International Journal of Advanced Smart Convergence Vol.11 No.4 88-95 (2022)
http://dx.doi.org/10.7236/IJASC.2022.11.4.88

IJASC 22-4-10

Simulation of High Vacuum Characteristics by VacTran Simulator

Hyung-Taek Kim* and Hyeongwon Jeong

** Professor, Department of Advanced Materials Engineering, Incheon National University, Incheon, Korea*
Graduate School, Department of Advanced Materials Engineering, Incheon National University, Incheon, Korea
***E-mail:** kim95118@inu.ac.kr, hkjung310@gmail.com*

Abstract

Vacuum simulation is associated with the prediction and calculation of how materials, pumps and systems will perform using mathematical equations. In this investigation, three different high vacuum systems were simulated and estimated with each vacuum characteristics by VacTran simulator. In each of modelled vacuum systems, selection of gas loads into vessel, combination of rough and high vacuum pumps and dimension of conductance elements were proposed as system variables. In pump station model, the pumping speed to pressures by the combination of root pump was analyzed under the variations of vessel volume. In this study, the effects of outgassing dependent on vessel materials was also simulated and aluminum vessel was estimated to optimum materials. It was obtained from the modelling with diffusion pump that the diameter, length of 50×250[mm] roughing line was characterized as optimum variables to reach the ultimate pressure of 10E-7[torr]. Optimum design factors for vacuum characteristics of modelled vacuum system were achieved by VacTran simulator. Feasibility of VacTran as vacuum simulator was verified and applications of VacTran in high tech process expected to be increased.

Keywords: *VacTran, Vacuum Simulator, Vacuum System Modelling, Vacuum Characteristics, Simulation*

1. INTRODUCTION

Engineering simulation is a productive estimation by allowing mathematical values to be calculated and then employed to predict and describe how a practical system and a process will perform. Vacuum simulation could predict the how systems will perform using mathematical equations when to do so using other means are impractical and costly. Modern vacuum systems in high tech process require highly developed components operating within exacting parameters, especially at the high or ultra-high end of the vacuum spectrums. In such circumstances, the vacuum components employed need to be precisely matched. Using special simulation

Manuscript Received: October. 9, 2022 / Revised: October. 12, 2022 / Accepted: October. 14, 2022
Corresponding Author: kim95118@inu.ac.kr
Tel: +82-32-835-8274, Fax: +82-32-835-0778
Professor, Department of Advanced Materials Engineering, College of Engineering, Incheon National University, Incheon, Korea

Copyright© 2022 by The Institute of Internet, Broadcasting and Communication. This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (http://creativecommons.org/licenses/by-nc/4.0)

software with the data provided by vacuum pump manufacturers(which allowed as input performance parameters), the overall operational performance details of vacuum system obtained. This could provide the matched components and systems for optimum operating performances, which result to produce tailor-made vacuum solutions. VacTran is designed to aid the vacuum engineer in the modeling of vacuum systems and enabling rapid predictions of vacuum system operational performance and design alternatives [1, 2]. Therefore, to achieve the ultimate vacuum and maintain the high quality vacuum consistently, simulation of vacuum characteristics in modelled vacuum systems would be effective, efficient and helpful to optimize the performances of vacuum system [3]. In this study, one of the commercial vacuum simulators, VacTran, was introduced to evaluate the feasibility of vacuum simulations based on the various modelling factors provided by VacTran.

Different vacuum systems were simulated and analyzed of each vacuum characteristics by VacTran modelling. In each of modelled vacuum systems, selection of vessel materials, combination of rough-high vacuum pumps and dimension of conductance elements(diameter and length) were proposed as system variables. In each modelling, the pump down times to ultimate pressures of different vessel materials(stainless steel, aluminum) was analyzed by the variations of vessel shapes and dimensions. In this model, the effects of permeation dependent on the materials was also simulated, and the cylindrical vessel was estimated to be the optimum vessel shape. It was also obtained that modelling of diffusion pump and diameter, length of 50×250[mm] roughing line was characterized as optimum variables to reach the ultimate pressure of 10E-7[torr]. Optimum design factors for vacuum characteristics of modelled vacuum system were achieved by VacTran simulations. By comparison of the simulation results, the feasibility of VacTran as vacuum simulator in high vacuum process was verified.

2. SIMULATIONS

2.1 VacTran (ver. 3.48) simulator

The VacTran startup screen contains a menu bar, a tool bar, two permanent windows for displaying text and graphs, and two floating palettes for inserting conductance and gas load elements into models [4, 5]. The overall control platform of VacTran is illustrated in figure 1. The main graph window and the main text window are permanently visible. These are used in almost all modellings of VacTran for displaying calculated data from simulation. Each time a curve is generated, it will be displayed in the main graph window. The corresponding data, which went into the graph, will be simultaneously shown in the main text window as shown in figure 2. The text updating can be shut off to speed up calculations. All calculations that update either the graph or text window will clear the previous contents, but text and graphs can be saved first. Basic goal of vacuum system for high tech. process is to remove an initial gas volume from a vacuum vessel, faster than new gas enters, to achieve a target pressure in a required time period. The other goal is to remove gas from a vacuum vessel at a rate equal to the rate it enters, maintaining an operating pressure that is acceptable to the vacuum process. Once the basic phenomena that affect vacuum systems, and the governing equations that help predict performance were understood, vacuum system design could be looked fairly reasonable. VacTran has been designed to mathematically simulate these situations, forming the basis of sizing vacuum pumping systems. The minimum system model of VacTran has a vessel, a pump, and a conductance path between the pump and the vessel. The basic flow diagram of this concept illustrated in figure 3 and 4. With the pump operating and valves open, gas will flow from the vessel, through the conductance, through the pump, and finally to the atmosphere. VacTran associates specific information with the vacuum vessel, such as its volume and type of gas being pumped (figure 5). The pump contains a performance curve representing pumping speed at different pressures. And, the conductance path can consist of various types of flow elements such as pipes, elbows, and orifices. Calculations based on systems with no gas load are ideal systems, for which pump down time is calculated using only the initial volume in the vacuum vessel. This volume is constant, making pump down time straightforward calculation. When “real” pump down time is calculated (with a gas load), the total volume being pumped will include the vacuum vessel plus additional process gas sources which may vary over time.

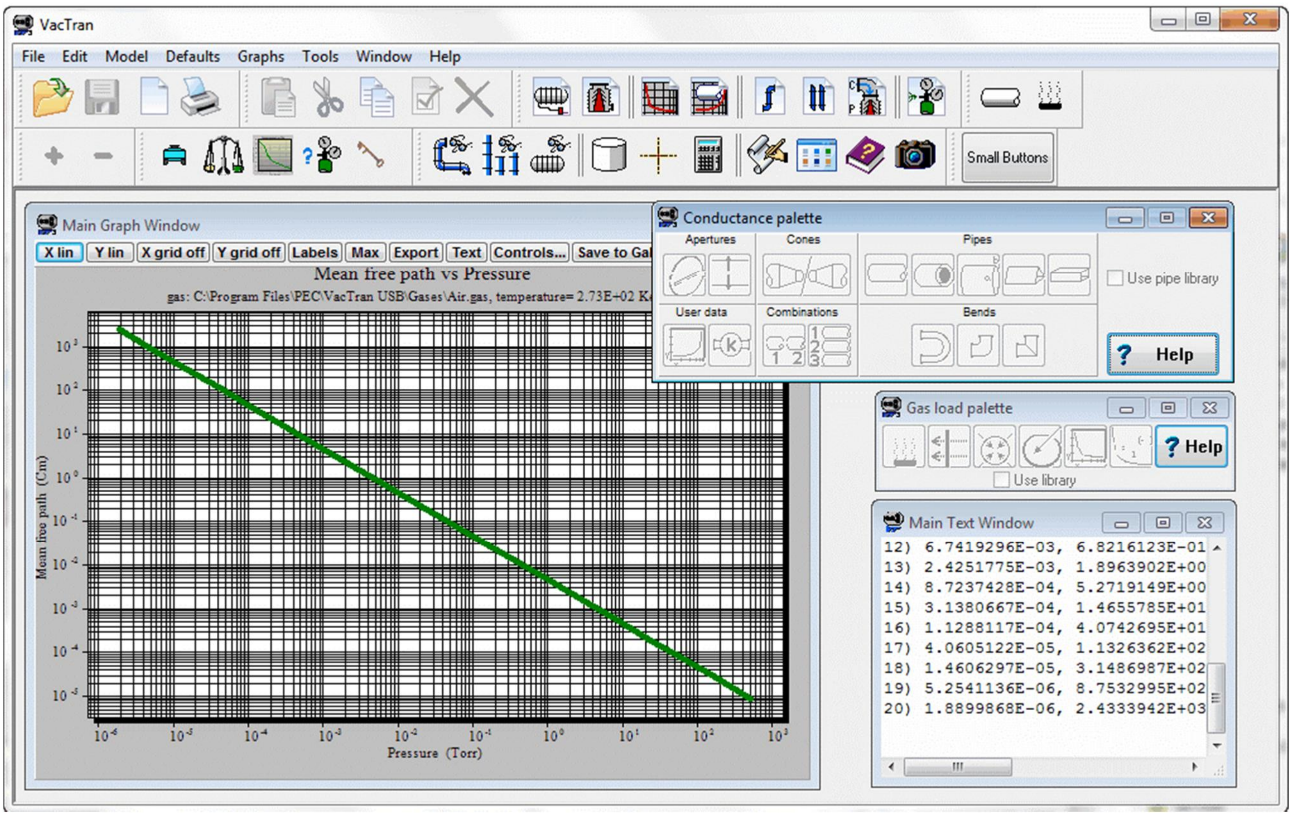

Figure 1. Overall startup platform of VacTran

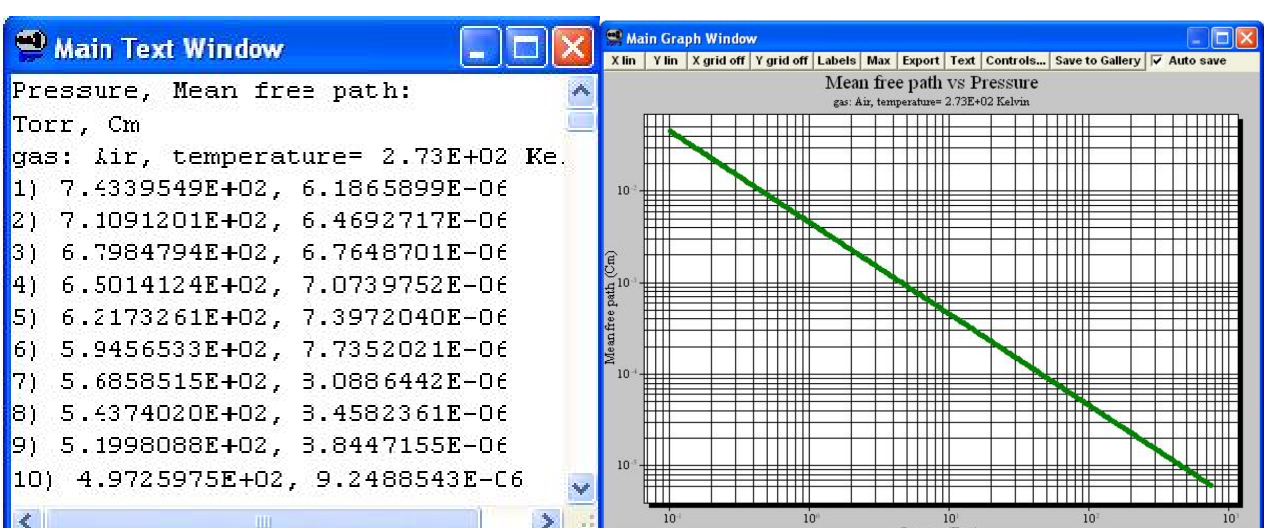

Figure 2. Calculated text data and generated graphic curve of VacTran

Since this total volume is variable, prediction of pump down time is somewhat more complicated. In this study, the modelling with the working gas loads employed for the application of real system. Each panel was available for users to simulate certain vacuum conditions [6,7]. If the model and variables were chosen among the list of panel, the chosen variable is shown on the separate dialogue window. Figure 4 and 5 showed selected variables of vessel volume, dimension of conductance element and pumping speed of employed pump station.

.

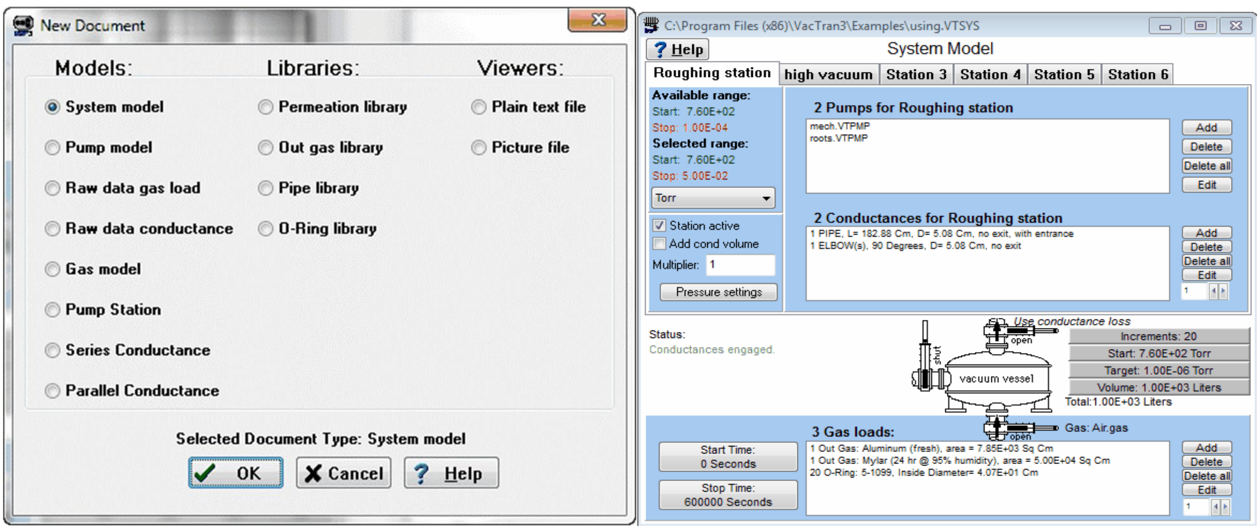

Figure 3. Schematic diagram of system modelling of VacTran

With setting up of all the specific system variables, the simulation result would be illustrated as a form of curved graph of the performance curve of modelled vacuum system (figure 6). VacTran provide at least fifteen different performance curves as simulation results. And, the result data could be achieved both as a curved graph or text file so that more specific information could be acquired. Powerful analysis functions were available as soon as simulation variable was entered into a VacTran system model. Furthermore, extra variables could be edited for each dialog window. Therefore, high expandability and practicality of VacTran as vacuum simulator was verified.

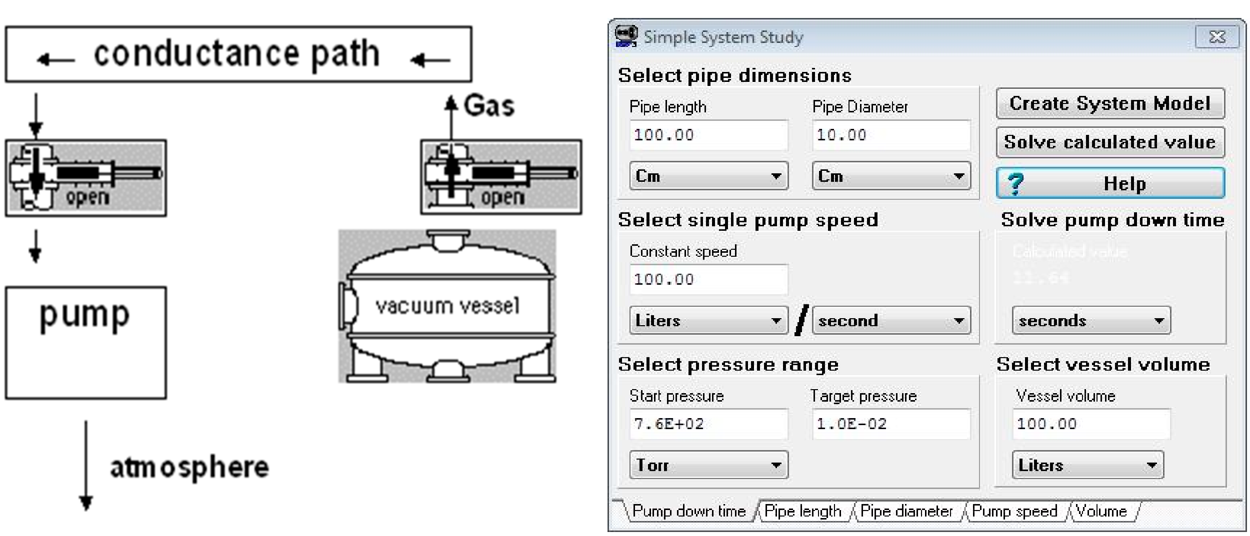

Figure 4. Modelling of vacuum system and variables in pump station of VacTran

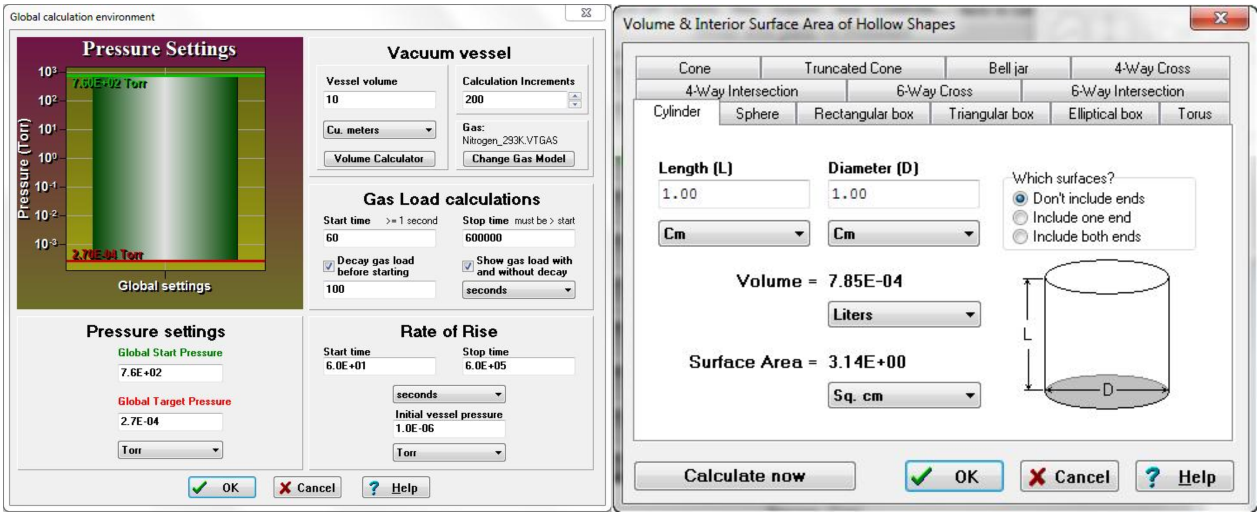

Figure 5. Control window of system variables of VacTran

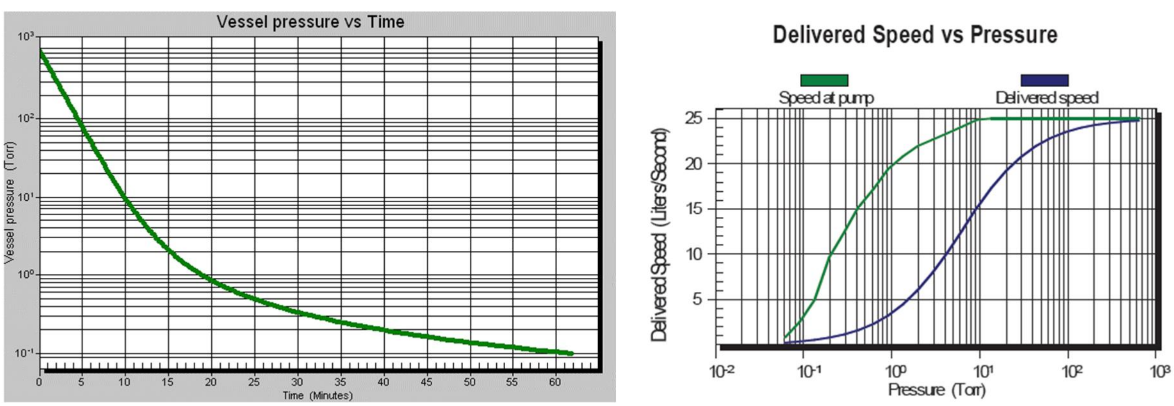

Figure 6. Performance curves of modelled vacuum system by VacTran

2.2 Simulation modeling

High vacuum system were modelled to estimate the time to reach 10E-7[$torr$]. For each model, as indicated in Table.1, three variables were chosen as system variables of proposed high vacuum system. If there's no additional mention, fixed variables (stainless steel-cylindrical-65.4[l] (volume of chamber) -vane pump- 50 and 500[mm] with roughing pipe's diameter and length- 90° elbow standard radius for bend- HiPace 1500 (TMP)) were used for simulation. By comparing time to reach ultimate pressure (10E-7[$torr$]), optimum design factor was achieved through the suggested high vacuum system.

Table 1. Proposed simulation modelling

(a)

Model No	Chamber shape	Chamber material	Diameter[mm]	Height[mm]	Volume[l]	Surface Area [$sq.cm$]
			500	333	65.4	7194
		Stainless steel				
1	Cylindrical		630	420	130.8	11430
		Aluminum				
			700	510	196.2	15063

(b)

Model No	Chamber shape	Chamber material	Roughing pump	High vacuum pump
2	Cylindrical	Stainless steel	Vane Vane with Roots	TMP Cryo-pump Diffusion pump

2.2.1 Simulation of vessel material

In this high vacuum model, different vessel materials in the vessel window, pumping time to ultimate pressure(10E-7[$torr$]) of stainless steel vessel was measured with aluminum vessel. Rather than comparing single volume, three volumes (65.4, 130.8, 196.2[l]) were compared for the higher reliability. Also, for vessel shape as cylindrical was employed as fixed variable in each simulation.

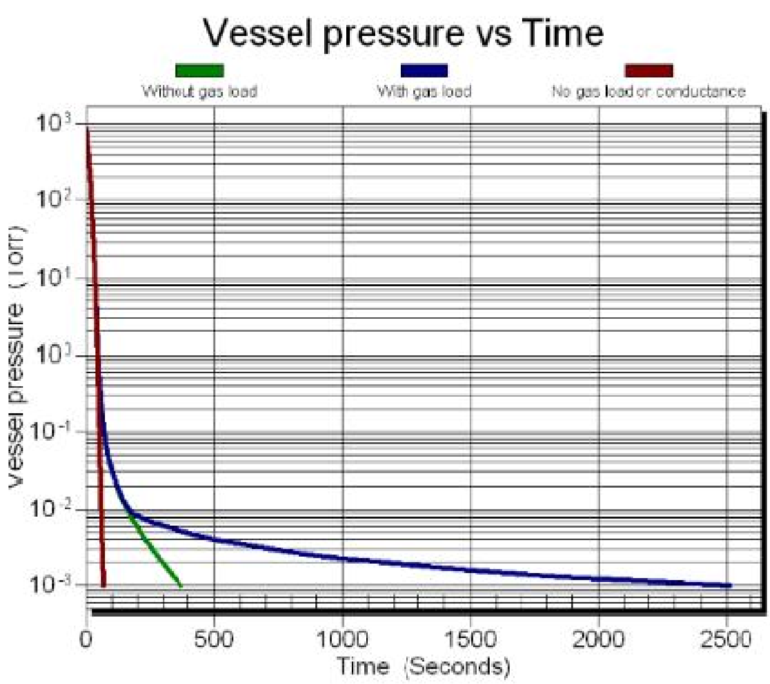

Figure 7. Pumping down time to roughing range with and without gas load

Table 2. Pumping times of stainless steel and aluminum vessel

Pressure [$torr$] / Time[s]	5.0E-05		1.0E-05		5.0E-06		1.1E-06	
	St	Al	St	Al	St	Al	St	Al
V = 65.4 [l]	22	1	200	15	400	30	2000	150
V = 130.8 [l]	35	3	350	24	700	45	3500	250
V = 196.2 [l]	45	4	450	30	900	60	4500	300

Figure 7 showed the effects of gas loads on pumping down characteristics of vacuum vessel with 196.2[l] volume from atmospheric to 1E-3[$torr$] roughing range. It was estimated that the gas load could be more significant factor to affect pumping time to reach the ultimate pressure for process than expected. With gas load model, it took almost five times longer (2500[s]) to reach 1E-3[$torr$] than that of without gas load model. Table 2 showed the pumping time of stainless steel and aluminum as a vessel material. In stainless-steel, rapid fall of pressure was found between 1E-5 and 1E-6[$torr$](about 600[s] in time). After that, the pressure change was stabilized quickly. In another case, similar drop occurred until 9E-7[$torr$]. In the smallest vessel size, the difference in pumping time to 1.1E-06[$torr$] between two different vessel materials was about 13 times. The difference became higher as the volume get larger. It was 14 and 15 times for 130.8[l] and 196.2[l] each. As the volume of vessel got larger, not only pumping time but also the difference of pumping time between two vessel got higher. Therefore, it was demonstrated that influence of outgassing became more dominant factor in larger volume of vessel.

2.2.2 Simulation of pump combination

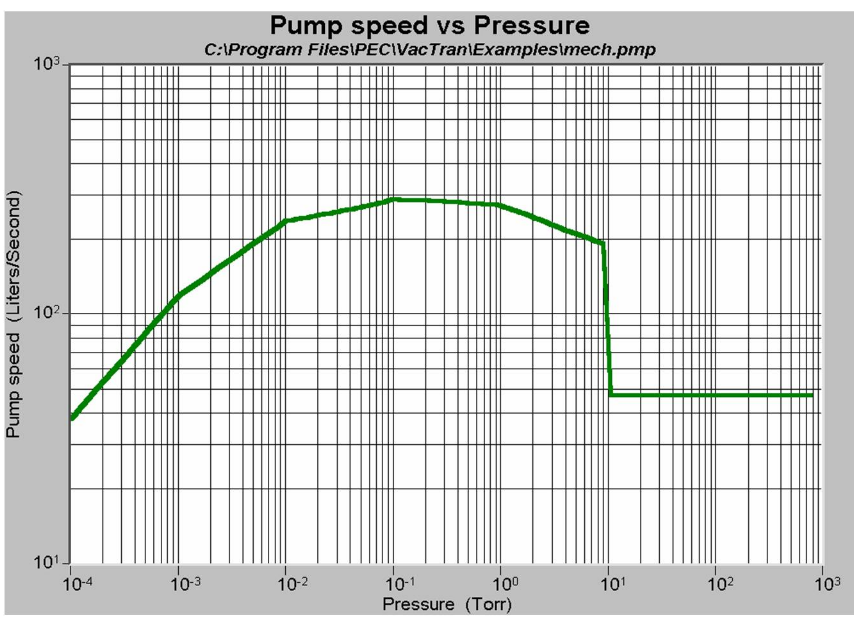

Figure 8. Pumping characteristics with vane and roots pump combination by VacTran

In modeling of pump combination, comparisons of pumping speed and ultimate pressure that were changed according to pump combination were simulated. The simulation pump types such as vane pump, TMP, diffusion pump, and cryo-pump which were employed in this high vacuum system were typically used in semiconductor processing. As showed in Figure 8, the difference of pumping time at 1E-2[$torr$] was about 100[s] which mean that roots with vane pump performed more efficiently. The difference became so huge below 1E-2[$torr$] that vane with roots pump had to be considered in that pressure range. And next, it was also simulated to compare performance between TMP, cryo-pump and diffusion pump. Thus, usability of VacTran was confirmed to reach ultimate pressure more efficiently.

3. CONCLUSION

In order to investigate the feasibility and applicability of the simulator VacTran, high vacuum systems were modelled and simulated by VacTran. Optimum simulation results which were obtained after numerous repetitive simulations were illustrated in the figures and tables. Three optimum design factors were obtained from the simulations as follows. Due to low outgassing effect, aluminum vessel was highly superior to stainless steel vessel in pumping time for 1E-7$[torr]$. As the optimum pump combination, vane with roots pump and diffusion pump was verified to be the highest in pumping speed. It had to be considered that because of lower ultimate pressure of cryo-pump, it should be employed below 1E-7$[torr]$ range. Shorter length and larger diameter of roughing line was demonstrated to be optimum factors from conductance modelling. The diameter of the roughing line was verified to increase conductance more effectively compare to the length of roughing pipes. These results of overall vacuum characteristics made high reliability of VacTran. As the applications of vacuum technology become larger and more important particularly in semiconductor industry, more fore-studies based on the results of this simulator are expected to be conducted. Therefore, the possibility of utilization of VacTran for the simulation of high or ultra-high vacuum system was verified. Comparison of the simulated vacuum characteristics between commercial vacuum simulators could be suggested as the future study developing this topic.

Acknowledgement

This work was supported by the Incheon National University Intra-Research Grant in 2020.

References

[1] Professional Engineering Computations, VacTran Operation Manual (window version 3.0), *http:// www.vactran.com,* 2016

[2] Vacuum Science World, An Introduction to Vacuum Simulation, *http://www.vacuumscienceworld.com,* 2018

[3] PEC, Vacuum Technology Software, *http:// www.vactran.com,* 2016.

[4] Vacuum Engineering & Simulation Software, VECOR, *http://www.vecorus.com,* 2014

[5] Technology Sources Ltd., User's Guide of VacSim$^{(Multi)}$ Simulator, *http://www.softsim.com,* 2001.

[6] Vecor, Vacuum Engineering and Simulation Software, VacCAD 1.0^{TM} Operation Manual, *http://www.vecor.com,* 2014

[7] Andrew Guthrie, Vacuum technology, John Wiley and Sons, pp. 135, 2008