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Advanced European Infrastructures for Detectors at Accelerators

Poster

Evaporative flow of Carbon Dioxide in micro-channels for detector cooling

Hellenschmidt, Desiree

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Evaporative flow of Carbon Dioxide in micro-channels for detector cooling

D. Hellenschmidt, CERN and Rheinische Friedrich-Wilhelms-Universität Bonn

Problem

- Minimizing the material to be crossed by a particle in a high energy physics particle tracker is one of the main constraints superimposed by physics onto the detector design
- The smaller the *Material Budget* the more accurate the detector
- This also applies for the **cooling technology** selected for the detector
- Conventional cooling methods use metallic pipes and ledges
- However, pipes, heat spreaders, thermal contact materials and local heat sinks add to the material budget and increase the mismatch of *coefficient of thermal expansion (CTE)* between the materials which may lead to mechanical stresses in the detector structure

How can these disadvantages be minimized to create an even more accurate detector?

A novel answer

A rather novel detector cooling method is the so-called

MICRO-CHANNEL COOLING

a method which was transferred from cooling of computer chips to *high energy physics (HEP)* experiments.

METHOD:

Micrometer sized channels are implemented into silicon wafers to form a microfluidic heat exchanger, where it is possible to circulate various coolants according to the wanted performance

Fig. 1 Micro-channels for the LHCb – Velo Upgrade

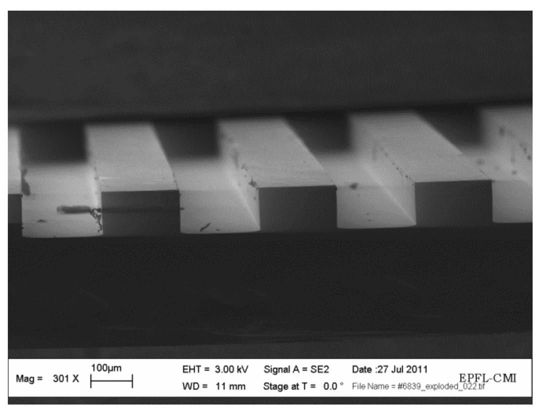


Fig. 2 Silicon micro-channels etched by plasma to obtain vertical sidewalls [Mapelli, 2012]

ADVANTAGES for HEP experiments:

- Reduction of material crossed by the particles
- Since this cooling method is designed mainly for the Silicon Semiconductor Pixel detectors a mismatch in CTE can be avoided
- The micro-channels can be placed in direct contact with the silicon surface of the detector and no heat spreaders are needed
- The large heat transfer surface involved allows for low temperature differences between heat source and heat sink
- Many different geometries are possible with micro-channel cooling to adapt to different detector configurations and is therefore a quite flexible approach

A rather novel refrigerating option is

EVAPORATIVE CARBON DIOXIDE

Unlike single phase heat transfer, which relies totally on the coolant's sensible heat rise, two-phase heat transfer uses the coolant's combined sensible and latent heat. Thus far greater amounts of heat can be absorbed [Kim, 2014].

Furthermore CO2 …

- is an ozone friendly fluid with a Global Warming Potential of 1
- has a very good heat transfer coefficient compared to traditional refrigeration fluids [Zhao, 2000]
- has a higher reduced pressure for a given saturation temperature [Ducoulombier, 2011].

This leads to …

- higher vapour density, lower liquid viscosity and lower surface tension [Ducoulombier, 2011].
- lower pressure drops (very important for small tubes) [Yun, 2005]

… just to mention a few benefits

Theoretical Approach

An extensive literature review has been carried out during the first year of activity:

LITERATURE REVIEW FINDINGS

- Many publications on micro-channel cooling seem to contradict each other. Reason for this is the fact that no systematic research was carried out so far (same refrigerant, same channel size, same flow parameters)
- Some publications are acknowledging certain uncertainty factors, some do not
- An arbitrary definition of micro-channels is used so far and no general definition is yet given
- Many correlations on fluid flow and heat transfer in micro-channels are found empirically and thus can not predict very well a different data set
- Non-empirical models are still rare and some physical behaviors in the channels are still subject of speculation

Based on the above given issues we have launched a very ambitious

RESEARCH PROGRAMME

- Minimize the uncertainty of the experiments by better controlling of possible error sources
- Create a bigger database with experiments carried out at different research sites (in collaboration with Universities in Manchester, Oxford & Twente)
- Finding and testing a theoretical micro-channel definition [based on the preliminary work of Y. Moussy]
- Furthermore this project seeks to extend the research with evaporative CO_2 in micro-channels further towards negative fluid temperatures and actual micrometer sized channel diameters

Experimental Approach

STEP 1 : Test simple single channels / tubes

To address the complexity of the physical processes occurring in micro-channels and for their better understanding

STEP 2 : Test more complex channel geometries

To address the immediate need for micro-channel cooling in HEP experiments using the gathered insights and results from Step 1

Parameters under test	Method
Fluid flow properties	DIRECT: flow visualization with high speed camera
	INDIRECT: Temperature & Pressure measurements
Heat transfer	DIRECT: Temperature measurements in the flow and on surrounding equipment
	INDIRECT: heat transfer visualization with infrared camera
Pressure drop	Absolute & relative pressure transducers

Preliminary tests

Preliminary tests were carried out on a setup at *Manchester University* with a so-called CO_2-Blow-System. Here CO_2 from a gas bottle is 'blown' into an experimental tube for measurements (CO_2 is not recirculated!)

MEASUREMENTS:

- Pressure (P1 & P2)
- Internal Temperatures (T1 & T2)
- External Temperatures (Thermocouple 1-6)
- Heat generation via Joule heating to simulate heat source

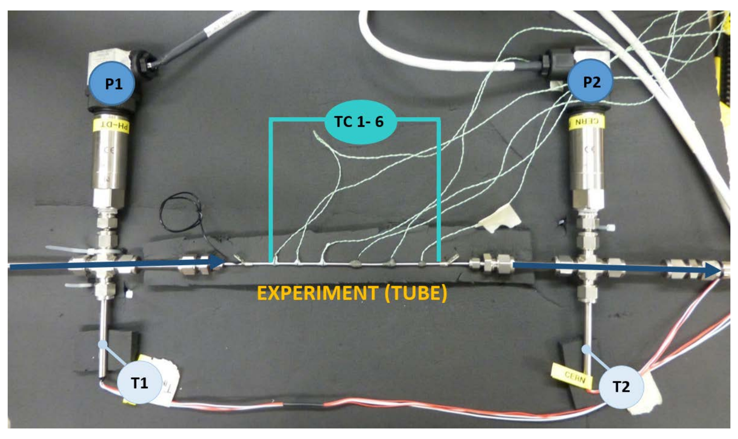


Fig. 3 Setup for evaporative CO_2 flow measurements

FINDINGS:

- It was difficult to set a constant flow for the experiment
- Thus steady-state data was not easily obtained

The gathered data was compared with a sophisticated model developed at CERN for evaporative CO_2 flow and heat transfer (COBRA = **CO_2 Bra**nch Calculator). The data is predicted well for a 1 mm tube since COBRA is established for tube diameters from 0.6 mm to 10 mm. For smaller channel sizes the validity of the model still has to be confirmed.

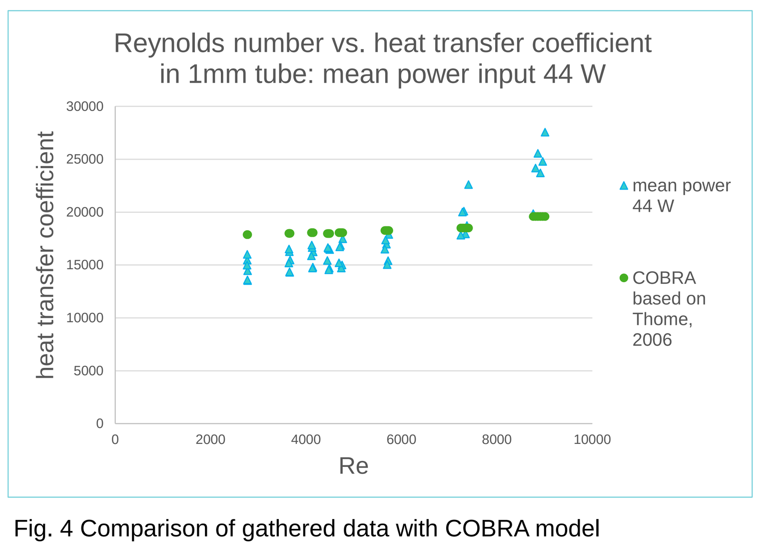


Fig. 4 Comparison of gathered data with COBRA model

CONCLUSION: To gather more accurate data a different setup is needed.

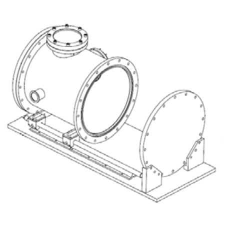
Experimental Setup

A new test stand has been designed for testing micro-channel cooling with 2-phase CO_2 in a more controlled surrounding. The main components are:

2-phase CO2

Transportable Refrigeration Apparatus for CO_2 Investigation (TRACI) CO_2 is recirculated!

vacuum surroundings



Vacuum vessel for adiabatic test conditions for more accurate heat transfer measurements

Pressure & temperature sensors

High precision measurements for flow & heat transfer applications

Flow meter

Direct high precision measurement of the mass flow rate

MEASUREMENTS inside the vacuum vessel:

- pressure and temperature sensors before and after the experiment (Measurement points = MP1 to MP4)
- temperature sensors on the experiment
- two Peltier elements as pre- and post-heater
- Mock-up heater (Joule Heater)

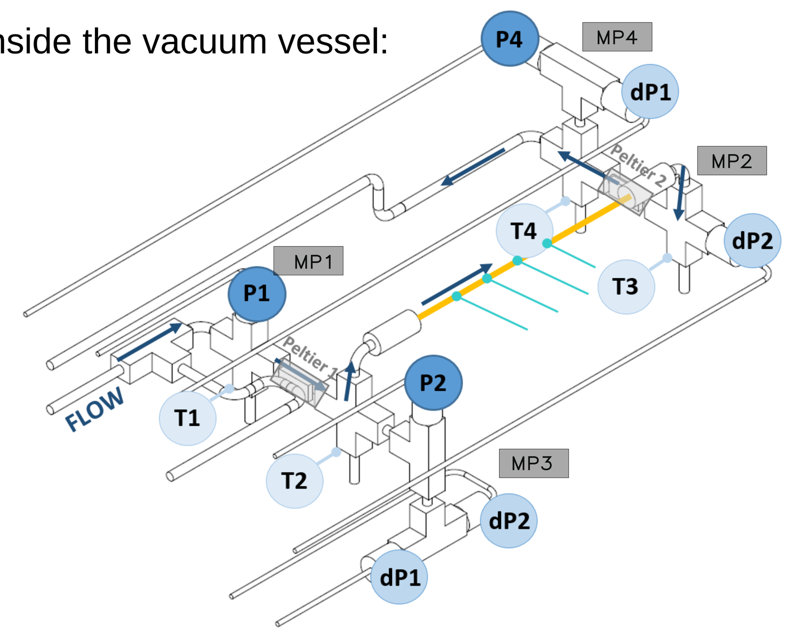


Fig. 5 New setup for evaporative CO_2 flow measurements

MEASUREMENTS outside the vessel:

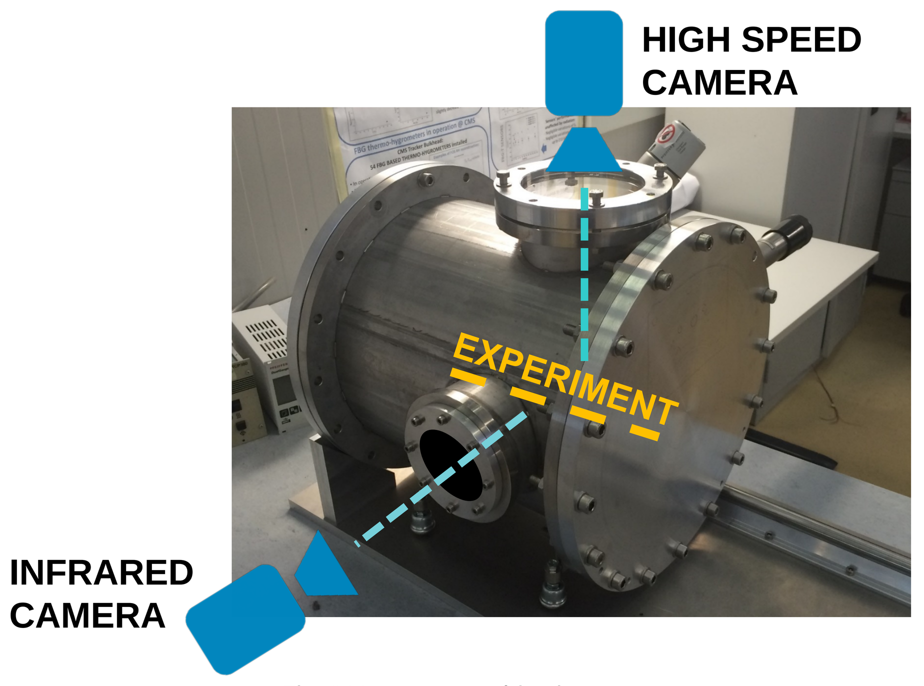
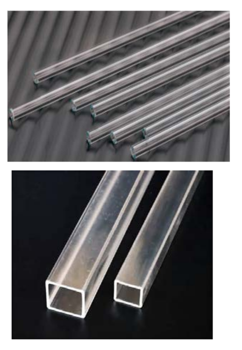


Fig. 6 Vacuum vessel for the new setup

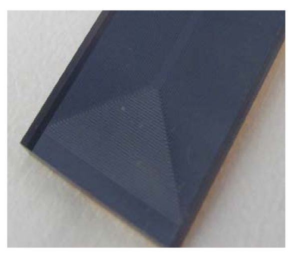
SAMPLES under test:

Stainless steel tubes
- < 1mm
- various diameters

Glass tubes
- < 1mm
- various diameters
- various cross-sections



Multi micro-channels
- e.g. 50 x 50 µm
- various channel sizes
- various geometries



Experimental activity

- Carry out the above mentioned measurements
- Compare with data and correlations found in literature
- Use findings for better understanding of the physical behavior of the flow and base a possible non-empirical model on them

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