EVALUATION OF THE POTENTIAL REDISTRIBUTION PHENOMENON OF MOLECULAR CONTAMINATION DURING LAUNCH

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ABSTRACT

Nowadays in space industry, aiming high performances for the earth observation satellites is a priority. The optical instruments are more and more efficient and sensitive to contamination which leads to performance degradation. Despite the fact that space hardware Assembly, Integration and Test is performed in cleanroom environment and all the taken precautions, the spacecraft accumulates molecular contamination that shall be characterized and quantified.
This study aims at investigating the behavior of the molecular contamination during launch depending on its chemical nature.

INTRODUCTION

The optical instruments are more and more efficient and sensitive to contamination. To ensure their proper operation until end-of-life, the overall contamination shall be controlled and minimized.
The amount of molecular contamination in ground phases is monitored and the one generated during flight can be estimated by computational modelling.
However, what happens to the accumulated molecular contamination during the ascent is still unknown. Spacecraft and contamination sensitive equipment undergo physical constraints such as mechanical and acoustical loads, temperature variations and depressurization that can interact with the deposited molecular layers.
This paper focuses on the impact of the depressurization on the behaviour of the molecular contamination.

EXPERIMENT

1.1. Reproduction of the molecular contamination

To make the deposition on several substrates easier, these contaminants were recreated with the standard solutions used for the Fourier-transform infrared (FTIR) spectroscope calibration (as per ECSS-Q-ST-70-05C).

The solutions were:
- Hydrocarbons (Hyc): Nujol (mix of liquid paraffin for spectroscopy; C_nH_{2n+2}, n from 8 to 19)
- Methyl silicones (M-Si): Dow Corning 200 (Dimethyl siloxane, with terminal grouping trimethyloxy)
- Phenyl methyl silicones (P-Si): Dow Corning 710 (Phenyl methyl siloxane, with trimethyl ending)

1.2. Substrates

The contaminants mentioned above were deposited on the following substrates:
- RQCM (Research Quartz Cristal Microbalance) 9MHz Maxtek by Inficon: a piezoelectric microbalance, highly sensitive to mass variation, used to see the evaporation of contaminants during time.
- Crystals in CaF_2: to measure, by spectroscopy IRTF, the quantity of contaminant before and after vacuum.

For each contaminant, two different concentration levels were deposited on the different substrates in order to investigate the potential impact of the contaminant amount. The various configurations are summarized in Table 1.

Tab. 1. Contamination levels of the different tested samples

Substrate	Contaminant	Deposited contamination (10^{-7} g/cm²)
QCM	Hyc	~10
QCM	M-Si	~10
QCM	P-Si	~10
CaF₂	Hyc	~10
CaF₂	M-Si	~10
CaF₂	P-Si	~10
CaF₂	Hyc	~2
CaF₂	M-Si	~2
CaF₂	P-Si	~2

1.3. Measurements

Measurements of the molecular contamination levels were performed using a Thermo-Fisher Nicolet 6700 FTIR spectroscope owned by the Contamination and Cleanliness Laboratory and located in clean room. Thanks to a calibration steps, it allows the quantitative measurement of the four chemical families: hydrocarbons, esters, methyl silicones and phenyl methyl silicones.

Fig. 1. Picture of the Thermo Fischer Nicolet 6700 and Continuμm Imaging System

Measurements are performed on CaF_2 molecular contamination witnesses from 1300 cm^{-1} to 4000 cm^{-1}.
In order to perform a two axes mapping of the contaminant concentration at the surface of the substrates Thermo-Fischer Nicolet Continuμm Imaging System was also used.

1.4. Test Chamber

In order to simulate the depressurization phenomenon, a specific stainless steel vacuum chamber of 30 cm height and 50 cm diameter was used.
The associated vacuum system was constituted of an Adixen ATP 400 turbo-molecular pump coupled to a primary dry pump.
The chamber was instrumented with a vacuum gauge, a RQCM and molecular contamination witness in order to monitor the behaviour of the contaminant deposited at the surface of the substrate during the experiments.
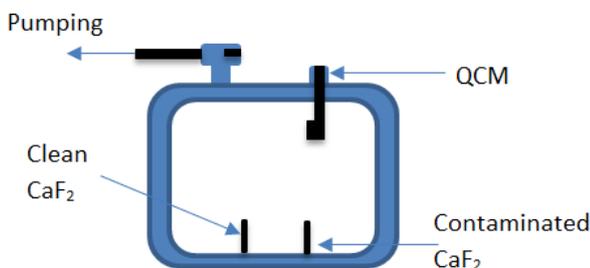

Fig. 2. Drawing of the test chamber

RESULTS

1.1. Depressurization

Two phenomena could happen during the depressurization: the removal of molecules due to the interaction with air flow and the spontaneous desorption of the contaminants.

The Ariane 5 overall launch duration is typically 1200 seconds. During this time the variation of pressure does not exceed 2 kPa/s with less than 5 seconds at 4.5 kPa/s and is displayed in Fig. 3.
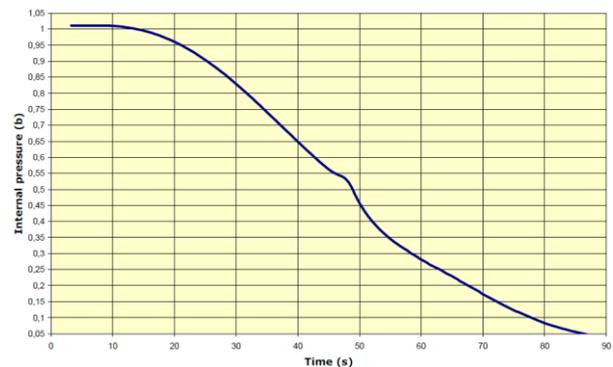
Fig. 3. Variation of pressure under Ariane 5 fairing [1]

The depressurization inside the chamber was monitored and compared with the one under fairing in Fig. 4.
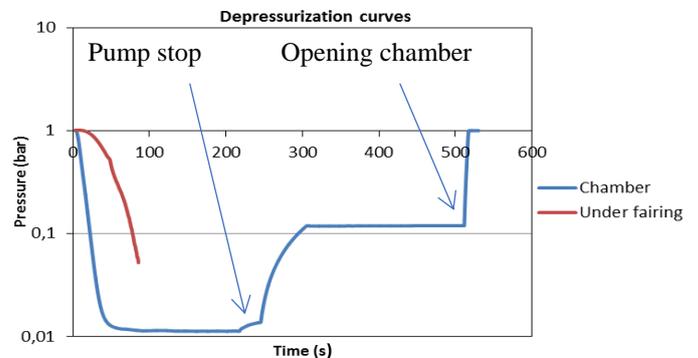
Fig. 4. : Comparison of the curves of depressurization induced by launch and by the vacuum chamber

The depressurization inside the chamber is faster than under fairing and it has a final step of ambient pressure recovery that does not exist for a spacecraft instrument. However this experiment allowed the rough reproduction of the phenomenon to highlight the induced effects.

Before starting the experimental campaign, a blank test has been performed with molecular contamination witnesses in order to check the cleanliness level of the chamber.

Then, successive depressurization runs were performed with the different substrates (RQCM and molecular contamination witnesses). Each run was dedicated to a specific contaminant to study its behaviour individually.

1.2. Tests with RQCM

The first set of runs was dedicated to the evaluation of the behaviour of the contaminant monitored by the RQCM. The recorded signals for the different contaminants are displayed and summarized in Fig. 5.
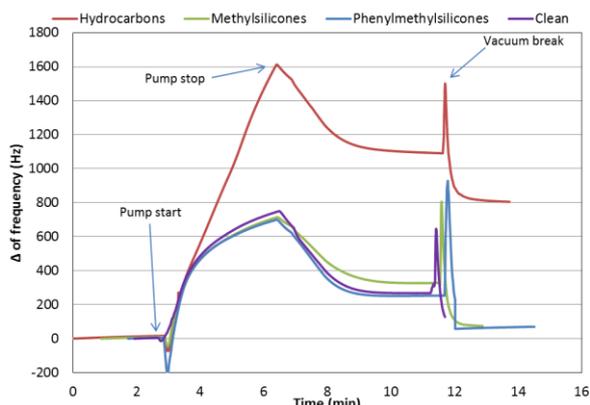
Fig. 4.: Frequency variation of RQCM during depressurization

In order to get a reference measurement, a blank test with a clean RQCM was performed to record only the signal induced by the test conditions (pump start and stop, vacuum break, …).

Then, successive runs with contaminated RQCMs have been performed and compared to the baseline signal.

The main outcome is that a different behaviour can be observed between hydrocarbons and silicones contaminants. Indeed, whereas similar signals are recorded on RQCMs with silicones compared to the baseline, the signal delivered by the RQCM contaminated with hydrocarbons shows a significant difference.

Thus, based on these results, the main hypothesis is that methyl-silicones and methyl-phenyl-silicones are not influenced by the depressurization and that the deposited contamination amount remains at the surface of the RQCM crystal. Conversely, the clear increase in frequency monitored for hydrocarbons suggests that a mass loss occurred at the surface of the RQCM crystal and that a part of the contamination spontaneously desorb due to the depressurization of the chamber.

These measurements performed with RQCM allowed a real-time monitoring of the behaviour of the contamination during the test. However, considering that these RQCMs were not initially dedicated to be used under vacuum, these results are only qualitative and give a trend of the behaviour for the different contaminants studied.

1.3. Tests with molecular contamination witnesses

Based on the results obtained with the RQCMs and in order to obtain quantitative values, the same experiments were performed with molecular contamination witnesses.

The samples were measurement before and after depressurization tests and the results obtained are displayed in Fig. 5.
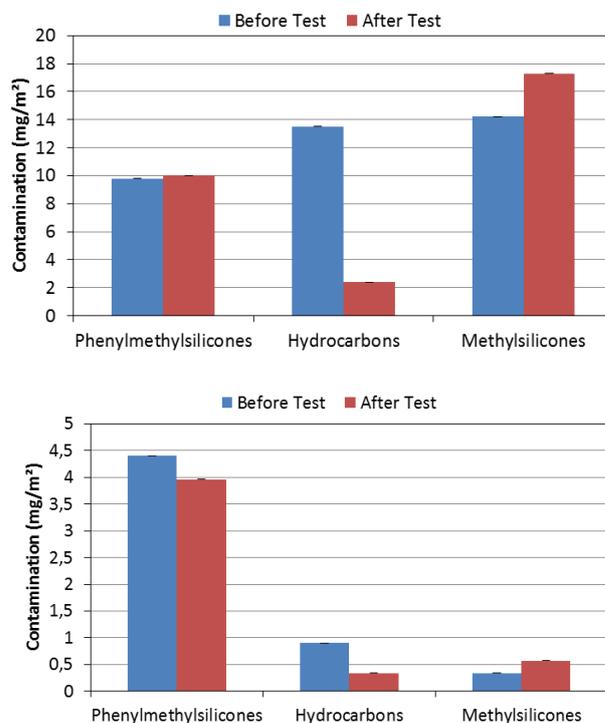
Fig. 5.: Concentration of the contaminants before and after test for high (top) and low (bottom) levels

The trend previously observed with RQCMs for both phenyl-methyl-silicones and hydrocarbons is clearly confirmed by the values recorded with the molecular contamination witnesses. While the amount of phenyl-methyl-silicones remains almost the same, a significant decrease of the quantity of hydrocarbons is measured, from 60 to 80% for low and high concentrations respectively.

The behaviour of the methyl-silicones is quite remarkable. Indeed, an increase of the amount is measured after testing. Considering that the blank test performed ensured that no contamination is induced by the experimental set-up, this phenomenon was investigated in order to understand the observed behaviour. Measurements on the molecular contamination witnesses were performed using attenuated total reflectance (ATR) in order to perform a mapping of the contamination layer at the surface of the substrate. The results of the mapping are displayed in Fig. 6.
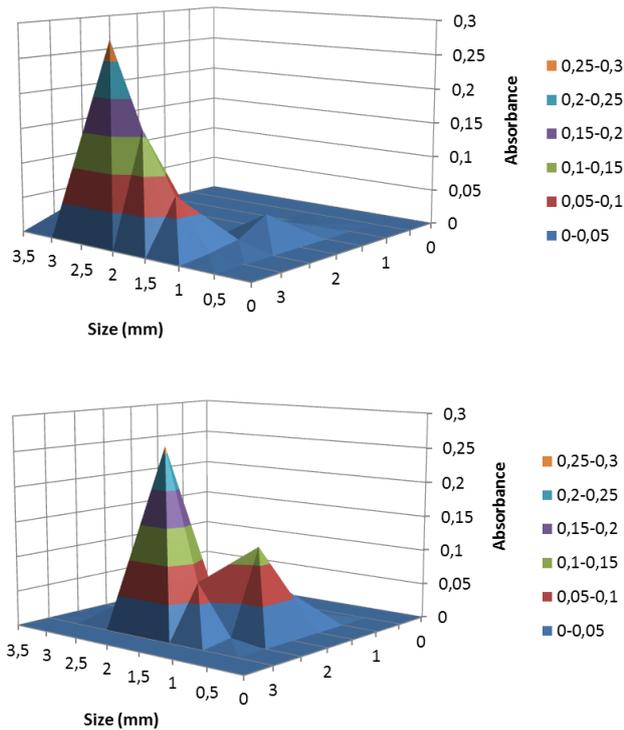
Fig. 6.: Mapping of the methyl-silicones concentration before (top) and after (bottom) test

What can be seen from the mapping is that a migration phenomenon appeared at the surface of the molecular contamination witness. Hence, the quantity of contaminant included within the infra-red beam area is higher, leading to an artificial increase of the methyl-silicones concentration during the measurement.

This phenomenon could be partly due to the fact that the contamination was artificially deposited at the surface of the substrate and did not form a homogeneous layer compared to typical contamination deposition behaviour in clean room.

CONCLUSIONS

The aim of this preliminary study was to investigate the behaviour of the molecular contamination during launch. The contaminants considered are typical compounds representative of two major chemical families: hydrocarbons and silicones.

The results presented in that paper focused on the potential effect of the depressurization on the molecular contamination during the ascent. This phenomenon was reproduced thanks to a set-up allowing the reproduction of the pressure decrease in a vacuum chamber. Other effects such as acoustic or mechanical vibrations have also been considered but no significant impact on molecular contamination was observed.

The main outcome of this study is related to the specific behaviour of the hydrocarbons during the depressurization, characterized by an important concentration decrease due to spontaneous desorption and leading to a lowering of the contamination level from 60 to 80%, depending on the initial concentration.

This study constitutes a first step in the understanding of the behaviour of the molecular contamination during launch. Further testing needs to be performed with most representative contamination, directly coming from clean room or outgassing of actual materials used for space hardware manufacturing.

From cleanliness and contamination point of view, these preliminary results are very interesting. If the behaviour of the hydrocarbons is confirmed and the contamination reduction properly quantified, this will allow the consideration of this decrease on the overall in-orbit performance of the instruments.

REFERENCES
1. Ariane 5 User's Manual, Issue 5 Revision 2