# Numerical Simulations of the Flow Field in a Vacuum Chamber for the Drying Test Equipment of Spent Fuel

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## 1. Introduction

Drying equipment is being developed for the dry storage of spent fuel. There are two types of drying system, vacuum and forced helium drying [1]. The vacuum drying process depends on the reduced pressure to evaporate moisture from the spent fuel cask. CFD analyses were performed to simulate the flow field in a vacuum chamber for the drying test equipment.

## 2. Flow Field for Vacuum Analysis

At a low pressure such as a vacuum chamber, the gas behaves differently from standard conditions. To distinguish the flow regimes, the Knudsen number($K_n$) is defined as follows.

$$k_n = \frac{\lambda}{L} \quad (1)$$

$$\lambda = \frac{k_B T}{\sqrt{2}\pi d^2 P} \quad (2)$$

Where,

λ : mean free path [m]
L : characteristic length of chamber [m]
$K_B$ : Boltzmann's constant [J/K]
T : temperature [K]
P : pressure [Pa]
d : diameter of molecule [m]

Based on the Knudsen number, the kinetic gas flow can be classed into three regimes[2].

- Viscous flow : Kn < 0.01
- Transient flow : 0.01 < Kn < 1
- Free molecular flow : Kn > 1

Table 1 shows some typical values for air at different pressures of room temperature [3]. $K_n$ is calculated with the mean free path and the chamber length of 0.5 m.

The pressure of the vacuum chamber is expected to be within about 400 Pa(3 Torr). In this low vacuum pressure, the $K_n$ is estimated to be about 2.0E-04. Therefore, the viscous flow can be applied for the CFD analysis of the vacuum chamber.

Table 1. Mean free path and Knudsen numbers

| Vacuum rage | Absolute P.(Pa) | Mean free path(m) | Knudsen number($K_n$) |
|---|---|---|---|
| Atmosphere | 1.0E+05 | 6.8E-08 | 1.4E-07 |
| Low Vacuum | 1.0E+04 | 2.5E-07 | 5.0E-07 |
| | 1.0E+02 | 1.0E-04 | 2.0E-04 |
| Medium Vacuum | 1.0E+01 | 1.0E-03 | 2.0E-03 |
| | 1.0E+00 | 1.0E-02 | 2.0E-02 |
| High Vacuum | 1.0E-02 | 1.0E+00 | 2.0E+00 |
| | 1.0E-03 | 1.0E+01 | 2.0E+01 |

## 3. Flow Analysis Model

Three dimensional CFD analysis model was constructed for a vacuum chamber as shown in Fig. 1. The outer diameter and internal length of the chamber are 406 mm, 500 mm, respectively. The internal volume of the chamber is 51.8 liter.

W2V60 vacuum rotary vane pump is connected to the suction port of the canister. The pumping speed is 600 liter/min. The suction port of the pump is NW 40 with inner diameter of 32 mm. The velocity at the suction port is calculated with 12.4 m/s in the atmospheric pressure. Fig. 2 shows the performance curve for the vacuum pump. The pumping speed is rapidly decreasing as the pressure drops below 1.0E-03 Pa.

Velocity inlet boundary condition is considered in the suction port. Velocities in the port are considered with constant value of 12.4 m/s and P-V(Pressure-Velocity) curve utilizing Fluent's User Defined Functions(UDF). The P-V curve is obtained from the pump's performance curve.

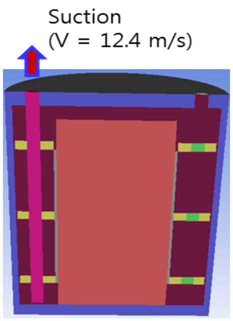


Fig. 1. CFD model.

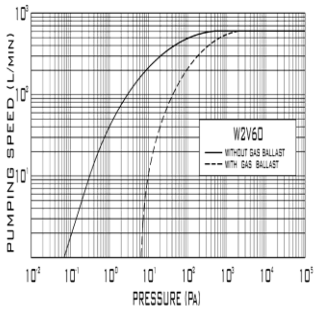


Fig. 2. Performance curve.

## 4. Results and Discussion

CFD analyses for the vacuum chamber were performed under the evacuation velocities at the constant and P-V curve. Fig. 3 shows the pressure and velocity distributions in the chamber according to the evacuation time. Fig. 4 shows the pressure and density contours for the P-V curve velocity condition.

At the constant velocity condition, the internal pressure dropped more rapidly than the P-V curve velocity condition. As the internal pressure decreases, the performance of the vacuum pump decreases and velocity also decreases. Therefore, P-V curve velocity should be considered to for the vacuum process.

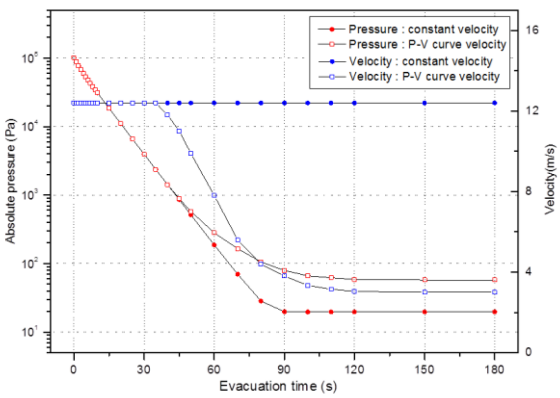


Fig. 3. Pressure and velocity distributions.

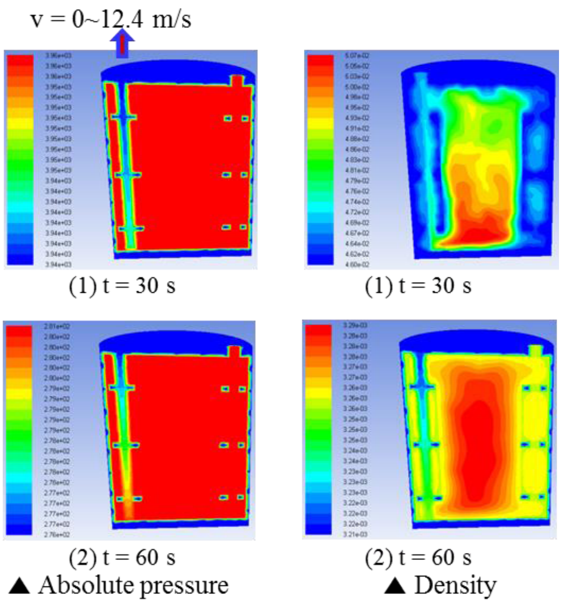


Fig. 4. Pressure and density contours.

## 5. Conclusion

The Knudsen number was estimated to distinguish the flow state for the vacuum chamber, and the viscous flow can be applied for the CFD analysis. The internal pressure dropped more rapidly at the constant velocity than the P-V curve velocity. The results of this study can be used as the basic data for the design and test of the vacuum drying equipment.

## REFERENCES

[1] ASTM C-1553-16, “Standard Guide for Drying Behavior of Spent Nuclear Fuel, ASTM, 2016.

[2] Oerlikon Leybold Vacuum, Fundamentals of vacuum technology, 2007.

[3] Brunglinghaus, Marion, “Mean free path”, European Nuclear Society, Retrieved 2011.11.8.