AN EFFECTIVE LOW COST CRYO-HYBRID CLEANING PROCESS FOR THERMAL VACUUM CHAMBERS

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Molecular contamination, Vacuum chamber cleaning, CO2 cleaning, dry ice blasting, Knudsen flow

ABSTRACT

One of the chambers in RAL Space premises (i.e. Space Test Chamber 2) was heavily contaminated with hydrocarbon molecules after a black paint failure of thermal shrouds which makes it unsuitable for a vacuum test. In order to clean the chamber, a new cryo-hybrid method was developed in this study. The method was shown to be effective on a small bake-out chamber which had gross levels of hydrocarbon contamination. This method not only involves the CO2 spraying (in the form of compressed air driven dry ice) followed by hand cleaning using acetone and IPA lint free wipes but also purging chamber walls with Ar/N2 under vacuum for creating Knudsen flow to knock low binding energy hydrocarbon chains free and send them down the roughing pump line.

1. PROBLEM DESCRIPTION AND PROPOSED SOLUTION

Due to the severe impacts of molecular contamination on spacecraft performance, an extensive contamination control has to be carried out during environmental testing activities. For this purpose, the materials tested in thermal vacuum chambers are selected based on their outgassing characteristics [1]. Additionally, the internal surfaces of vacuum chambers should also be kept clean and this should be demonstrated to the test requester as one of prerequisites prior to the test [2].

One of the 5m chambers in RAL Space premises (Space Test Chamber - 2, STC-2) was heavily contaminated with hydrocarbon molecules after a black paint failure of thermal shrouds which makes it unsuitable for a vacuum test (see Fig.1). In order to remove contamination on its vessel (made up of stainless steel 304L), normal and known practice is to perform a bake out at elevated temperatures (> 80°C) at which the hydrocarbon molecules becomes volatile on the internal surface of the vessel [3,4]. However, due to the very high thermal inertia of the chamber vessel (48000 kg's of stainless steel), the amount of heating energy needed to excite the molecules on the surface (to reach >80ºC) is significant and this approach is not cost effective. Furthermore, the chamber had only been designed to withstand 30ºC of thermal expansion/stress. Therefore, a different method was investigated and for this on a small bake-out chamber (SBOC, Ø= 1.67 m, L= 3.9m) which had gross levels of hydrocarbon contamination on all internal surfaces was selected before scaling up the same process to STC-2. In Fig.2 SBOC can be seen.

Figure 1: The door of STC-2 before cleaning. Note colouration

The intention was to be able to heat a region of SBOC replicating some shroud heating conditions that we will see in STC-2. It is impractical to replicate the entire shroud so a region close to the Residual Gas Analyser (RGA) port was considered. By this way, heat load on the chamber wall during shroud heating which would provoke outgassing of surfaces is also considered and that will be

witnessed by the RGA.

Figure 2: Small bake-out chmaber (SBOC)

The SBOC is 5.25x smaller in terms of surface area than the STC. If we take a body shroud panel as the STC heating source and heat the panel to 400K (127 ºC) and for the SBOC create a panel 5.25 x smaller and heat to 400K we may be able to scale up the outgassing rate seen on the SBOC to replicate a full equivalent shroud and scale up further to estimate the outgassing rate that could be seen when testing the STC-2.

The cleaning starts with baseline RGA measurements and it will be made followed by the panel heating to provoke contamination from the chamber surfaces. Once a baseline has been established the chamber will be vented for CO2 cleaning followed by solvent cleaning starting with Acetone and followed by IPA to finish. The turbo pump shall be baked to prevent cross contamination from back to the chamber, more scans of the chamber shall be taken pre Knudsen gas flow cleaning, the process shall then be carried out followed by a post Knudsen gas flow cleaning analysis. To finish a repeat of the baseline and panel heating test shall be carried out and the data compared the goal being to assess whether the cleaning procedure demonstrates any significant reduction in contamination.

2. CLEANING PROCESS

The sequence of the proposed cleaning process is depicted in Fig. 3. In subsections, the detail explanation is given regarding intermediate processes.
Based on the flowchart the proposed cleaning executions steps as follows:

(1) Pump down and leak check SBOC with scaled shroud panel positioned in front of RGA port
(2) Wait for base pressure to be achieved e.g. 24 hours of turbo pumping, note pressure
(3) Turn on RGA and record 0-200AMU analog scan and also masses vs time selecting peaks (2, 12, 14, 15, 16, 18, 32, 40, 44, 50, 52, 55, 57, 62, 65, 67)
(4) Start ramp of heater panel at 50 ºC per hour up to 127 ºC
(5) Monitor pressure and RGA peaks in case pressure gets too high and RGA filament needs to be stopped
(6) Note pressures every hour and at what temperature the panel was at
(7) When peaks start to reduce or no change is seen after 24 hours at 127 ºC, start cool down at 50 ºC per hour
(8) Vent SBOC.
(9) Apply CO2 spraying.
(10) Wipe the chamber internal surfaces by using lint free wipes with Acetone. Repeat the wiping with IPA.
(11) Check the wiped surface with a clean cloth, if the colour of the wiped cloth is white continue with the next step otherwise go back to step (9)
(12) Clean the pumping system and heater panel if required. A replacement turbo may be required if saturated.
(13) Once cleaning process complete, mount flanges and move SBOC back to original location
(14) Mount the pumping system, instrumentation and the heater panel
(15) Repeat test steps 1 -5 and compare the data.
(16) Set up Knudson flow cleaning test with the addition of a needle valve on a port connected to an Argon cylinder and Nitrogen cylinder with suitable two stage regulators and pressure relief (see Fig. 3). Turn off RGA filament, wait 15 minutes, increase the pressure with Argon to $1x10^{-2}$ mbar.

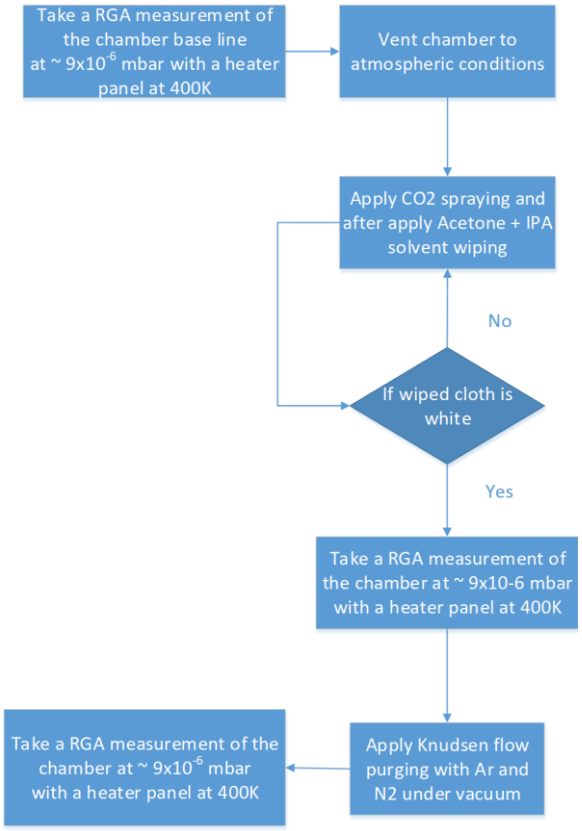

Figure 3: Flowchart of the cleaning process

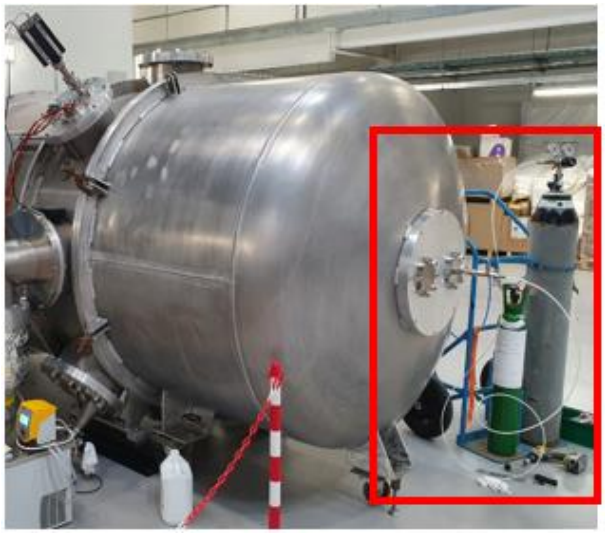

Figure 4: N2 and Ar plus needle valve on inlet. Installed perpendicular to pumping port

(17) After half a cylinder of Argon has been depleted, allow pressure to recover and turn on RGA to compare spectra.
(18) Turn off RGA filament, wait 15 minutes, increase the pressure with Nitrogen to $7.5x10^{-1}$ mbar. After half a cylinder of Nitrogen has been depleted, allow pressure to recover and turn on RGA to compare spectra.
(19) Cool down to room conditions and vent SBOC.

2.1. CO_2 (Dry ice) Cleaning

CO_2 or dry ice cleaning is a form of carbon dioxide cleaning, where dry ice, the solid form of carbon dioxide, is accelerated in a pressurised air stream and directed at a surface in order to clean it (see Fig. 5). The method is similar to other forms of media blasting such as sand blasting, plastic bead blasting, or in that it cleans surfaces using a media accelerated in a pressurized air stream, but dry ice blasting uses dry ice as the blasting medium. Dry ice blasting is nonabrasive, non-conductive, non-flammable, and non-toxic. Compared to other media blasting methods, dry ice blasting does not create secondary waste or chemical residues as dry ice sublimates, or converts back to a gaseous state, when it hits the surface that is being cleaned. Dry ice blasting does not require clean-up of a blasting medium [5].The waste products, which includes just the dislodged media, can be swept up, vacuumed or washed away depending on the containment.

CO_2 cleaning/spraying should be started at the top of the chamber and arcing down below the midpoint, systematically driving all contamination down working front to back then at the lower level, systematically driving from one end of the chamber out through the other end. CO2 cleaning of the doors should be again from the top to the bottom.

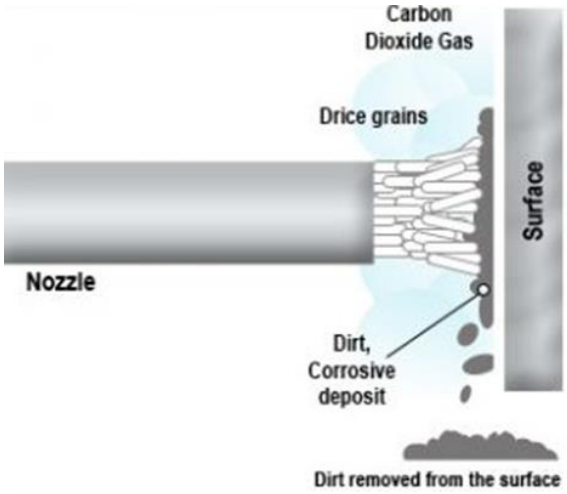

Figure 5: Dry ice cleaning/blasting process [6]

2.2. Detailed “Hand” Cleaning

Following the CO2 cleaning cycle, in order to remove the contaminant on the vessel, hand cleaning is applied using Acetone [7] and lint free wipes followed by Isopropyl alcohol [7].

Lint free wipes are used with Acetone to clean surfaces, a systematic approach will be taken starting with the upper portion of the vessel down to mid-plane to bottom position, progressing from one end of the chamber to the other extremity. The process will then be repeated using lint free wipes and Isopropyl alcohol. Regular folding of wipes and discarding of wipes to ensure using a clean portion of wipe will be required. Until the colour of the wiped cloth is white, wiping continues to be applied after dry ice basting process. In Fig.6 examples of wipes are shown after dry ice blasting.

Figure 6: Example of wipes after CO2 blasting

2.3. Vacuum Knudson Flow Cleaning

The idea of this process is to utilise the turbulent flow regime of Knudson flow (see Fig. 7 for flow regimes) to knock low binding energy hydrocarbon chains free and send them down the roughing pump line. In order to perform this, medium vacuum is reached where Knudsen number is between 0.01 and 0.5. Dry Argon (5.0 grade) being a heavy inert molecule was used to purge the internal vessel surfaces followed by Nitrogen (5.0 grade) which also has good cleaning properties and will help flush residual Argon away also.

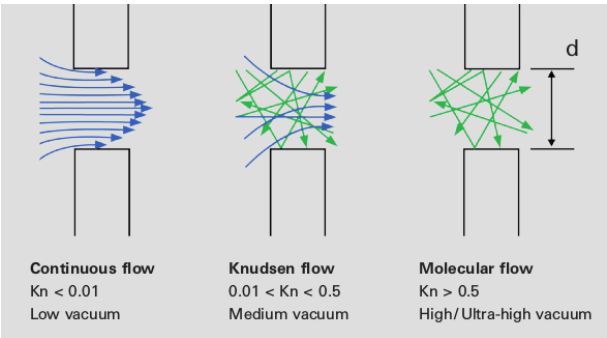

Figure 7: Profiles of the various types of flow regimes [8]

The pressure ranges to obtain Knudson flow are given below for both gas:

- Ar – $6x10^{-4}$ mbar to $3x10^{-2}$ mbar with an optimum pressure of 9x10-3 to 1x10-2 mbar (optimum ensures some margin for error preventing the flow becoming laminar or less turbulent)

- N2 – $9x10^{-4}$ mbar to $4x10^{-2}$ mbar with an optimum pressure of $1\text{-}2x10^{-2}$ mbar (optimum ensures some margin for error preventing the flow becoming laminar or less turbulent)

3. RESULTS AND DISCUSSIONS

After the hand cleaning step, the SBOC again pumped down with an RGA installed on it as per the given steps in section 2. The below figure shows the partial pressures read by the RGA with respect to molecule types (i.e. atomic mass unit). As can be seen once under vacuum it can be seen that the contaminants are present in higher partial pressures than before the cleaning process (i.e. the base line) as they seem to have a much lower Van der Waals forces. However, this actually indicates at same time that the contamination now is easier to pump away. The Knudsen gas flow cleaning seems to assist this and acts as an optimised pump purge cleaning with the Argon gas flow cleaning doubling up as a more physical bombardment step to the Nitrogen cleaning following. As can be seen in Fig.8, the final contamination level in SBOC is the lowest.

In Table 1, the partial pressure differences of identified contaminant hydrocarbon molecules are listed for process steps in order to show the effectiveness of each. As can be seen from the post hand cleaning RGA measurements, the partial pressure of hydrocarbon molecules increased significantly. This indicates that dry ice blasting helps contaminant to be removed from the surfaces. The final measurements after Knudsen flow cleaning showed that the dis-attached contaminants from the vessel surface were pumped out successfully where the partial pressures decreased by 25-90% comparing to baseline readings.

4. CONLUSION

In this study, an effective low cost cryo-hybrid cleaning process for thermal vacuum chambers is proposed. The process not only involves the dry ice blasting followed by hand cleaning using acetone and IPA lint free wipes but also purging chamber walls with Ar/N2 under vacuum for creating Knudsen flow to knock low binding energy hydrocarbon chains free and send them down to roughing pump line.

By comparing RGA spectra of the baseline with the post CO2 and solvent cleaning, and the post Knudsen gas flow cleaning, it was demonstrated that that the contaminant species result in a significant reduction to a qualitative level at the end. Thus, the combined cleaning process have been found successful and effective which can be scaled up and implement to STC-2.

5. REFERENCES

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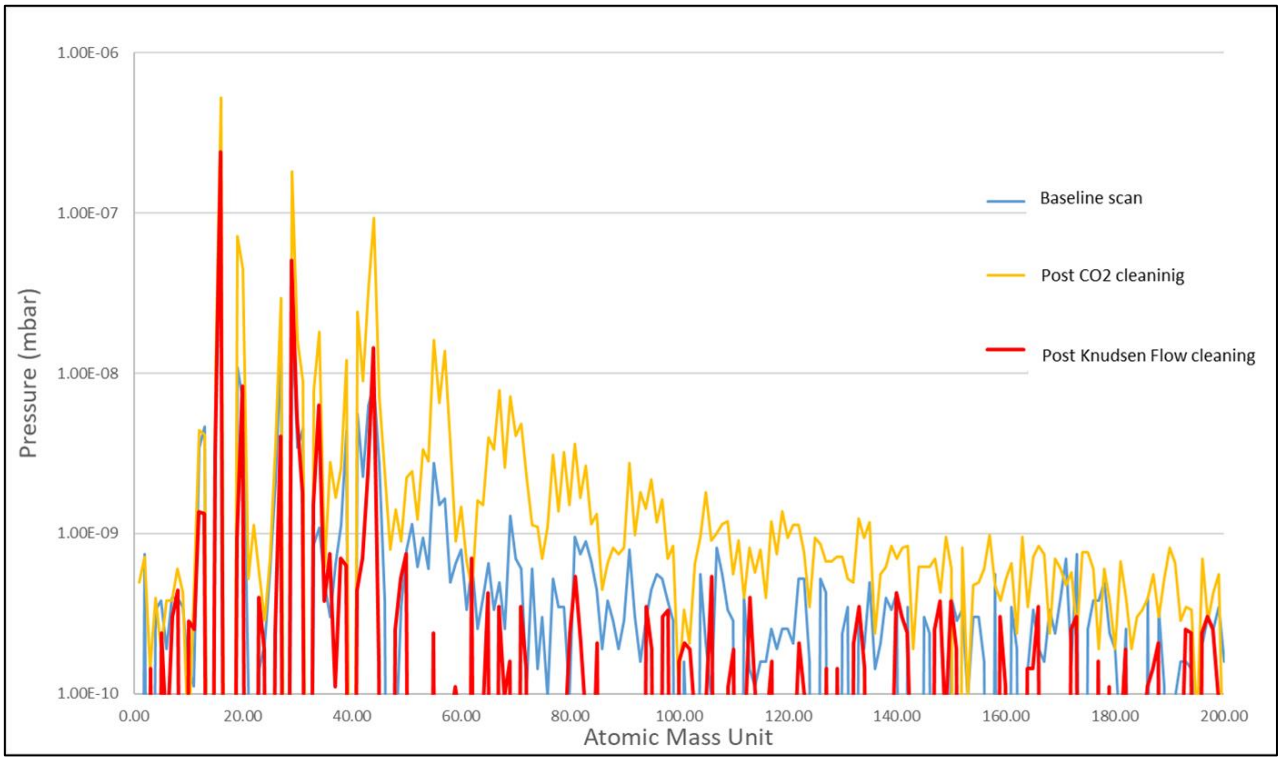

Figure 8: RGA Spectra throughout the cleaning process

Table 1 Partial pressure comparison of hydrocarbon molecules between the steps of the process

AMU	Baseline (mbar)	Pre gas clean (Post CO_2/hand clean) (mbar)	Relative difference to baseline (%)	Post gas flow clean (mbar)	Relative difference to baseline (%)
55	2.75E-09	1.61E-08	+483.6	2.38E-10	-91.3
57	1.65E-09	1.37E-08	+727.3	9.54E-11	-94.5
81	9.54E-10	3.64E-09	+282.0	5.40E-10	-43.3
121	2.07E-10	1.13E-09	+445.4	3.38e-11	-83.6
134	1.91E-10	9.38E-10	+391.1	1.43E-10	-25.0