PRELIMINARY ANALYSIS OF RESULTS OF COMPARATIVE LIFE TEST OF 6063 ALUMINUM ANODIZED AND NON-ANODIZED THERMOSYPHONS CHARGED WITH ACETONE AS WORKING FLUID.

Nadjara dos Santos
INPE, Instituto Nacional de Pesquisas Espaciais.
São José dos Campos – SP, Brasil.
nadjara.santos@inpe.br

Jorge Bertoldo Junior
INPE, Instituto Nacional de Pesquisas Espaciais.
São José dos Campos – SP, Brasil.
jorge.bertoldo@inpe.br

Erly Brazolin
INPE, Instituto Nacional de Pesquisas Espaciais.
São José dos Campos – SP, Brasil.
hbrazolin@yahoo.com.br

Suely M. H. Gondo
INPE, Instituto Nacional de Pesquisas Espaciais.
São José dos Campos – SP, Brasil.
suely.gondo@inpe.br

Pedro Cândido
INPE, Instituto Nacional de Pesquisas Espaciais.
São José dos Campos – SP, Brasil.
pedro.candido@inpe.br

Valeri V. Vlassov
INPE, Instituto Nacional de Pesquisas Espaciais.
São José dos Campos – SP, Brasil.
valeri.vlassov@inpe.br

José Antonio Batista Neto
INPE, Instituto Nacional de Pesquisas Espaciais.
São José dos Campos – SP, Brasil.
jose.neto@inpe.br

Olga Kchoukina
INPE, Instituto Nacional de Pesquisas Espaciais.
São José dos Campos – SP, Brasil.
olga.kchoukina@lit.inpe.br

ABSTRACT: *This work purpose is to present a specific stage of development of HP (Heat Pipe) for space applications. The heat pipes are devices designed to transport or distribute heat very efficiently without generating significant temperature gradients. The HPs are widely used in satellites for thermal stabilization of structural panels and homogenization temperature in areas of higher heat dissipation due to the operation of electronics equipments. An important aspect to operation HPs is compatibility of the working fluid and the material used in the tube. Even when fluid is considered compatible very slow chemical reactions between the tube material and the fluid itself or impurities or usual rests may generate a small amount of non-condensable gas (NCG), which accumulates in the vapor channel and blocks part of the tube length affecting operating characteristics of the tube. The required qualification test is the Life Test (LT), which is usually conducted during at least two years in thermosyphon manufactured from the same material that the HPs and charged with the same working fluid In the proposed comparative LT the purpose was to evaluate if the internal anodizing contributes to improving the compatibility between the fluid and the material of the tube. Anodizing is an electrochemical process which consists in producing an oxide layer on the aluminium surface this layer of aluminum oxide (alumina) with hexagonal structure is compressed during sealing which is the last stage of the anodizing process. The sealing hydrates alumina pores, hampering the entrance of aggressive agent structure, making the tube more resistant to undesirable chemical reactions. In Life Test stands with 6 one-meter-long thermosyphon from Aluminum 6063, three of which are non- anodized and three - anodized. The thermosyphons* *were fixed in a vertical position, with the evaporator down (so-named reflux HP mode). The assembly was subjected to heating up to 100W with a maximum temperature of 80 °C using natural convection to cooling the condensation zone. The LT was run for 6 months and Temperature profile along each tube was measured and recorded in data acquisition system. Based on these preliminary results it was possible to determine the effect of non-condensable gases (NCG) by changing the temperature profile over last 4 months of operation. The experimental results are then used in a mathematical model that will be able to predict the location of the barrier and lencth of NCG in the HP. The conclusions about the reasons for generation of NCG in the devices were derived and analyzed.*

Keywords: *thermosyphon, anodizing*

1 INTRODUCTION

As a reliable passive two-phase thermal control device, heat pipes have been extensively applied to perform the temperature control in satellites and spacecrafts.

In space applications, HPs are mainly developed as passive thermal control devices of electronics, batteries, structures and sensors.

A special issue regarding the operation of HPs is always related to the working fluid used, especially when aluminum-ammonia HPs are used in thermal control systems. The purity and chemical stability of working fluids under Space radiation and materials used in HP as well as compatibility feature are determinative in space missions, which can last to 15 years.

It is always desired to find new potential working fluids that represent less hazard and lower costs for purification and charging. The search to substitute the so used high-saturated-pressure and toxic ammonia is related to reduce the hazard during the working fluid manipulation and operation. The selection of acetone also relies on its low freezing temperature (-93.15 °C), which is below the –78 °C for ammonia (Faghri, 1995). As the purpose of assessing the application and development of heat pipes with alternative working fluids, INPE adopted a research program CONTER (PJHPACETONA), which includes the development of two phase technologies employing low-pressure and low hazardous working fluids (Vlassov, 2008). To evaluate the compatibility with alternative working fluid, life tests must be performed. Life tests of HP are performed to verify the system behavior along time and the interaction between the tube and the working fluid or its usual impurities and admixtures.

In some cases can occur chemical reactions between fluid and metal and thus generate non-condensable gases (NCG) Swanson, T. D. (2006) presented the methodology of accelerated life tests for HP and showed the reliability in performing such a life tests in conditions that present higher temperatures than those for that the system was designed. In this work it was also concluded that the life test can be conducted over thermosyphon instead of real Heat Pipes. The thermosyphon is a heat transfer device consisted of a hollow metal tube and, diferently of heat pipes, does not have a capillary structure: the condensed fluid returns to the evaporator by gravity. Therefore, for that does not occur the lack of working fluid in the evaporator, because it always located below the condenser. (Peterson, G.P., 1994)

In order to contribute in improving the compatibility and thereby prevent the generation of non-condensable gases, there has been the realization the anodization process on the thermosyphon internal surface.

Especially for the development of this technology is designed thermosyphons to perform the life test of power up to 100 W, using acetone as the working fluid. This paper presents the results of the investigation of 6 thermosyphons Aluminium 6063, of which 3 are non- anodized and 3 anodized, in which the comparisons between the HPs are important to evaluate the influence on the HP overall performance.

2 PARAMETERS OF THE THERMOSYPHONS ANODIZING

The anodizing is a surface treatment whose goal is to produce uniform protective film on aluminum alloys. The anodic revetment is obtained by immersion of aluminum in aqueous acid solution, the electrolytic process; this layer consists of hexagonal cells with a superimposed central portion. (Reis, I. M. D. M., 2003; MIL – A – 8625F, 1993)

All anodization process comprises a preliminary degreasing, alkaline cleaning and an acid pickling. The formation of non-hydrated layer generates a compact thin base oxide structure and a hexagonal tubular pore such as shown in Fig. 1.

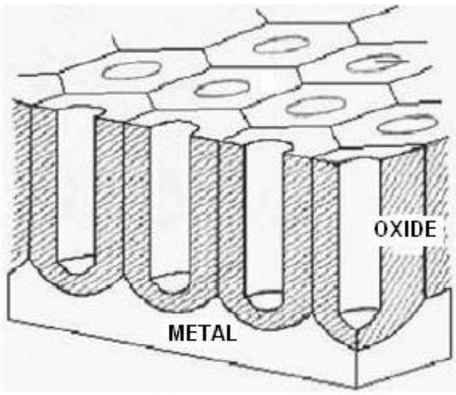


Figure 1- Structure of the anodized layer.

At the beginning of the cleaning process was conducted in the thermosyphon consisting of three parts: degreasing removing greases, oils, oxides and other contaminants residue surface. The pH should be between 9-11 and the temperature 60 to 80 ° C, and then the permanency time is 5 to 10 minutes. The matting that occurs soon after washing, is a slightly satiny solution that removes the organic elements being on the surface and its temperature action is around 60-70 ° C, so its operating time is around 5-10 minutes.

The neutralization removes any particles of intermetallic or hydroxides present on the surface of the tube is an aqueous sulfuric acid solution that function with a concentration of 120- 150g/L at environment temperature and its operating time is around 1-4 minutes . This allows acid to be chemically inert aluminum protecting it during washing in water prior to anodizing properly. (Reis, I. M. D. M., 2003; MIL – A – 8625F, 1993)

The tubes were treated with conventional sulfuric acid anodizing that is at environment temperature 17-24 ° C, with density varying of 1.5-2.0 A/dm^2 , the percentage aluminum in the solution was dissolved in 4g / L. The process was conducted with current and voltage 15-20V in about 120 minutes.

The anodizing process must to affect the wettability that is the key property of HP operation. To achieve the required wettability, the pores must be sealed as long as possible. In sealing the tube walls are hydrated to form hydrated alumina.

3 EXPERIMENTAL SETUP

The LT setup consists of 6 thermosyphons fabricated from Aluminium 6063 cylindrical profile, of which 3 are non- anodized and 3 anodized positioned at vertical orientation. The setup presented in the Fig. 2.

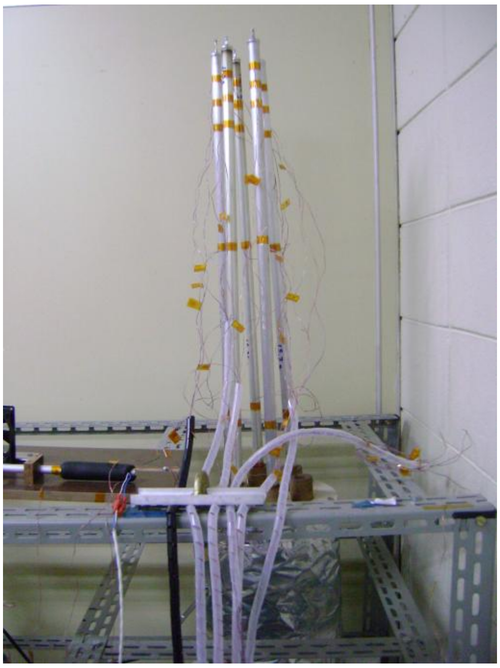


Figure 2- Thermosyphon Life Test Setup.

In Fig. 3 and in Tab. 1 are shown the configuration and location of the thermosyphons.

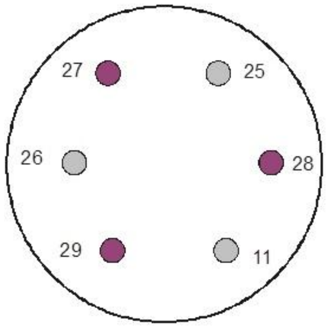


Figure 3- Configuration and position- Thermosyphon.

Table 1- List used in the testing of thermosyphon

Thermosyphon	
Thermosyphon non-anodized	**Thermosyphon anodized**
HP11 TC01-06	**HP27 TC19-24**
HP25 TC07-12	**HP28 TC25-30**
HP26 TC13-18	**HP29 TC31-36**

The thermosyphon were inserted and fixed inside the PVC (Polyvinyl Chloride) cylindrical container sealed at the ends where a commercial lamp 100 W for heating has been installed. The heating occurs by radiation heat transfer; to provide conditions for that, the evaporator zones were covered with high-emissivity Kapton flim, and internar surface of the container was covered with Aluminium high-reflectivity thermal blaanked. The PVC container has a length of 340 mm and radius of 110 mm, the upper top was pierced for the insertion of the thermosyphon. The container was insulated by 20-mm thick isopor from the ambient. Seven thermocouples are attached along the length of each thermosyphon to measure the temperature along the tube at different positions, see Fig. 2.
Basic dimensions of the thermosyphon are shown in Tab. 2.

Table 2- Geometric characteristics of Thermosyphon.

Total Length (mm)	**1000**	**Evaporator (mm)**	**200**
Diameter OD/ID (mm)	**19.05/15.08**	**Condenser (mm)**	**200**
Material	**Aluminum Alloy 6063**	**Average Charge (g)**	**13,29 ± 3g**

Total thirty six type-T thermocouples (deviation of ± 0.3 °C at 100 °C) were installed throughout all tubes.
A data acquisition system was responsible for reading and recording the temperatures, which was used to monitor the tube's behavior during the tests.
The tests were performed at ambient temperature that varied between 20 and 25 ° C.
The thermosyphons were charged with acetone .Tests were conducted by the following manner: 1) Daily connect the system to impose the power on the heating lamp to reach the maximum operating temperature of 80^{0}C, using natural convection for cooling in the condensation zone and with registration the time on-off; 2) monthly data

reading the system. It is important to note that the system must remain on daily as much as possible to accumulate hours in operation mode.

4 SIMULATION MODEL

The numerical simulation aims to reproduce the thermosyphon performance measured by the temperature profile in order to investigate hypotheses that explain this profile behavior. Fig. 4 shows the model built using the SINDA FLUINT software, on which were also placed the thirty-six thermocouples used in the experimental setup.

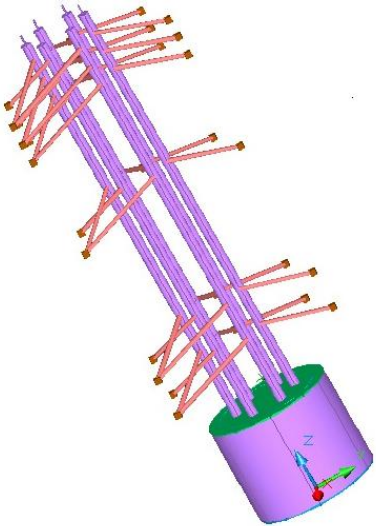


Figure 4 - Numerical simulation model that reproduced experimental setup using SINDA FLUINT.

The model consists of 32 submodels and contains total 2608 nodes. Each thermosyphons is simulated with 3 main parts: thermosyphon cross section, vapor channel and non-condensable gases blocked zone with variable length to simulate different experimental results possibilities.
Some thermosyphons presents characteristics shows a situation without non condensable gas generation, e.g HP 11, that was simulated with insignificant blocked zone for model validation.
The boundary conditions in the model reproduce the experimental setup and laboratory environment. Both, natural convection and radiative heat transfer to laboratory ambient were combined in the model to precisely describe the experiment conditions.
The components used to reproduce the temperature profile obtained by experimental setup characterized by high conductivity solids which simulate heat transport through the vapor channel thermosyphons as can be seen in Fig. 5.

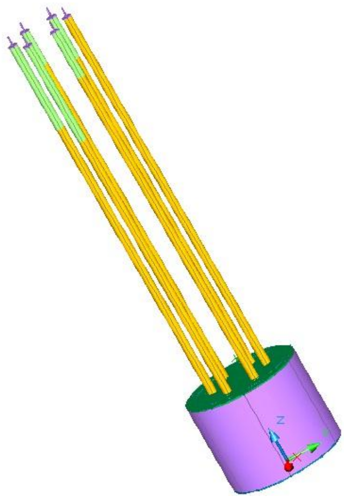
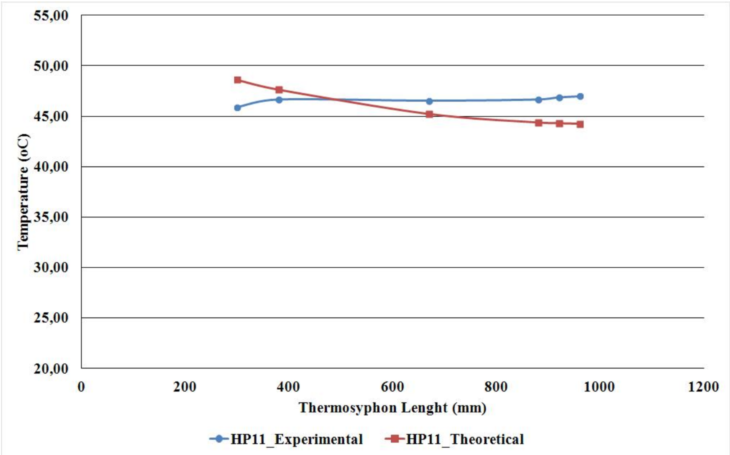


Figure 5 - High conductivity solids used to simulate the profiles temperature.

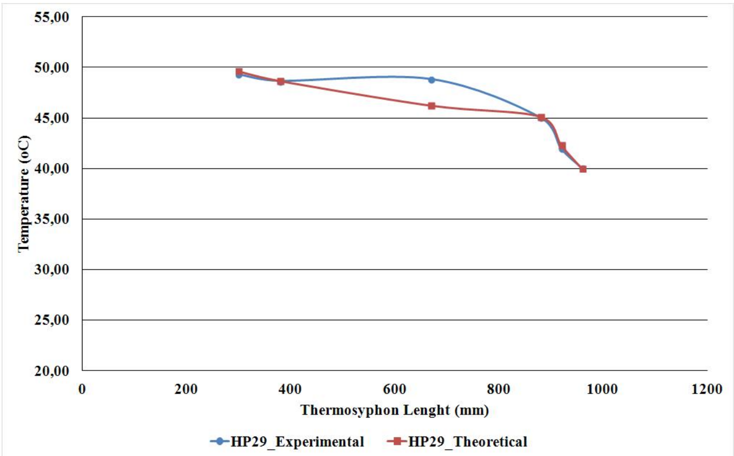
The hypothesis to be investigated through simulation model is the formation of a block in the channel vapor decreasing the thermosyphon heat transport capacity. The influence of this block is simulated by insertion of low conductivity solids in the model, showed in Fig. 5 in green color, which are coupled to high conductivity solids that simulate thermosyphons vapor channel, showed in the Fig. 5 in yellow color. The process of NCG length determination consists of several simulations varying the NCG length in the model by such a manner that the theoretical temperature profile fits the experimental profile by the best way based on the minimization of average temperatures deviations.

5 RESULTS AND DISCUSSIONS

The experimental tests with thermosyphon had a great importance for research, as based on the results; we were able to detect the NCG presence in several tubes and were able to determine the length of the blockage in each tube from measured temperature profiles of the LT run during 6 months. Developed detailed the mathematical model was able to predict the location of the barrier NCG in each thermosyphone. The following temperature profile is shown in the experimental and theoretical data along the entire length of each thermosyphon at steady state. To eliminate the influence of ambient temperature, the curves were plotted is relative temperature, i.e. condenser temperature above the ambient temperature (T_{cond}-T_{amb}); The sequence of graphs was determined according to the location of the thermosyphon system shown in Fig.3; Profiles are presented by pairs anodized-non-anodized for better visual comparison, however there is no any link between tubes in each pair and between pairs.



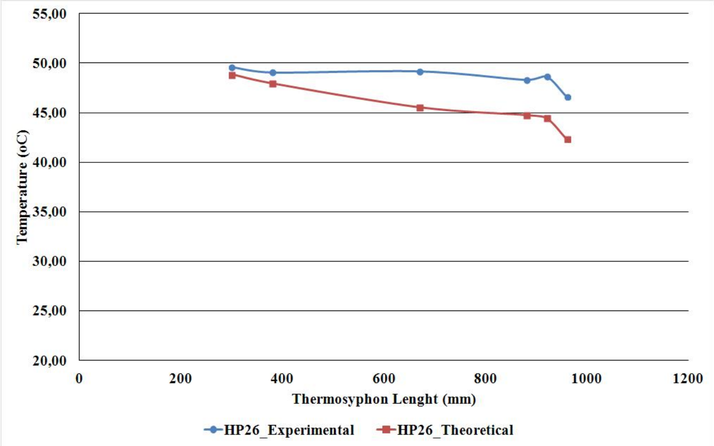
(a)



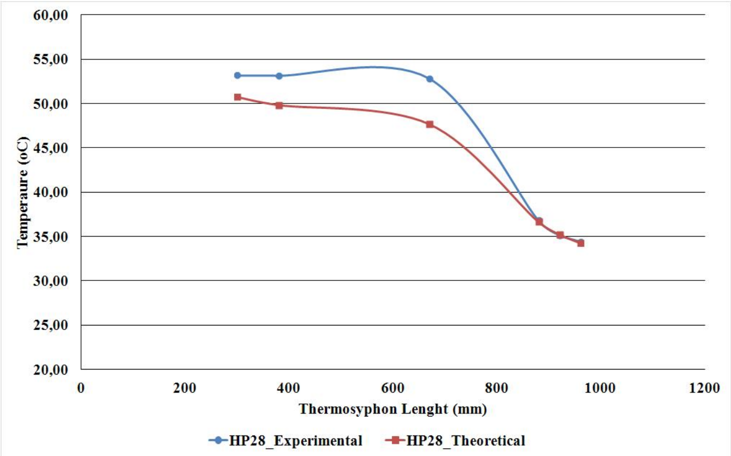
(b)

Figure 6- Theoretical and experimental temperature profile of- (a) non-anodized thermosyphon HP 11 and (b) anodized thermosyphon HP 29.

At Fig.6 (a) can verify a proper operation of the thermosyphon with no NCG. The temperature profile over the condenser length is a nearly horizontal line. The thermosyphon showed reliable operation and no indication of temperature difference at the end of condenser zone. In Fig.6 (b) shows the anodized thermosyphon temperature steady-state profile in the condenser region the temperatures go slightly down that can indicate a brief presence of non-condensable gases.



(a)



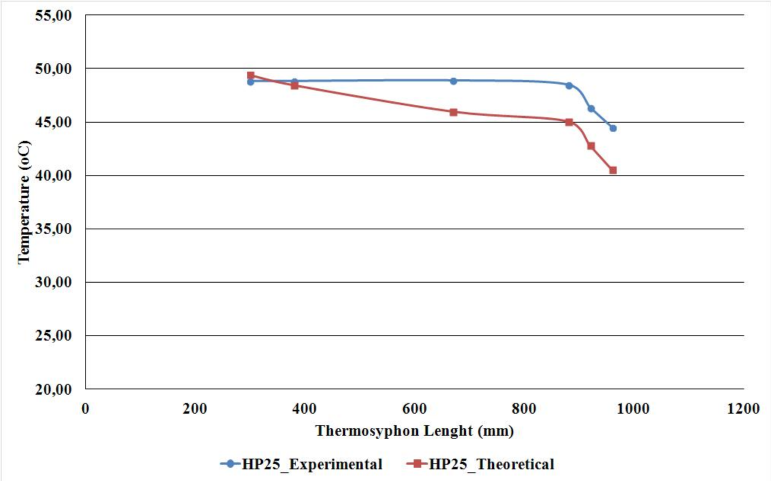
(b)

Figure 7- Theoretical and experimental temperature profile of (a) non anodized thermosyphon HP26 and (b) anodized thermosyphon HP 28.

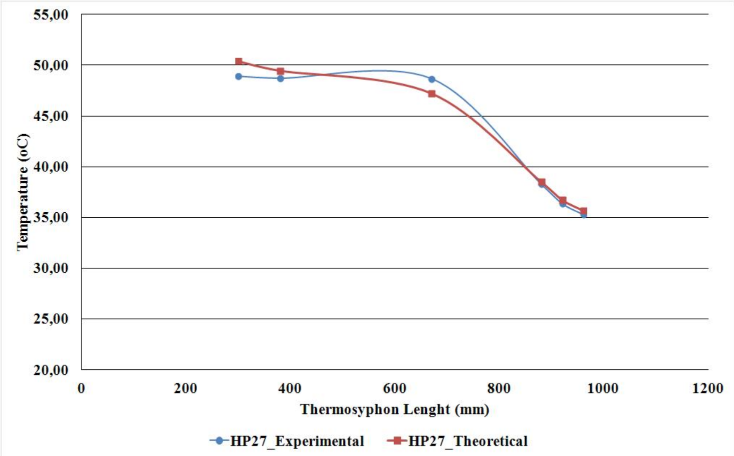
In Fig. 7 (a) thermosyphon temperature profile presented some degradation at the condenser end that also can indicate the presence of small amount of NCG.

In Fig. 7 (b) it can be observed the presence of non-condensable gases in an emphasized mode, that indicates a large amount of NCG generated. Such behavior of the thermosyphon is usually considered as inappropriate. By the analysis with the mathematical model, there was a reduction in the effective length of heat transport, which can be observed by the sudden drop in temperature in the thermosyphon.

The profiles shown in Fig. 8 are similar to those of Fig. 7.



(a)



(b)

Figure 8- Theoretical and experimental temperature profile of (a) non anodized thermosyphon HP25 and (b) anodized thermosyphon HP27.

Tab. 3 presents summary results on NCG length obtained with the mathematical model by the correlation with the experimental data.

Table 3 – Summary results on NCG length.

HP	Code	Treatment	Fill Charge Date	L_NCG (m)
HP11	HP11 1000 A2 00	No	2011-03-12	0,001
HP25	HP25 1000 A2 00	No	2012-12-18	0,1
HP26	HP26 1000 A2 00	No	2012-11-29	0,08
HP27	HP27 1000 A2 01	Anodized	2012-03-12	0,2
HP28	HP28 1000 A2 01	Anodized	2012-12-20	0,23
HP29	HP29 1000 A2 01	Anodized	2012-11-12	0,11

Fig. 8 (a), as well as Fig. 6 (a) and Fig. 7 (a) had an adequate performance as the performance of a thermosyphon. In two of three not-anodized thermosyphones at the end of the condenser there was a small decrease in temperature. This decrease at the end of the condenser did not have any problem in the operation of

the thermosyphon however indicates the presennce of NCG blockage zone. The only difference btween these thermosyphones that first one (HP11) was charged with acetone 99.8% of purity while others (HP26 and HP27) where charged with 99.5% acetone, that may explain the difference in the results.
In Fig. 8 (b) as in Fig 7 (b), in two of three anodized thermosyphon, charged also with 99.5% acetone, the behavior described above shows an anomaly by significant decreasing the temperature in the condenser. This is a characteristic of generation of large amount of non-condensable gases during operation of anodized thermosyphons. This is an unusual result because as expected the anodizing film should prevent the NCG generation.
One of the possible problems that may cause such intensive NCG generation is a possible local destructoin of the anodyzing film by a high temperature soldering of the pipe cups.
The photo on Fig. 9 shows color changes on the external surface, also anodized, after soldering.

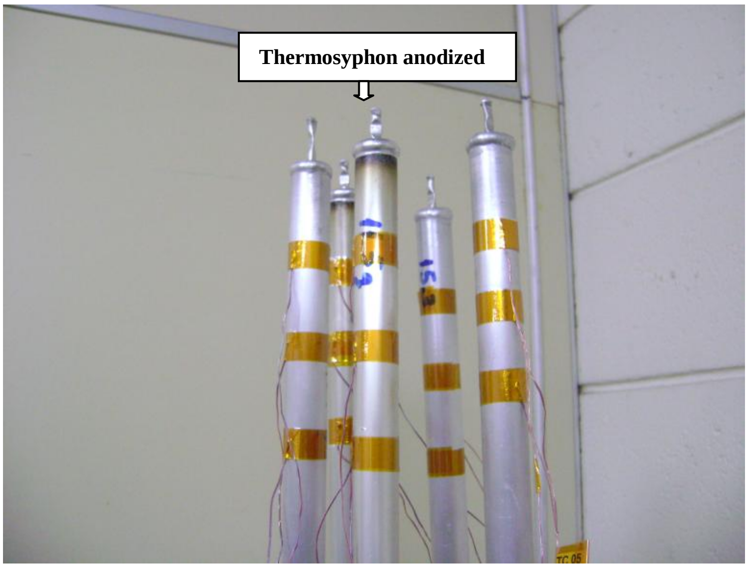


Figure 9- The thermosyphons anodized and non- anodized after soldering.

The soldering tends to stress the anodized film facing to differential expansion. Besides, the high temperature yields some additional chemical reactions over the sealing materials which produce some new chemical substances that in turn may provoke additional NCG generation. These new obtained data shall be still studied.

6 CONCLUSION AND DISCUSSIONS

Short time 6-mongth Life Test, considered as preliminary test, was conducted over 3 anodized and 3 non anodized thermosyphons in attempt to evaluate if the anodyzing can contribute to the reduction in NCG generation when easely available commertial 99.5 % acetone used as a working fluid. The detailed mathematical model was developed which was able to simulate the termosyphon behavior with part of vapor core blocked with NCG. The length of NCG blockage was determined by correlation the theoretical temperature profile by experimental data.
The non- anodized tubes were charged with 99.8 % acetone (HP11) and with 99.5% (HP25 and HP26). After LT, the last two showed slight degradation in performance that indicates a small amount NCG generation. HP11 did not show any signs of degradation. It confirms that the purity of acetone influences HP life time and certain efforts have to be carries out to additional purification in case the commertial acetone 99.5 % is used.
As for anodizad tubes, all of them presented a significant degradation in performance that as assumed is a consequence of large amount of generated NCG. However the straightforward conclusion that the anodizing provokes additional NCG generation may be false and incorrect. It was observed, that high-temperature soldering affects the anodizing film by different ways, including possible production of some new chemical substances that in turn may provoke additional NCG generation.
Therefore, instead of answer the obtained new questions and new studies shall be continued. The next steps to perform will be the chemical analysis of the acetone taken from the anodized tubes, probably an infra-red analysis and analysis with the mass spectrometer, and microscopic destructive analysis of the internal surface in the locals affected by soldering.

7 ACKNOWLEDGMENTS

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