ATLAS project	*ATLAS Inner Detector Evaporative Cooling System* *Tests*		
ATLAS Project Document **ATL-IC-ER-0002/II**	Institute Document No.	Created: ***25/10/2003*** Modified: ***06/11/2003***	Page: ***1 of 12*** Rev. No.: ***1.2***

Inner Detector Evaporative Cooling System

Heat exchanger, heater and capillary tests II

(Part 2 – ***Pixel Discs*** *power loads)*

Abstract

This document describes the test performed at CERN with Pixel disc sector loads and adequate behavior of the heat exchanger of the C1 type with different installed capillaries .
The performance of NEW heat exchanger, capillaries at the various operating and test conditions are presented and discussed in detail.

Prepared by:	Checked by:	Approved by:
V. Vacek – CERN&CTU Prague	**B. Gorski, CERN & TU Crakow**	

Distribution List

History of Changes

Rev. No.	*Date*	*Pages*	*Description of changes*
1.0	24/10/2003	Introductory [1-7]	The first draft after the initial runs were performed. Modification of the cooling circuit was necessary (It took a place at Bldg. 175 between October 22 and 23 of the year 2003)
1.1	26/10/2003	All	The extended version followed by the the evaluation of the complete run with capillary ID=0.47 mm of the legnth L=1.25m
1.2	04/1182003	**Some corrections**	Overall check of the Aluminum ID was performed after the tests. It was found that Al capillaries, used for the pixel power load tests and the HEX performance test have the different ID from the implied value 0.47 mm. **The real diameter** of the Aluminim capillary **is ID = 0.55 mm.** [See the closing notes]

Table of Contents

1 INTRODUCTION 4

2 THE COOLING CIRCUIT CHARACTERISTICS 4

2.1 Set up changes: 5

3 INSTRUMENTATION AND DAQ: 7

4 MEASURING PROCEDURES 8

4.1 Standard approach both capillaries: 8

4.1.1 1st Aluminum capillary, ~~ID=0.47 mm~~ ID=0.55 mm , effective length 1.83 m 8

4.1.2 2nd Aluminum capillary, ~~ID=0.47 mm~~ ID=0.55 mm, effective length 1.25 m 9

5 HEAT EXCHANGER AND HEATER PERFORMANCE 11

6 SUMMARY 12

Notes: 12

1 Introduction

These measurements were urgently requested and they just preceded the tests of the SCT prototypes. Vic Vacek and Bogdan Gorski conducted the tests between October 23 and October 25, 2003. Some technical assistance was kindly provided by Jocelyn Thadome. The main tasks of the measurements were similar to the barrel ones and the goals were as follows:

- to verify the function of the heat exchanger type C1, [the HEX], with pixel disc loop at projected parameters (nominal refrigerant flow around 1.31 g/s, projected max. power load on the disc loop approximately 85 W),
- the previous measurements performed by LBL colleagues and CTU colleagues in early September 2003 were realized with much refrigerant overflow (2 times higher than nominal value),
- to find running parameters for the Cooling circuit (acceptable pressure ranges, optimal flow limits with the installed HEX)
- to find limits or a recommendation for the length of the capillary
- to study "stability resistance" of the running cooling circuit with respect to the sudden changes of the stave power loads.

2 The cooling circuit characteristics

Existing cooling set up, installed in the Bldg. 175, has been used for the measurements. The schematic representation is showed in Fig.1. The schematic reflects the installation of the new heater that is controlled via PLC.

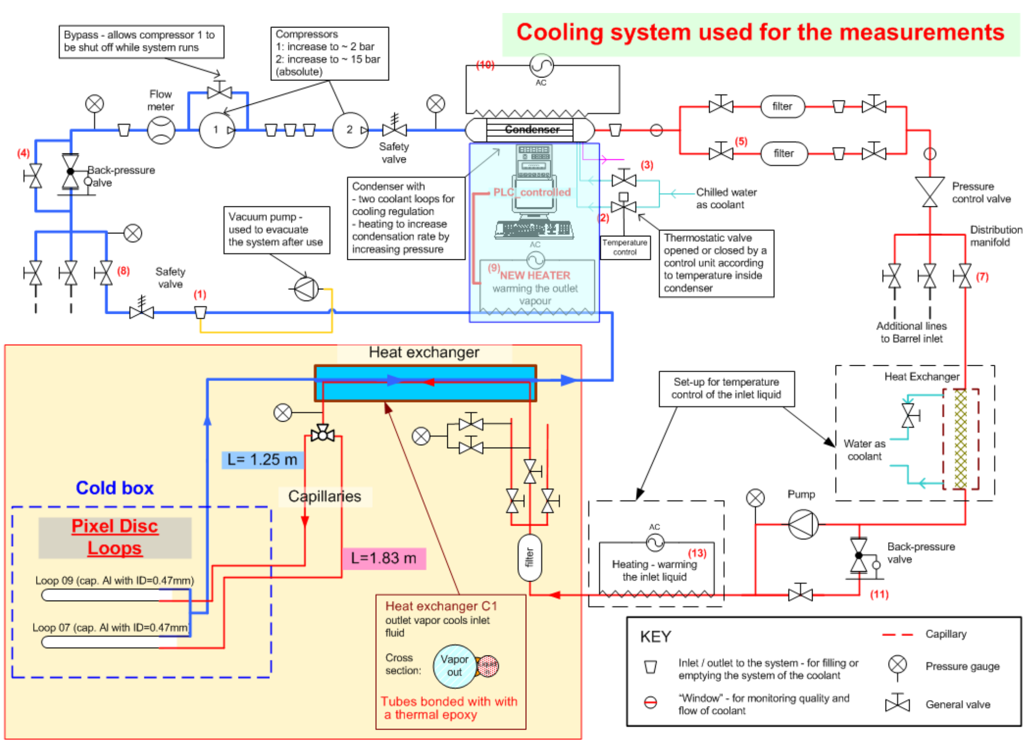

Figure 1: Cooling set up modification prior to pixel disc mock up measurements

The identical heat exchanger (HEX), as described in previous report ATL-IC-ER-0002, has been used. Its characteristics are summarized in the Fig.2 and explained below.

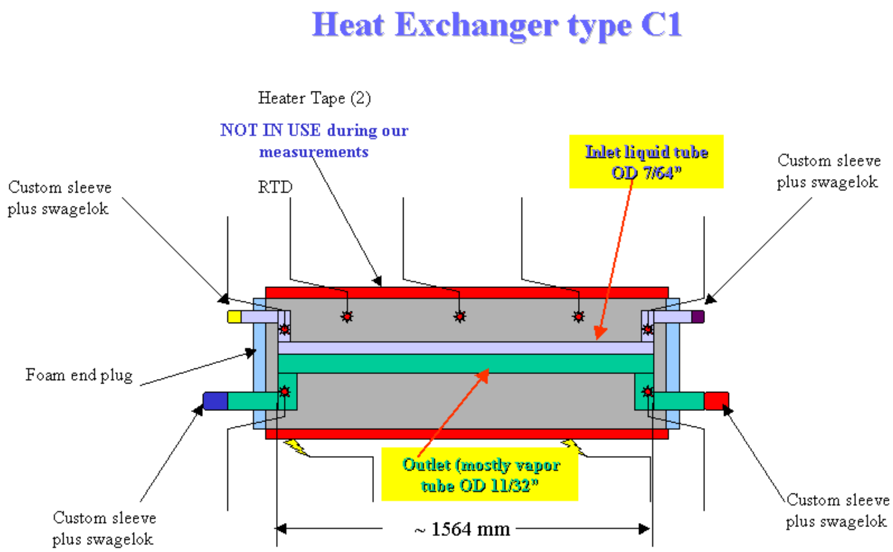

Figure 2: Heat exchanger (the HEX) type C1, manufactured at the LBL and being used during the tests.

The heat exchanger is shaped by the liquid supply tube of the ID=2.07 mm that is attached the to exhaust tube of ID=7.92 mm. The approximate contact length is1500 mm. Bonding of the supply tube to the exhaust tube is done with a thermal epoxy of thermal conductivity coefficient ~ 4 W/m^2-K. The standard swagelok were used to connect appropriate tubes.

2.1 Set up changes:

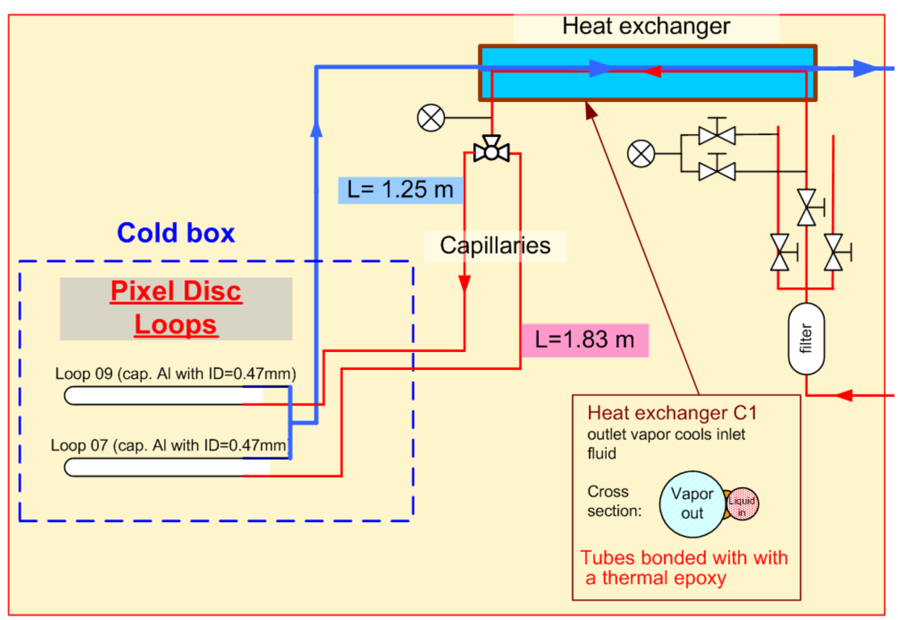

Figure 3: Investigated Aluminum capillaries and the heat exchanger [real ID=0.55 mm]

The cooling circuit was opened and two different Al capillaries were installed between the HEX of the C1 type and pixel mockup structure. Two capillaries both with ID = ~~0.47~~ 0.55 mm, had lengths L=1.25m (Loop09) and L=1.83 m (Loop07) respectively.

There were no real disc structures available, so the existing pixel loops were used instead loaded with discs powers. Average pressure drops over the loops during the measurements displayed values around 0.03 bars.

The new heater has replaced a manually controlled old heater and there were some minor additional changes done on the adequate pipelines.

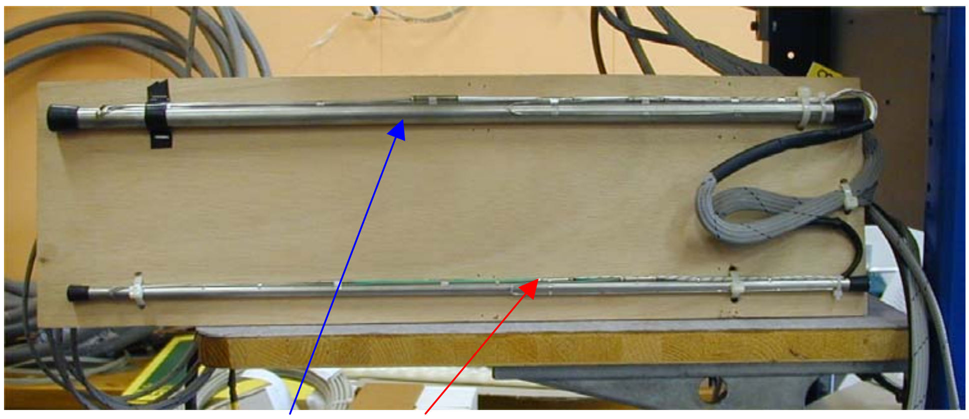

Figure 4: The new heaters for the **SCT** and **Pixel** loops

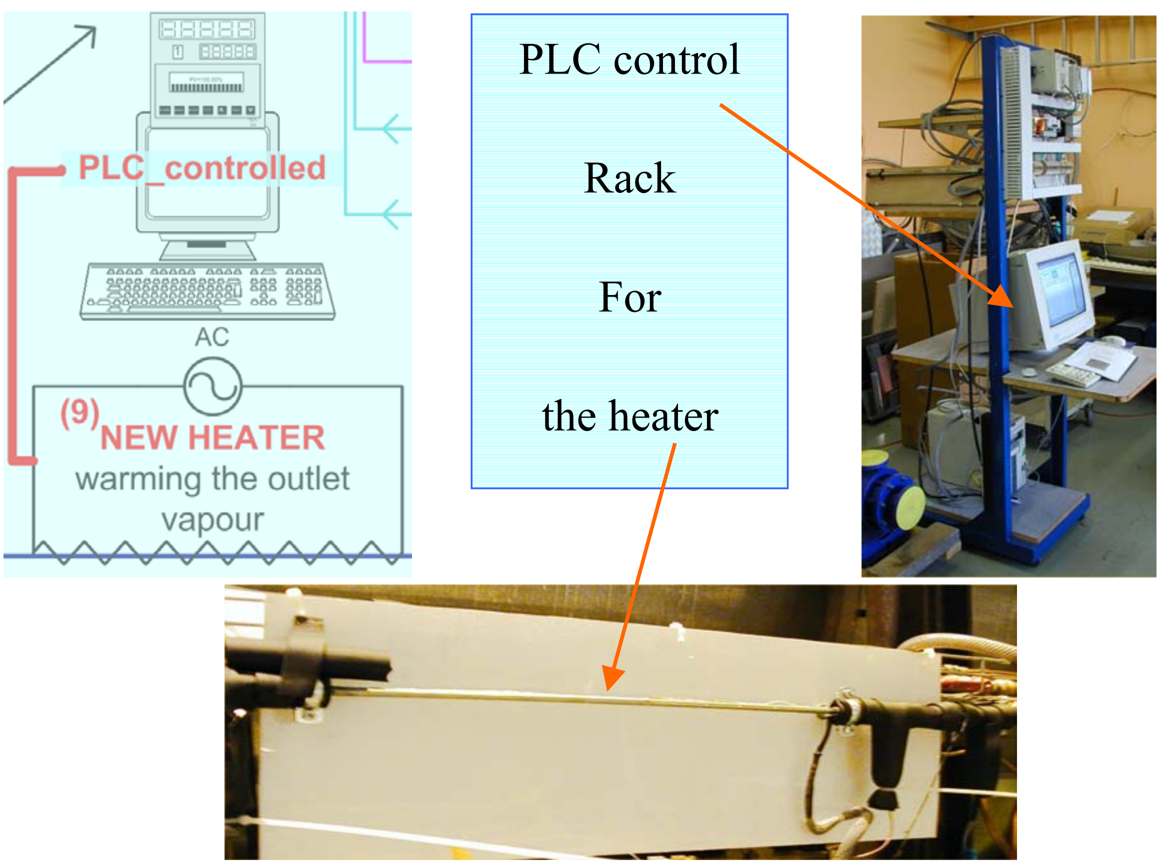

Figure 5: Schematics of the control and monitoring PLC system and the heater detail within the circuit

3 Instrumentation and DAQ:

The basic information about the DAQ layout and sensors bring Fig. 6 and Table 1.

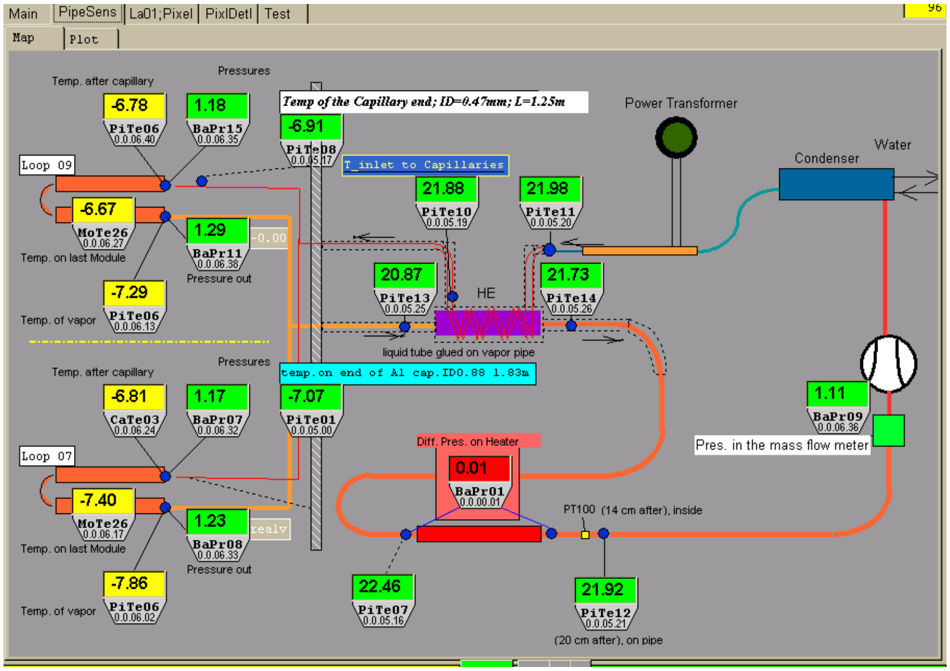

Figure 6: DAQ sensors layout

Table 1: Sensor description.

ELMB	Channel	Name of the sensor	Position of the sensor
0	1	BaPre01	Pressure drop over the **heater**
5	0	Pite01	End of the Al capillary L = 1.83 m
5	16	Pite07	Inlet temperature into the main heater
5	17	Pite08	End of the Al capillary L = 1.35 m
5	18	Pite09	outlet temperature from the main heater
5	19	Pite10	Temperature inlet into the both capillaries
5	20	Pite11	Temperature of the preheated liquid [usually around 40 C]
5	21	Pite12	Temperature after the **main heater** [On the tube_ 20cm after]
5	25	Pite13	Temperature of the vapor entering the HEX
5	26	Pite14	Temperature of the vapor exiting the HEX
6	2	Pite06_1	Outlet temperature of the vapor from 2nd stave Loop 07
6	13	Pite06_2	Outlet temperature of the vapor from 2nd stave Loop 09
6	17	Mote26	Modul temperature on the 2nd stave Loop07
6	24	Cate03	Inlet temp [or outlet capillary temp] into the stave Loop 07
6	27	Mote26	Modul temperature on the 2nd stave Loop09
6	32	BaPr07	Inlet pressure [or after capillary] 1st stave Loop 07
6	33	BaPr08	Outlet pressure_ 2nd stave Loop 07
6	35	BaPr15	Inlet pressure [or after capillary] 1st stave Loop 09
6	36	BaPr09	Pressure in the flow meter
6	38	BaPr11	Outlet pressure_ 2nd stave Loop 09
6	40	Pite06_3	Inlet temp [or outlet capillary temp] into the stave Loop 09
PLC	New heater	**To be added:**	**Values monitored by PLC DAQ system**
PLC		Pt100_1	In the tube 14 cm after the heater
PLC		Thermocouple "K"_1	On the heating element
PLC		Thermocouple "K"_2	On the outer surface of heater
PLC		Heater [cycles]	"ON" and "OFF" profile
PLC		Power [W]	Power input of the heater

Fig. 6 introduces the valid layout of the sensors read via ELMB' s by the PVSS Pixel project 20. Two new sensors were attached to the ends of both capillaries and a differential pressure transducer was installed to measure the pressure drop over the new heater. The detailed explanation of the sensors and their placement within the investigated loops are summarized in the Table1.

Number of measured values was still unfortunately required to be read from analog devices (pressure drops over the HEX, both on liquid and vapor side, temperature in the flow meter, flow meter value – in m^3 and appropriate elapsed time from the stop watch to evaluate the mass flow, etc.). The synchronization of the two set of data from the PVSS and PLC has to be improved.

Some improvements are foreseen soon, once the new pressure sensors and mass flow meter arrive.

4 Measuring procedures

The starting conditions for all runs were similar. Normal set conditions were as follows: drive pressure set by pressure regulator ≤ 16 bar_a [possibly close to 14 bar_a]; back pressure setting ~ 1.9 to 2 bar_a [i.e. evap. temperature ~ -22 to –20 ºC]; inlet liquid entering the HEX preheated up to temperature ~ 40° C.

4.1 Standard approach both capillaries:

- Start of the system with 0% power load on the staves and set the flow close to the nominal value in the circuit with preheated inlet liquid refrigerant temperature up to 40 °C entering the heat exchanger (HEX).
- Increase step by step the power load, tuning the input pressure, and observe the behavior and stability of the system.
- Once the 100% of power is reached check if the outlet vapor quality from the heated structures is <=0,9. If not increase the flow until the outlet quality is sufficient.
- Make several power circles and check the stability of the system, keeping the inlet pressure setting the same. If the same conditions at 100% power are not reached back after a power trip, then investigate the power ramp up/down rate required to achieve stable behavior (Power step changes of 25%, 50% and 100% were used).

4.1.1 1st Aluminum capillary, ~~ID=0.47 mm~~ ID=0.55 mm , effective length 1.83 m

The first runs with the capillary indicated that it is rather long for the present set up and normal run conditions. It would require significant increase of driving pressure (above 16 bar_a) to deliver enough fluid to cope with higher power load changes. It was decided to switch our investigation to the shorter capillary studies immediately.

4.1.2 2nd Aluminum capillary, ~~ID=0.47 mm~~ ID=0.55 mm, effective length 1.25 m

Overall summary of the longest run with heavy power cycling's is shown on the Fig. 7.

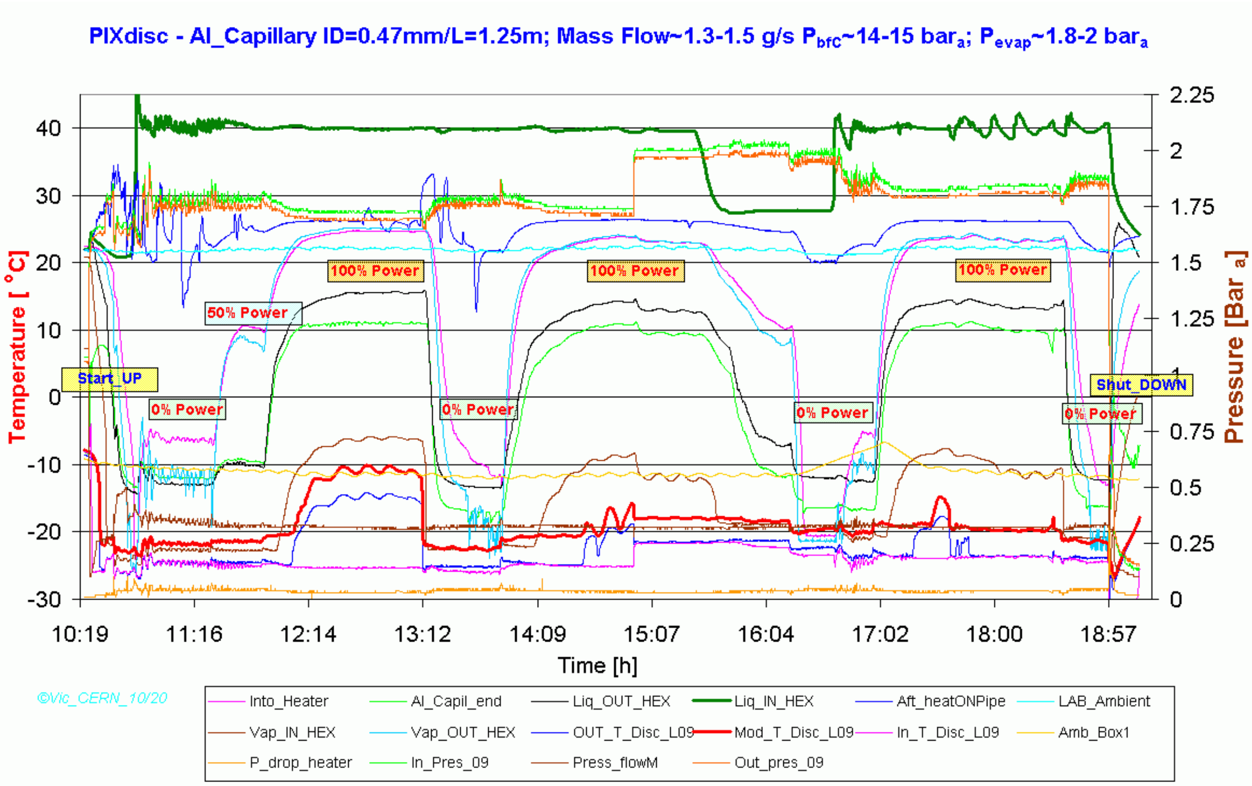

Figure 7: 2nd Al capillary, ID= **0.55** mm, effective length 1.25 m exposed to the disc power load changes

The staring running conditions were set up in the following manner:

Driving pressure	p_{bfC}	= 14 bar_a
Evaporation pressure	p_{evap}	= ~1.8 bar_a
Mass flow	mFl	= ~ 1.30 g/s
Pressure drop over the capillary	dP	= 12 bar

The 2nd Al capillary performed reasonably well, but it has also shown some slight difficulties around the boundary value of the nominal projected flow. This indicates that the capillary's length is just at limit for the current arrangement and design. Nevertheless, it could nearly cope with the power load variations of the disc – changing the power between 0% and 100% [85 W] with steps of 50% [42.5 W].

The fixed flow is not strictly "fixed", due to the evident "self changes" of the flow while the power loads were varied. These "self" variations (from 1.3 to 1.5 g/s) have significant impact on the HEX functioning.

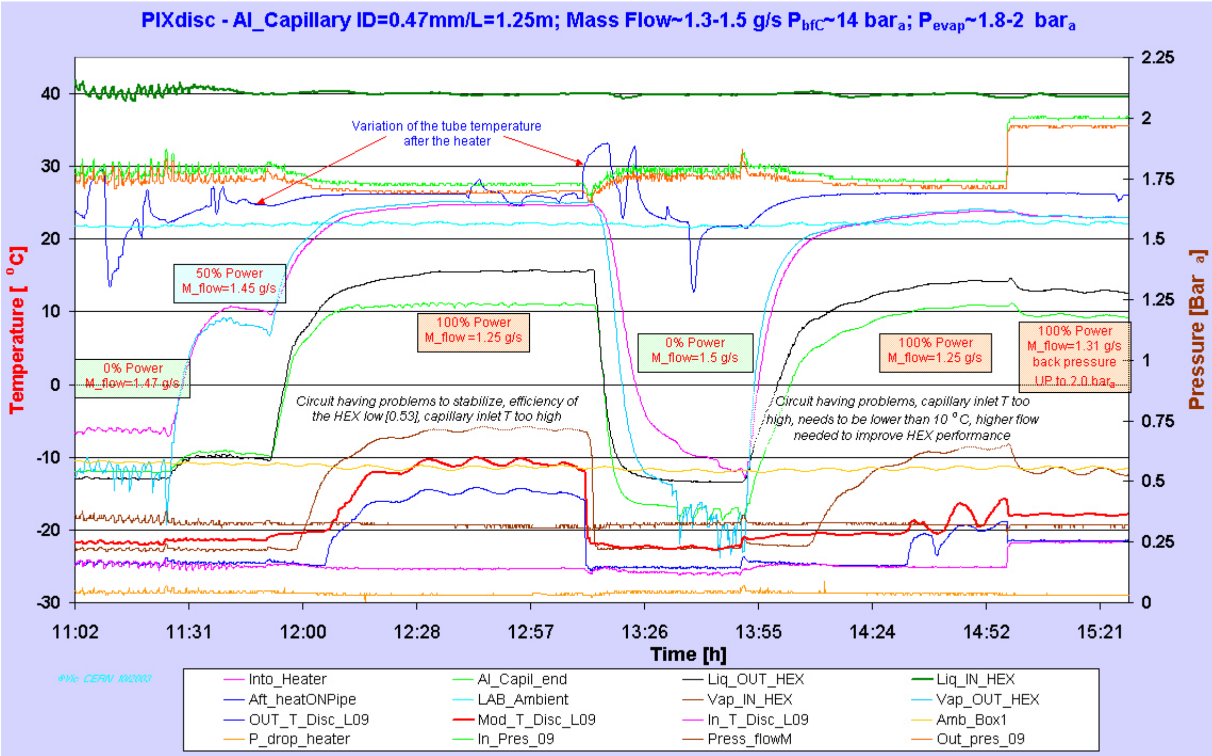

Figure 8: 2nd Al capillary, ID = **0.55** mm, effective length 1.25 m at different run conditions

The results in Fig. 8 show that the performance of the circuit is just at the "edge" after the maximum power load jumps. Some corrections are necessary; the fastest one is to increase p_{evap} and to gain a few kJ/kg of latent heat necessary for the HEX.

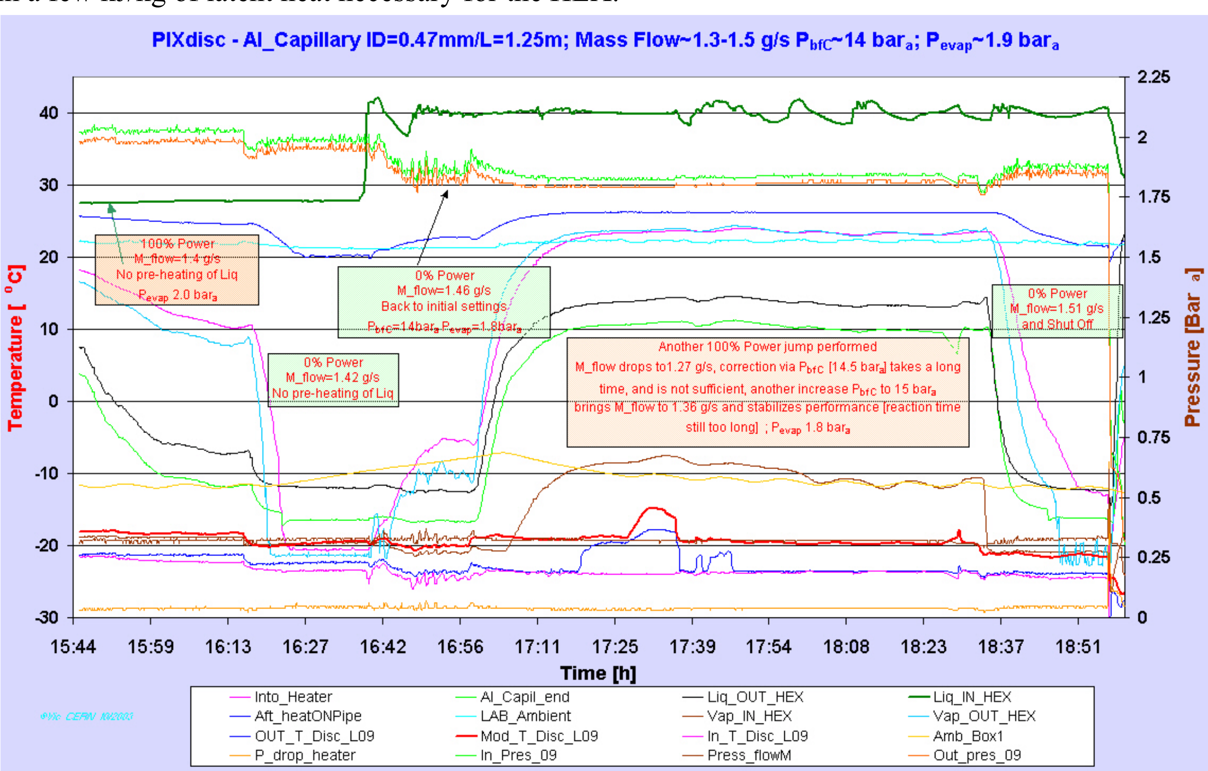

Figure 9: 2nd Al capillary, ID = **0.55**mm, effective length 1.25 m under the changes of the run parameters

5 Heat exchanger and heater performance

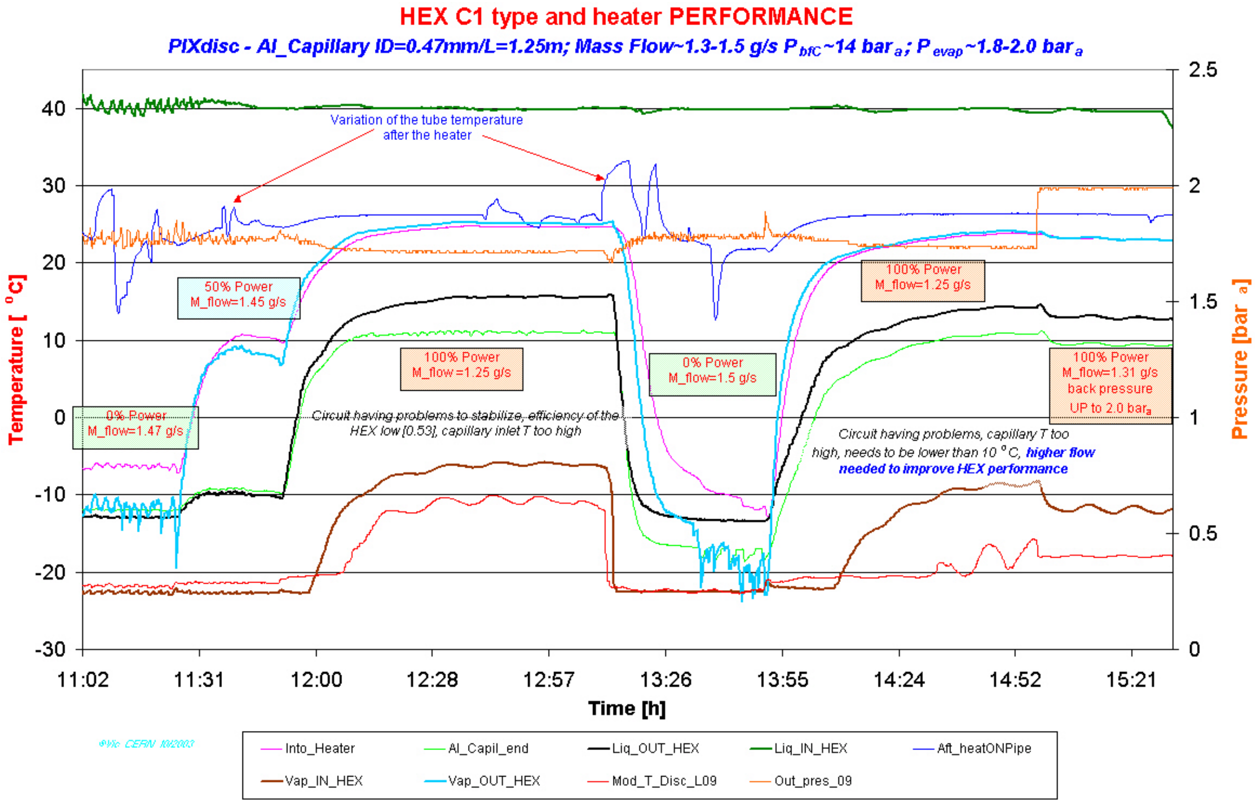

Figure 10: Extracted temperature profiles along the HEX and the heater

Similar conclusions also apply for the tests with pixel disc loads to those explained in document concerning barrel tests (ATL-IC-ER-0002). The current positioning of the heat exchanger (HEX) in the region where two-phase flow may occur in the outlet (exhaust) tube, transforms the HEX in to the "not uniquely determined one". It is then not easy controlled combination of the evaporator (section, where some excess liquid droplets will evaporate – with relatively high heat transfer coefficient) and counter flow HEX with already superheated vapor in the outlet tube (having a low heat transfer coefficient) on one side and liquid in the inlet tube on the other side. A contact heat exchange surface between the two is very limited by the HEX design itself.

The inlet temperature of the capillary plays an important role and under the constant driving pressure p_{bfC} it should be kept maximally stable (i.e. to fix starting point before throttling in the capillary). The temperature should be lower then 10 º C for the pixel disc power loads and for the currently used HEX (The value can be slightly higher than for the pixel barrel loads, where the recommended value was below 5 º C, due to the lower mass flow and consequently lower heat transfer between the fluids).

This can only be achieved, when the mass flow of the refrigerant is approximately 15% higher then "estimated" nominal value. The excess mass flow of the refrigerant is then used to improve "efficiency" of the HEX (in fact, expanding its "evaporative portion" part).

The new heater performed well with relatively small power cycling ranging between 50-70 W when no power was imposed on the disc loop. Once the maximal power load was applied on the disc loop, we have observed powers on the heater in the range of 10 to 15 W. We have to note that control algorithm for the PLC regulation is still under the development and the observed value may change.

6 Summary

The aluminum capillary with ID=0.47mm and the effective length of 1.25 m was very stable at the intermediate loads of 50% [~42.5 W], 75% [~64 W] per disc loop, and, of course, under 0 W loading. With full power load 100% [~85 W] we had to make minor corrections to the circuit run parameters, very often due to the unstable pressure regulator keeping the driving pressure. The results from our measurements and comparisons with capillary length prediction calculations lead us to conclusion that capillary could be even slightly shorter. Respecting the present status of design development, available hardware and quality of measuring instruments, we conclude that for the pixel disc loop and the current heat exchanger (the HEX, type C1) the following set of running conditions and capillary specification is recommended:

- Capillary, ID=0. **0.55** mm, with the effective length 1.1 m
- Driving pressure p_{bfC} = 14 bar_a
- Evaporation pressure p_{evap} = ~ 1.9 bar_a
- Mass flow mFl = ~ 1.5 g/s
- Pressure drop over the capillary dP = ~12 bar.

These recommendations assume that:

1. The quality of the all the produced HEX's will be uniform, i.e. contact heat exchange surface [being a relatively small] realized by the epoxy bonded tubes will be comparable and it will survive 10 years of operation in a "healthy state".
2. Mass flow of the refrigerant is at least 15% higher then the nominal design value (1.31 g/s).
3. Inlet temperature of the liquid into the heat exchanger is kept constant at the level not higher than 40 º C.
4. ID of the capillary is uniform and its ID and pressure drop will be checked and verified before use.

Notes:

- **Measurements of the inner diameter of the Aluminum capillaries have been performed, after the tests, with three different samples and two different filling fluids during the observations [water and C_6F_{14}]. It is obvious that the implied value 0.47 mm of the Aluminum capillaries has in reality different value, ie. ID = 0.55 mm**
- It has been again observed that a pressure regulator is not keeping the steady inlet pressure and needs "slight corrections", i.e. micro tuning – at the border conditions it may effect negatively the stability of the cooling circuit performance.
- Cooling system still needs general maintenance to improve leak tightness.
- New electronic sensors should be employed especially for the precise pressure and flow measurements.