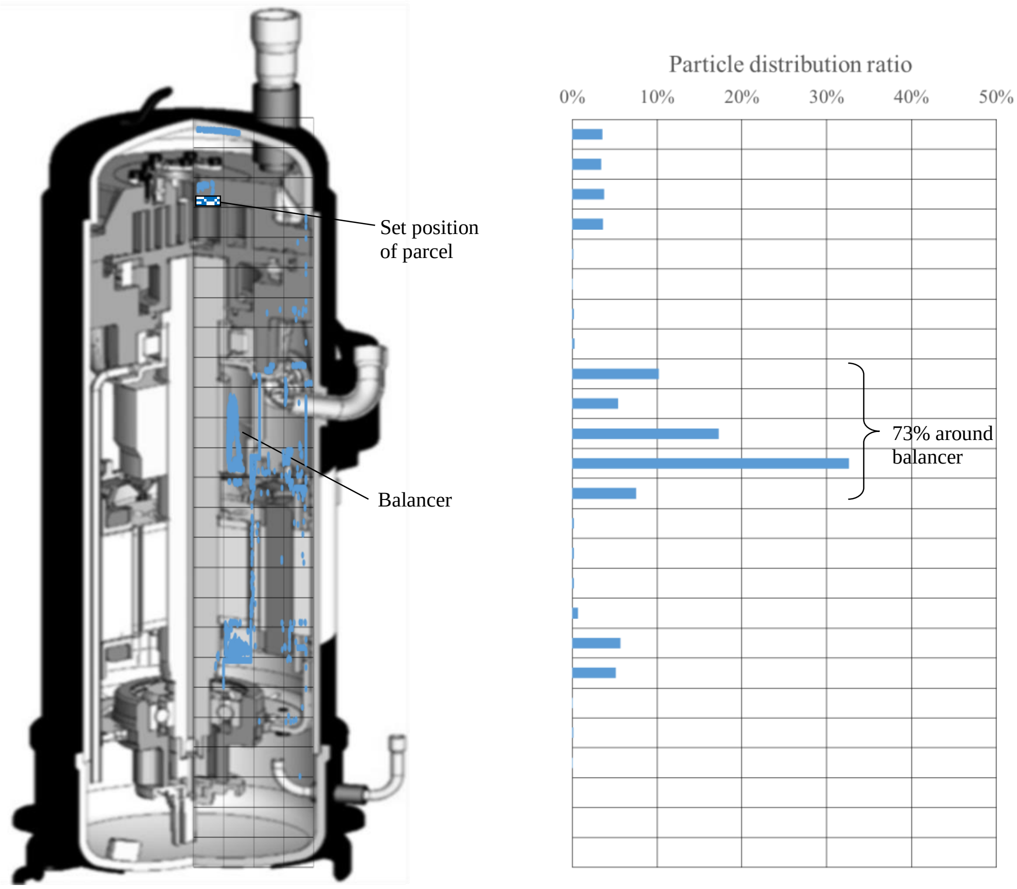


Fig. 3: Particle flow from the discharge port of the fixed scroll at 130[rps]

3.2 Trajectory of oil mist collected on top of motor

According to another experiment in which a sight glass was attached to a compressor to observe the internal conditions, a phenomenon was observed in which oil accumulated in the space above the motor during high-speed operation, generating a swirling flow. Since oil mist is likely to be generated by this swirling flow, an analysis was conducted for the case where oil mist was placed on the top surface of the motor.

Fig. 4 shows the distribution of the arrival position of oil mist on the top surface of the motor. The figure shows that the oil mist on the motor top surface can be roughly divided into two types: one that swirls in the motor upper space and the other that enters the motor lower space through the motor outer circumferential notch. It was found that more than 50% of the oil mist accumulated around the balance weight.

3.3 Trajectory of oil mist generated in the oil reservoir at the bottom of the compressor

Observations made inside the compressor in another experiment revealed that oil swirls violently in the lower part of the compressor as well as in the space above the motor during high-speed operation. Therefore, we analyzed the case of oil mist on the top surface of the oil pool at the bottom of the compressor to understand the phenomenon.

Fig. 5 shows the distribution of arrival positions of oil mist on the upper surface of the oil reservoir. The figure shows that most of the oil mist stays in the space below the motor, but a small portion accumulates near the balancer. Although the percentage of oil mist that accumulates near the balancer is as small as about 1%, it may increase to a non-negligible figure if the amount of oil mist generated itself is large.

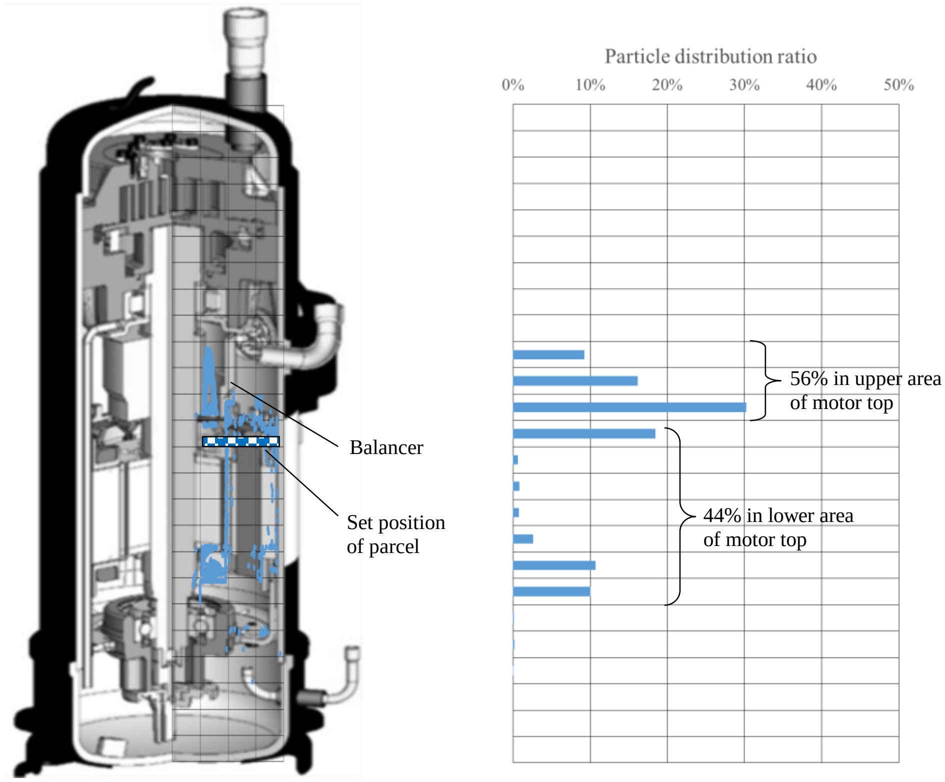


Fig. 4: Particle flow from the motor top at 130[rps]

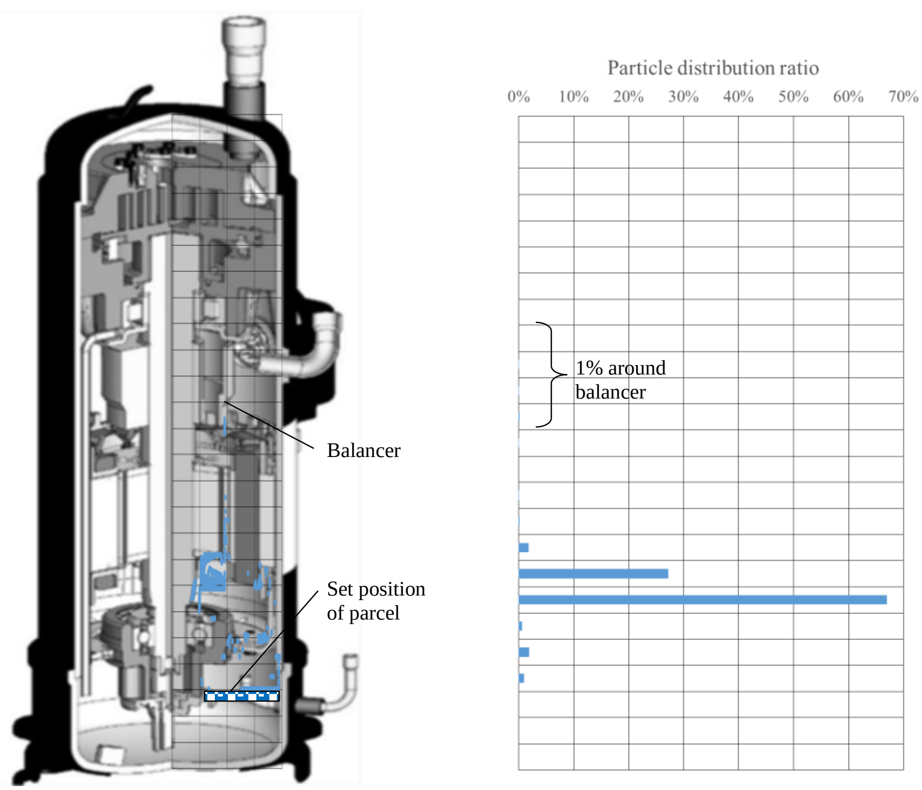


Fig. 5: Particle flow from the oil pool in the bottom of the scroll compressor at 130[rps]

4. INVESTIGATION OF OCR MECHANISM AND PREDICTION

Based on the analysis results of the trajectory of oil mist leaving the discharge port of the fixed scroll, the trajectory of oil mist accumulating on the top surface of the motor, and the trajectory of oil mist generated in the oil pool at the bottom of the compressor, the behavior of oil mist in the compressor can be summarized as shown in Fig. 6. Tracing back the flow of oil mist from the discharge pipe side, the oil discharged from the discharge pipe into the refrigeration cycle is generated from the oil accumulated on the top surface of the motor. The oil that accumulates on the top surface of the motor is generated by oil mist that accumulates near the balancer and is supplied from two locations: the discharge port of the fixed scroll and the oil reservoir at the bottom of the compressor.
If the oil mist flow is shown in Fig. 6, the OCR can be estimated by the following equation.

$$OCR = A \times R_2(B \times R_1 + C \times R_3) \tag{1}$$

where R_1 is the ratio of oil mist discharged from the fixed scroll discharge port that accumulates near the balancer, R_2 is the ratio of oil accumulated on the motor top surface that is discharged into the cycle pipe, R_3 is the ratio of oil mist discharged from the oil pool that accumulates near the balancer, and A, B, and C are the coefficients.
Fig. 7 summarizes the calculated and measured OCR values for various models, with the horizontal axis representing the calculated OCR value estimated from Eq. (1) and the vertical axis representing the measured OCR value. The models evaluated were different in terms of compressor length, compression stroke volume, motor core diameter, motor geometry, balancer geometry, and other structures under various operating conditions, such as rotation speed and operating pressure. The black circles in the figure indicate models that were able to predict within ±1 wt% accuracy of the measured OCR values, while the white circles indicate models that fell outside the ±1 wt% accuracy range. As shown in the figure, OCR estimation using particle method analysis can predict OCR within ±1wt% of the measured value for 80% of the models. On the other hand, the remaining 20% is strongly influenced by phenomena that are not captured by the present particle method analysis approach.
One phenomenon that was not considered in this study is the case where the distribution of oil mist differs depending on the angle of rotation, as shown in Table 2. In this case, the amount of oil mist accumulated around the balance weight and the amount of oil mist entering the discharge pipe vary with the rotation angle as shown in Table 3. Therefore, the prediction accuracy of OCR may be improved if the rotational angle is evaluated by changing the rotational angle finely.

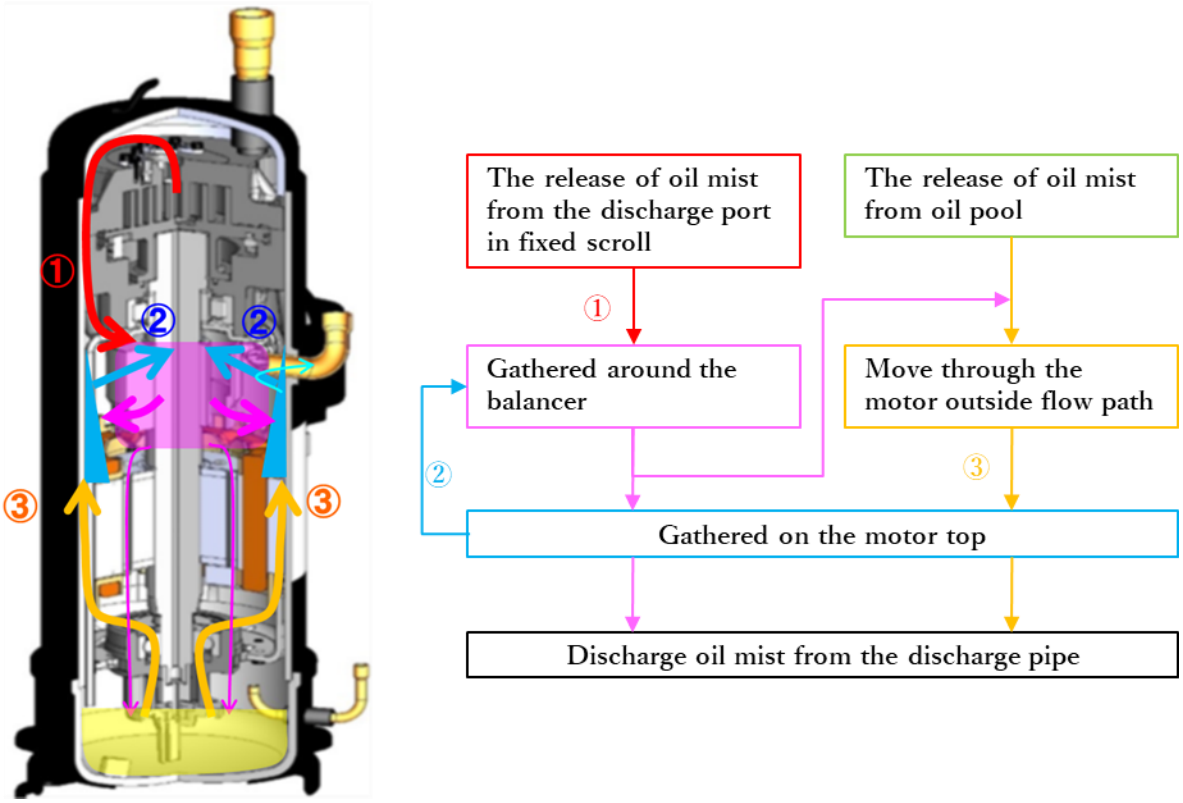


Fig. 6: Mechanism of Oil mist behavior in the scroll compressor

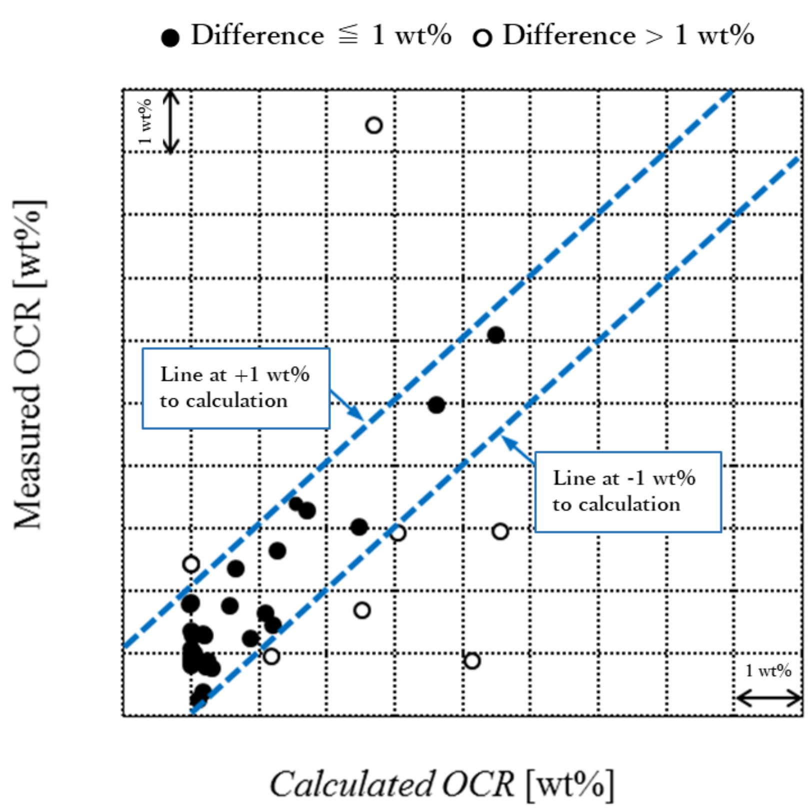
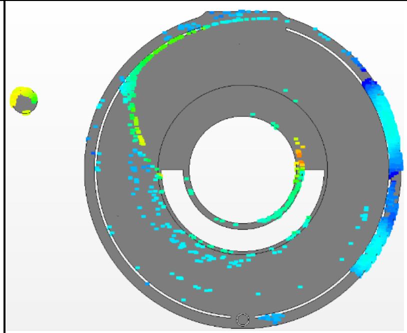
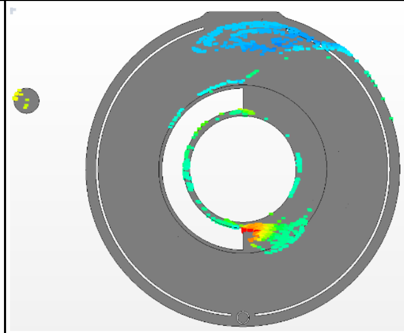
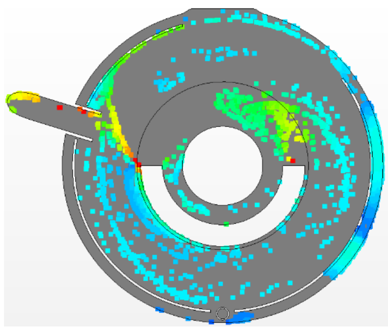
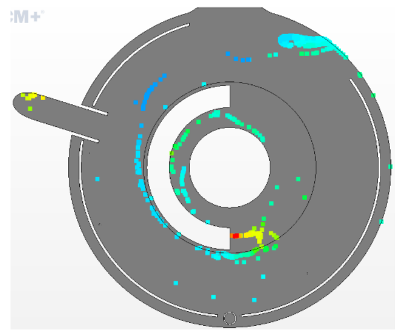
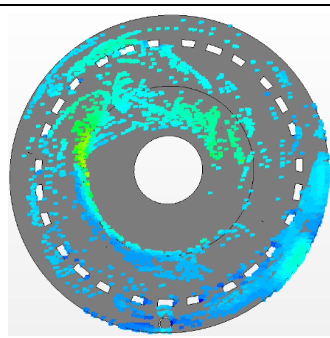
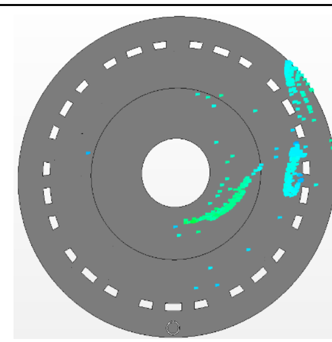
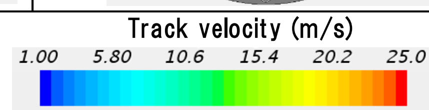


Fig. 7: Relationship between Measured and Calculated OCR

Table 2: Difference in Particle Flow due to Different of Balance Weight Positions

Cross section \ Rotation angle	0°	90°
Discharge pipe + 20 mm		
Discharge pipe		
Disdharge pipe - 20 mm		



The above study revealed that the flow of oil mist in a compressor can be explained as shown in Fig. 6. It was found that OCR could be predicted with an accuracy within ±1 wt% by using particle analysis to solve for three phenomena: the trajectory of oil mist leaving the discharge port of the fixed scroll, the trajectory of oil mist accumulating on the top surface of the motor, and the trajectory of oil mist generated in the oil reservoir at the bottom of the compressor.

Table 3: Difference in Analysis Results due to Different of Balance Weight Positions

Rotation Angle	0	90	180	270
D-Port to B.W.	0.00%	31.64%	15.21%	22.76%
D-Port to Dis-Pipe	2.58%	3.26%	4.48%	1.83%
Motor to Dis-Pipe	4.14%	9.68%	9.04%	2.62%

6. CONCLUSIONS

To understand the behavior of oil mist inside a compressor and to establish a method for predicting OCR, the following conclusions were obtained from analysis using particle method analysis with three initial locations of oil mist: fixed scroll discharge port, motor top surface, and oil reservoir.

- The oil discharged from the compressor into the cycle piping is part of the oil mist generated from the oil agitated in the space above the motor. The oil that accumulates on the top surface of the motor is generated by oil mist that accumulates near the balancer, which is supplied from two locations: the discharge port of the fixed scroll and the oil reservoir at the bottom of the compressor.
- By developing an OCR prediction method using particle method analysis, we were able to calculate OCR within ±1wt% of the measured value in 80% of the model cases.
- To further improve the accuracy of OCR prediction, there are phenomena that are not captured by the current particle method analysis approach, and a more detailed analysis that considers the effect of the angular position of rotating bodies such as balancers and reflects unsteady refrigerant flow is an issue for future improvement.

REFERENCES

[1] Yong-Jae Kim et. Al. (2004). Experimental Study of Refrigerant-oil Behavior inside Rotary Compressor. *International Compressor Engineering Conference at Purdue*. C046
[2] Toshiyuki Toyama et. al. (2006). Visual Techniques to Quantity Behavior of Oil Droplets in a Scroll Compressor. *International Compressor Engineering Conference at Purdue*, C026
[3] Toshihiro Suzuki et. al. (2006). Numerical Analysis of Refrigerant Flow in Housing Case of Scroll Compressors. *International Compressor Engineering Conference at Purdue*, C099
[4] Hirofumi Yoshida et. al. (2016). Fundamental Study on Oil Mist Separation in Swirl Flow. *JRAIA International Symposium 2016,* JRAIA2016KOBE-0202