Experimental campaign to test the capability of STARDUST-Upgrade diagnostics to investigate LOVA and LOCA conditions

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1 INTRODUCTION

An important issue related to nuclear fusion reactors is dust produced by PMIs (Plasma-Material Interactions). Dust is capable of being re-suspended in case of LOVAs (Loss of Vacuum Accidents) and LOCAs (Loss of Coolant Accident) and can cause serious hazard to the health of the operators (since particles are radioactive and of breathable size) and can cause explosions.

Given the urgent need to converge on precise guidelines for accident management in nuclear fusion plants, Quantum Electronics Plasma Physics and Materials (QEPM) Research Group developed "STARDUST-Upgrade" facility to investigate dust mobilization phenomena.

In the present work, the upper ports of "STARDUST-Upgrade" were used as inlet ports, reproducing not only LOVAs but also the consequences of coolant loss from the upper ports of an ITER-like vacuum vessel. A vacuum rupture in the upper part of the vessel could involve cooling fluids causing not only chamber pressurization and air intake but also refrigerant inlet.

The diagnostics required and the results of this first experimental campaign are presented, including a comparison with predictions obtained with preliminary CFD (Computational Fluid Dynamics) model developed by QEPM Research Group.

AIM OF THE WORK

Fine tuning of "STARDUST-Upgrade" facility diagnostics to investigate LOVAs and LOCAs and their consequences.

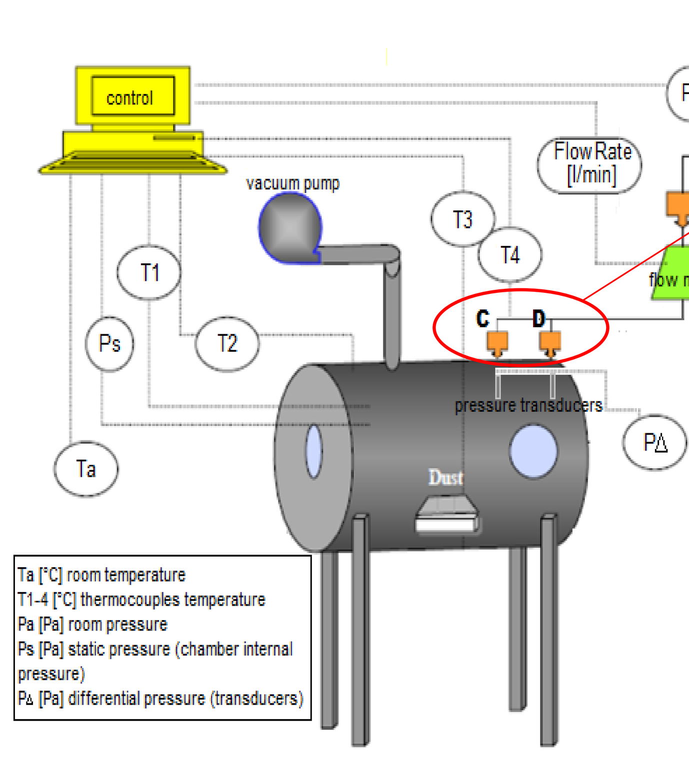
2 STARDUST-Upgrade FACILITY OVERVIEW

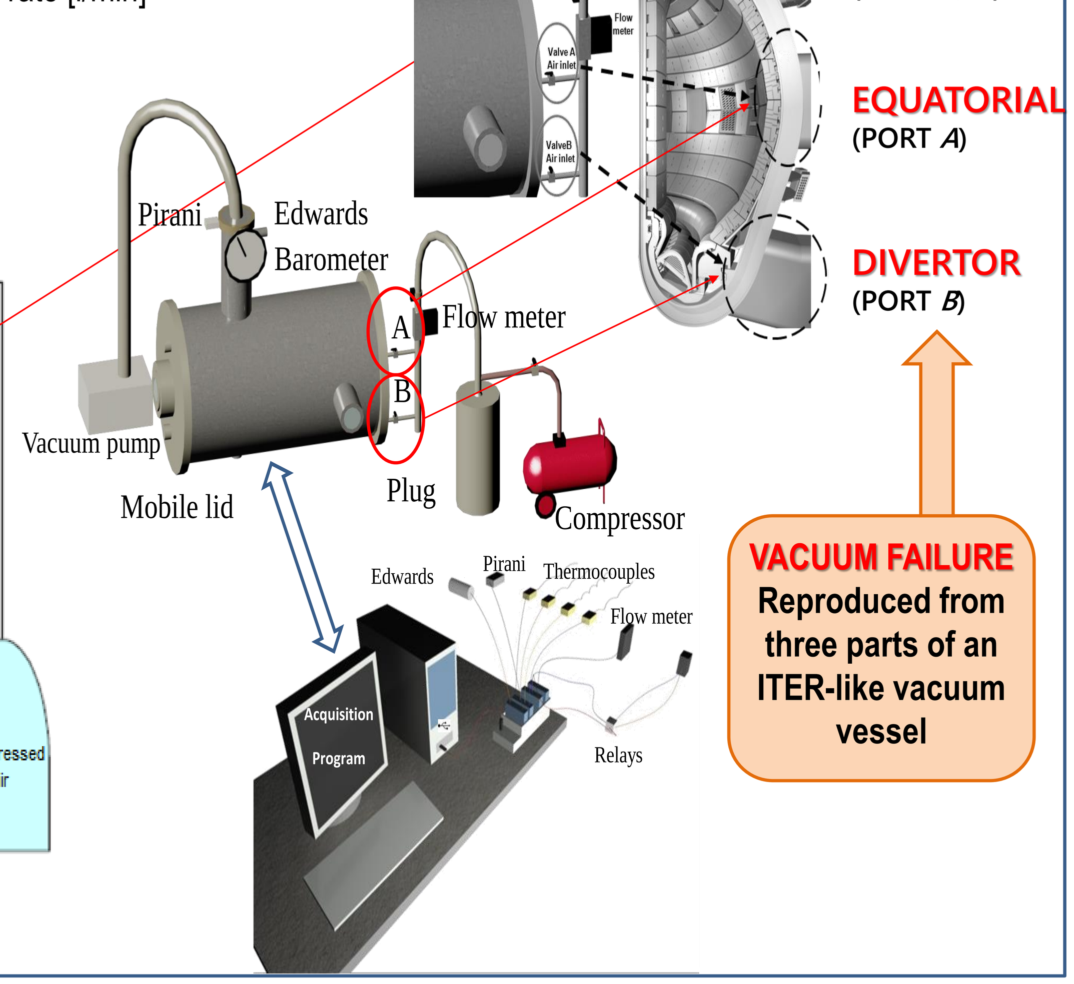
Data acquisition (at 50 Hz) for:

- J-thermocouples temperatures [°C]
- actual internal absolute pressure [Pa]
- air inlet flow rate [l/min]
- differential pressure from transducers [Pa]

Pressurization rate controlled by:

- initial and final internal absolute pressure [Pa]
- air inlet flow rate [l/min]





3 PRESSURIZATION EXPERIMENTS

"STARDUST-Upgrade" facility reproduced pressurization rates in the range of about 100-400 Pa/s including rates expected in a LOVA event according to General Safety and Security Report (GSSR) for ITER. Figure 4 shows pressurization for 300 Pa and 2000 Pa initial internal vacuum, and for three different air flow rates (10, 27, 40 l/min). Corresponding pressurization rates achieved are reported.

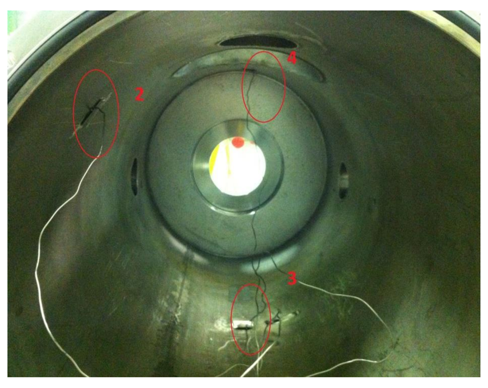


Figure 1 – J-Thermocouples inside the facility

Figure 2 – MKS Mass-Flow Controller

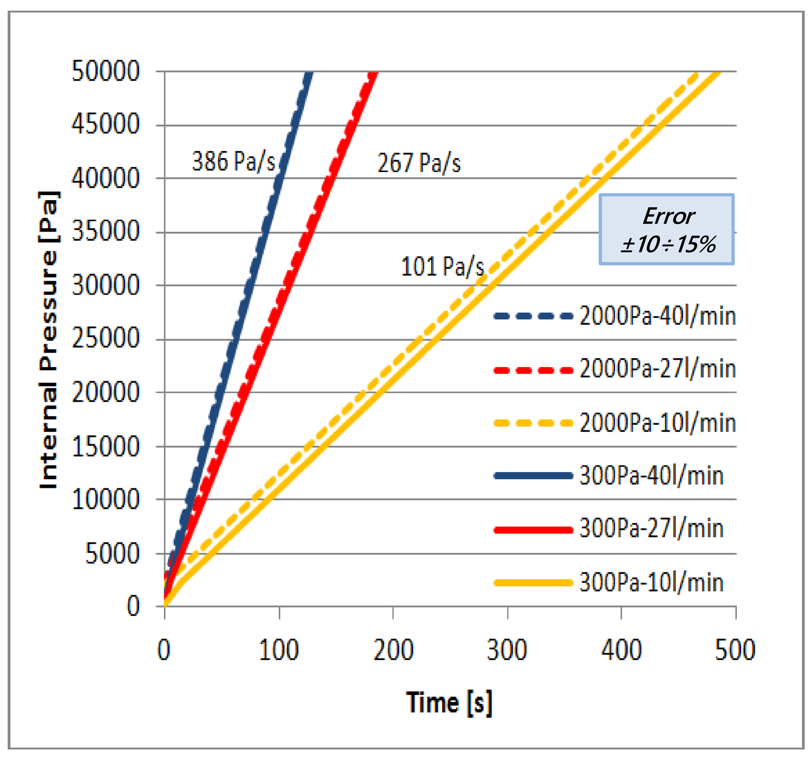


Figure 4 – Internal pressure trends measured by Pirani Gauge

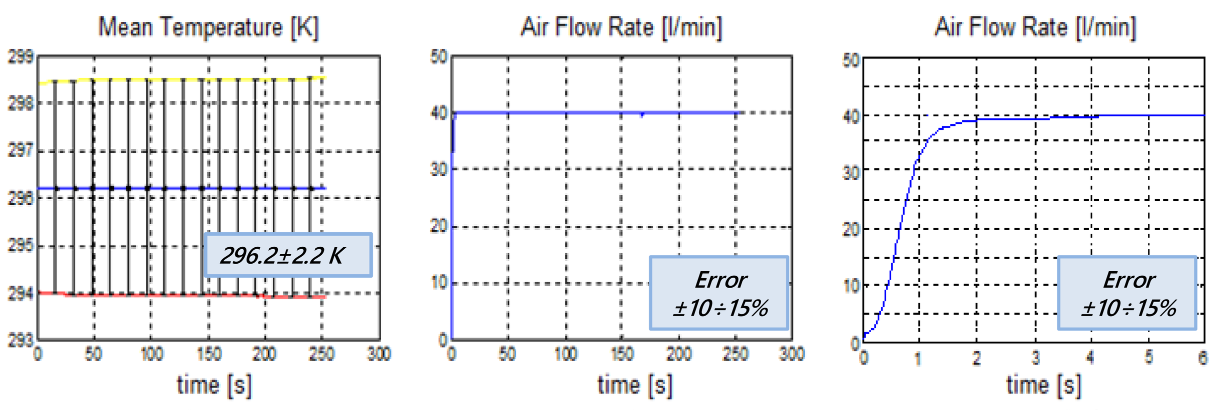


Figure 3 – Mean Temperature and Air Flow Rate trend during pressurization at 40 l/min

Figure 5 – Alcatel Pirani Gauge

4 AIR VELOCITY CALCULATION

Table 1 summarizes results on air velocity calculations. The max velocity value [m/s] is presented along with corresponding time [s] at which the maximum was observed. Transient velocity time [s] and corresponding velocity "v(0.50mV)" are also reported[1].

$k = c_p/c_v$ Ratio of the fluid specific heat at constant pressure c_p to the fluid specific heat at constant volume c_v;

$R = 8.314\ JK^{-1}mol^{-1}$ Universal gas constant;

$M = 0.028968\ kg/mol$ Dry standard air molecular mass;

$\bar{T} = \frac{1}{N}\sum_{i=1}^{N} T_i$ Mean temperature from i thermocouples [K];

P_S Static pressure [Pa] (measured by Pirani pressure gauge);

$P_\Delta = P_T - P_S$ Differential pressure [Pa] (measured by pressure transducers as a differential pressure between head and reference tube);

P_T Total pressure [Pa] (measured by transducers head).

$$v = \sqrt{\frac{2k}{k-1}\frac{R\bar{T}}{M}\left[\left(\frac{P_\Delta}{P_S}+1\right)^{\frac{k-1}{k}} - 1\right]}$$

Initial Pressure ***300** Pa*	Flow rate [l/min]	**40**			**27**		
	Replication	*#1*	*#2*	*#3*	*#1*	*#2*	*#3*
	Max velocity [m/s]	481.88	479.92	480.87	457.69	459.71	458.55
	Time [s]	3.36	3.36	3.36	2.80	2.80	2.80
	Transient velocity time [s]	58.69	57.78	55.56	45.97	49.17	48.20
	v(0.50mV)	48.32	37.68	40.23	56.35	49.12	45.93
Initial Pressure ***2000** Pa*	Flow rate [l/min]	**40**			**27**		
	Replication	*#1*	*#2*	*#3*	*#1*	*#2*	*#3*
	Max velocity [m/s]	377.91	407.19	375.34	339.93	334.84	342.45
	Time [s]	1.40	1.40	1.40	1.40	1.40	1.40
	Transient velocity time [s]	44.54	66.53	44.06	52.50	51.36	54.55
	v(0.50mV)	40.03	30.52	40.18	42.92	49.67	42.84

Table 1 – Air velocity calculation data sheet for 27 l/min and 40 l/min air flow rate at two different initial internal pressures (300 Pa and 2000 Pa)

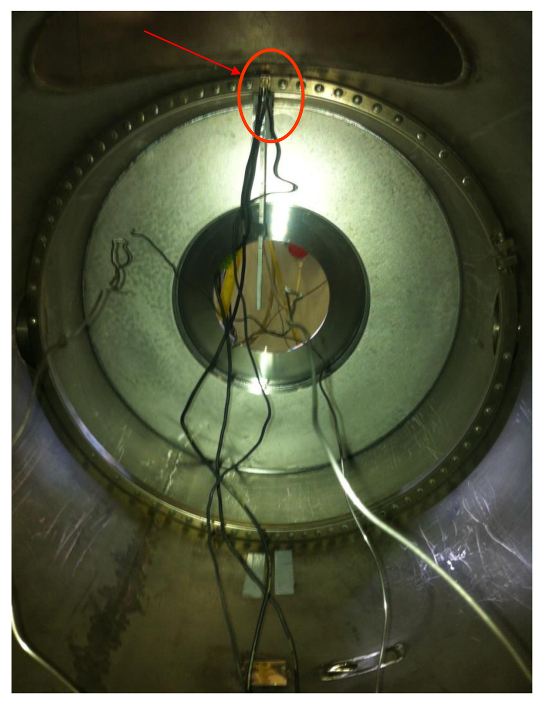


Figure 6 – Kulite Pressure Transducers array inside the facility

[1] **Transient velocity time** was calculated as the time at which the pressure transducer voltage signal returned 0.50 mV, corresponding to its maximum acceptable zero point, and so corresponding to the minimum velocity calculated by the system above signal-to-noise ratio (SNR). This velocity, namely "v(0.50mV)", is equal to the minimum air velocity detectable by the system. In the present work, "Transient velocity time" was defined in order to have information on time range in which mobilization is expected, namely *mobilization time*, at different pressurization rates.

5 PRESSURIZATION RESULTS

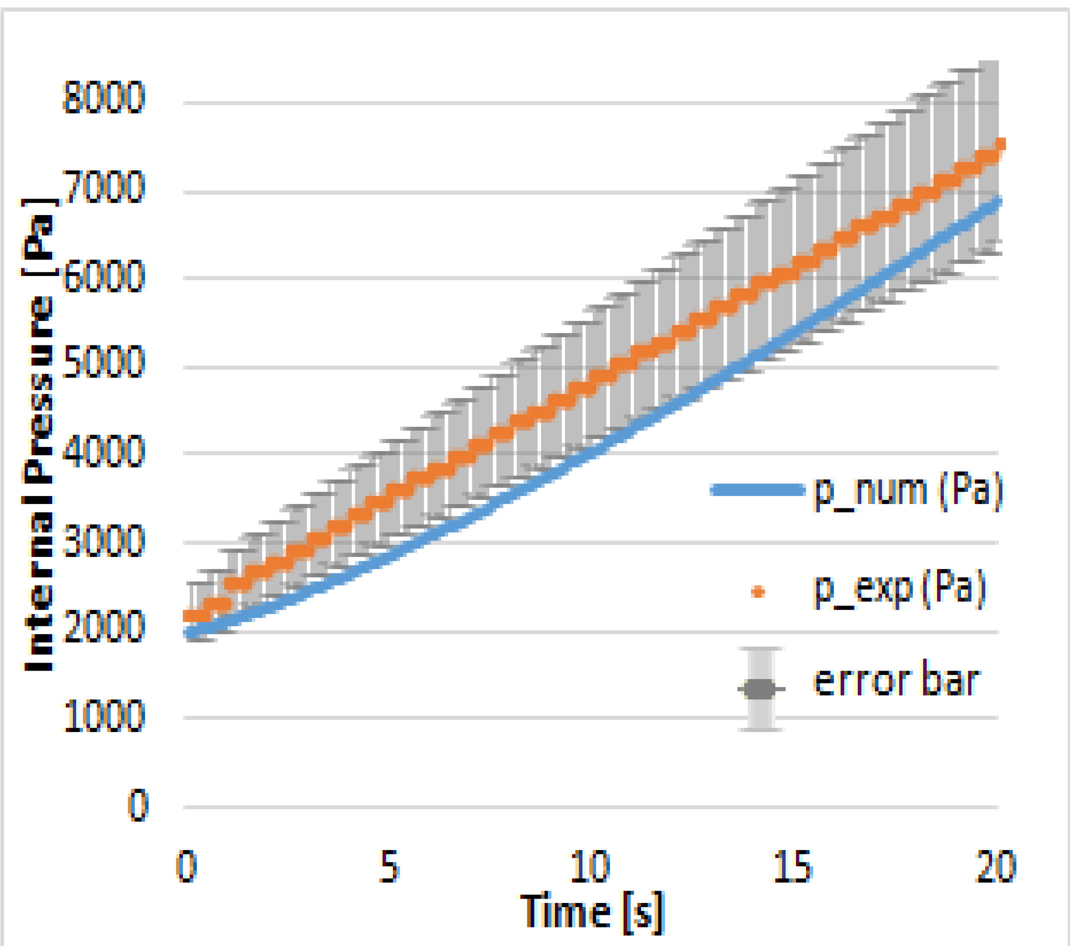


Figure 7 - Measured internal pressure [Pa] of the chamber with error bars (p_exp) compared to model prediction (p_num) for air intake at 27 l/min at 2000 Pa initial internal pressure

Pressurization curves:

- *p_exp* **measured experimentally** (error bars due to Pirani gauge direct error) - see also Figure 4
- *p_num* **CFD model prediction**

The two curves **show substantial agreement.**

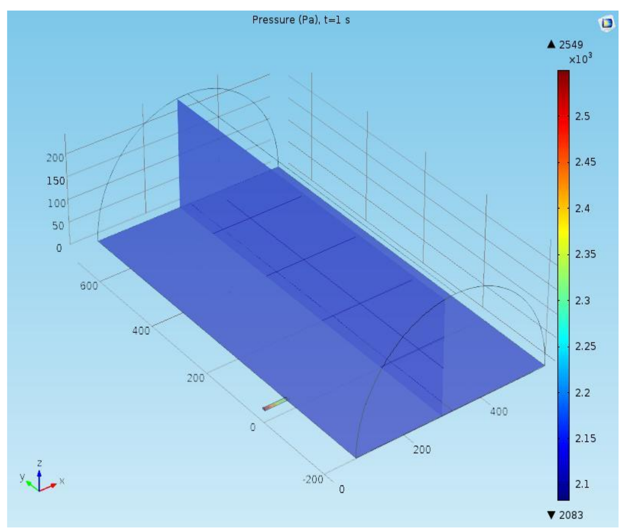


Figure 8 – Predicted internal pressure [Pa] after 1 s (CFD model) [J.F. Ciparisse et al., in 1st ECPD Conference 2015]

6 AIR VELOCITY RESULTS

Figure 10 presents **numerical** (*v_num*) and **experimental** (*v_exp*) air velocity trends for air intake at 27 l/min, that **show substantial agreement** for the first 20 seconds of pressurization. However, due to *numerical viscosity* effects, the numerical velocity predicted peak in the first seconds is lower than the experimental one.

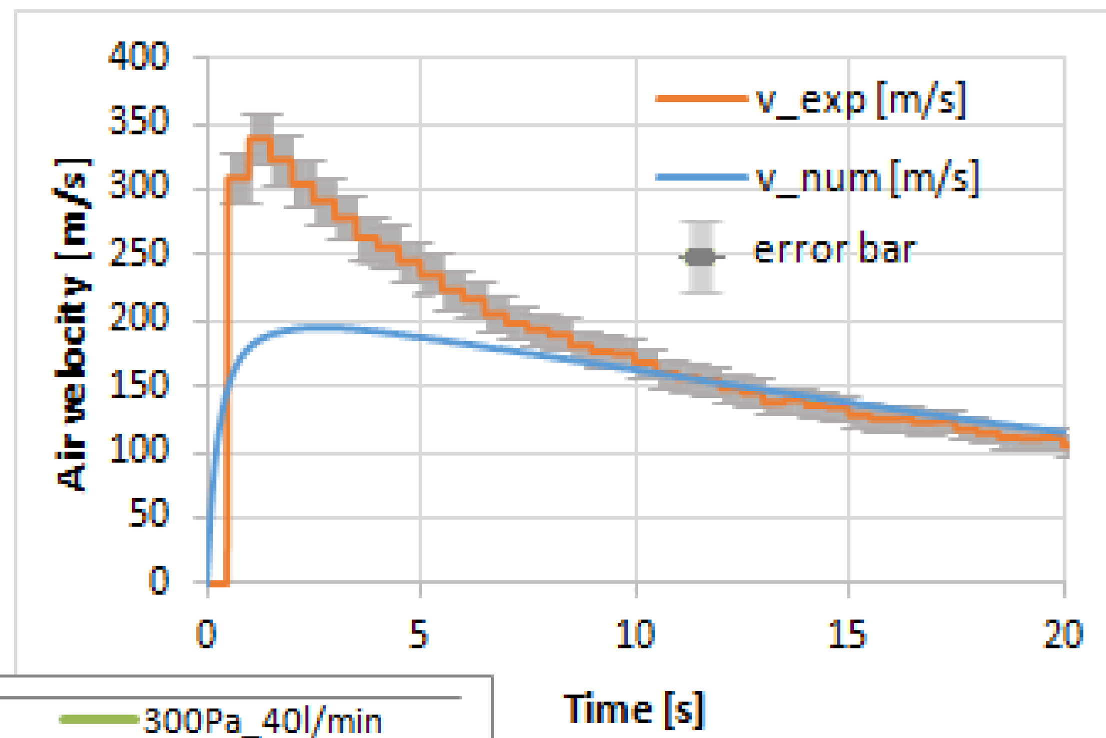


Figure 10 - Air velocity at the outlet of port C (v_exp) compared to model prediction (v_num) for air intake at 27 l/min at 2000 Pa initial internal pressure

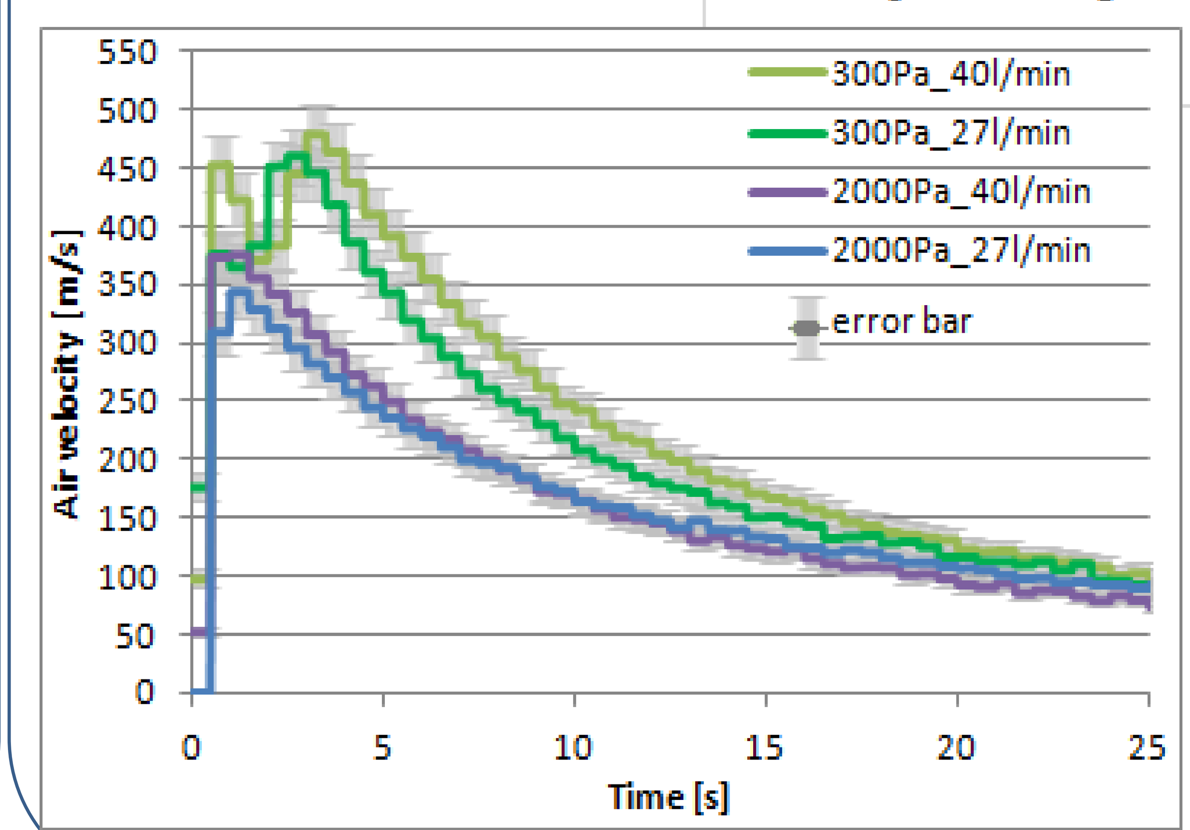


Figure 9 - Air velocity trends calculated for pressurization experiments

Air velocity trends for first 25 seconds of air intake are reported in Figure 9 that shows a **velocity peak** in the first four seconds. The corresponding pressurization rates are that shown in Figure 4.

7 CONCLUSIONS

- Pressurization achieved through air intake evidenced that "STARDUST-Upgrade" facility is able to reproduce a wide range of pressurization rates including what expected in GSSR Report.
- As expected, all air velocity trends (Figure 4) were similar and presented a sudden rise in the first seconds leading to the value, that increased with flow rate for both initial *maximum air velocity* pressures chosen. In addition, the *Transient velocity time* resulted smaller than 60 seconds for all replications demonstrating that investigation of dust mobilization is crucial in the first seconds.
- Figure 7 and 10 show a substantial agreement between numerical and experimental results, but the simulated air velocity peak value resulted lower than the same experimental measured peak value. This could be due to an insufficiently fine grid, which produces numerical viscosity. Future model development should improve the numerical accuracy.
- In conclusion, "STARDUST-Upgrade" facility is capable of reproducing the thermo fluid-dynamic consequences of a LOVA from lower, equatorial and upper part of the vessel, and only the pressurization consequences of a LOCA from the upper part of the vessel. A more complete reproduction of LOCAs consequences will be objective of future experimental campaigns.

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