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МУЛЬТИПРОФИЛЬНАЯ ЛАБОРАТОРИЯ ARCOLAB

TPC and ECAL cooling system: status

XIV Collaboration Meeting of the MPD Experiment at NICA

October 14, 2024

Speaker: Alexander S. Fedotov

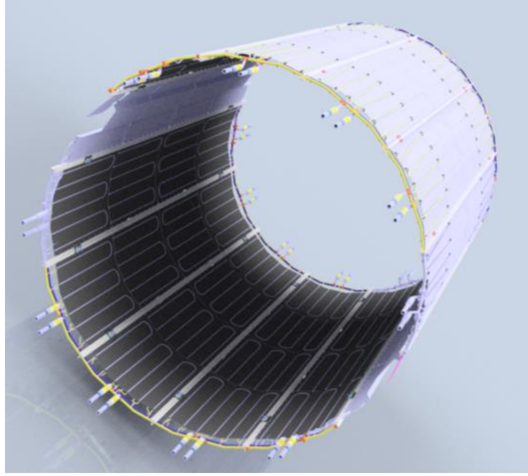
The system

System parameters:

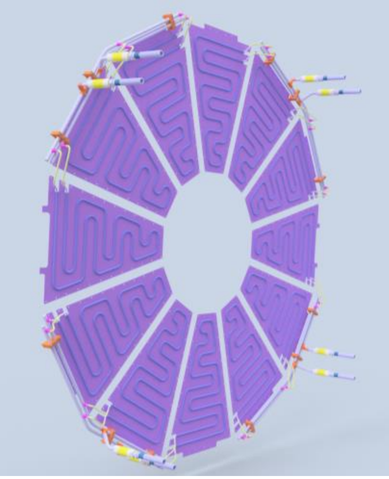
1. Total power: 32 kW
2. Total flow: 60 m^3/h.

Leakless regime of operation: absolute pressure in TPC & ECAL < 1 atm.

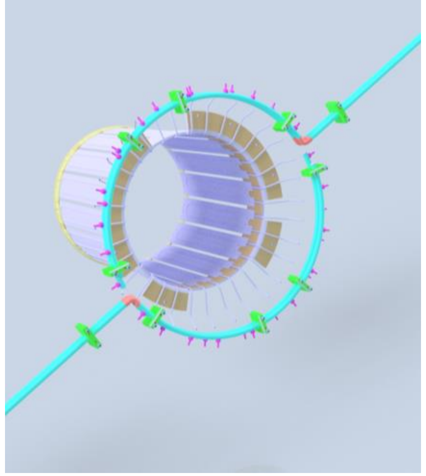
Thermal stabilization of TPC working gas mixture of 0.1 K



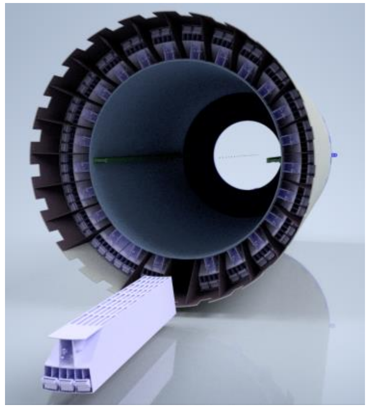
Outer thermal screen



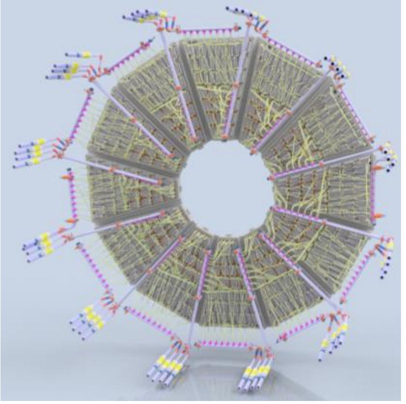
Frontal thermal screen



Internal thermal screen

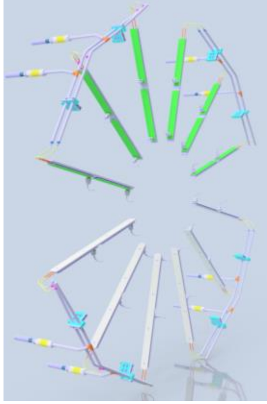


ECAL



SAMPA & FPGA electronics + ROC cases

Flanges



LVDB and reading controllers

The approach

Goal: to develop and install cooling & thermal stabilization system

Tasks:

- Make detailed hydrodynamic simulations;
- Verify simulations with hydraulic experiments;
- Prepare the technical design and deliver the equipment;
- Find appropriate regimes using thermal experiments;
- Develop control algorithms and assemble the system.

Hydrodynamic simulations - Done

Each contour was simulated using Navier-Stokes equations on a pipe graph:

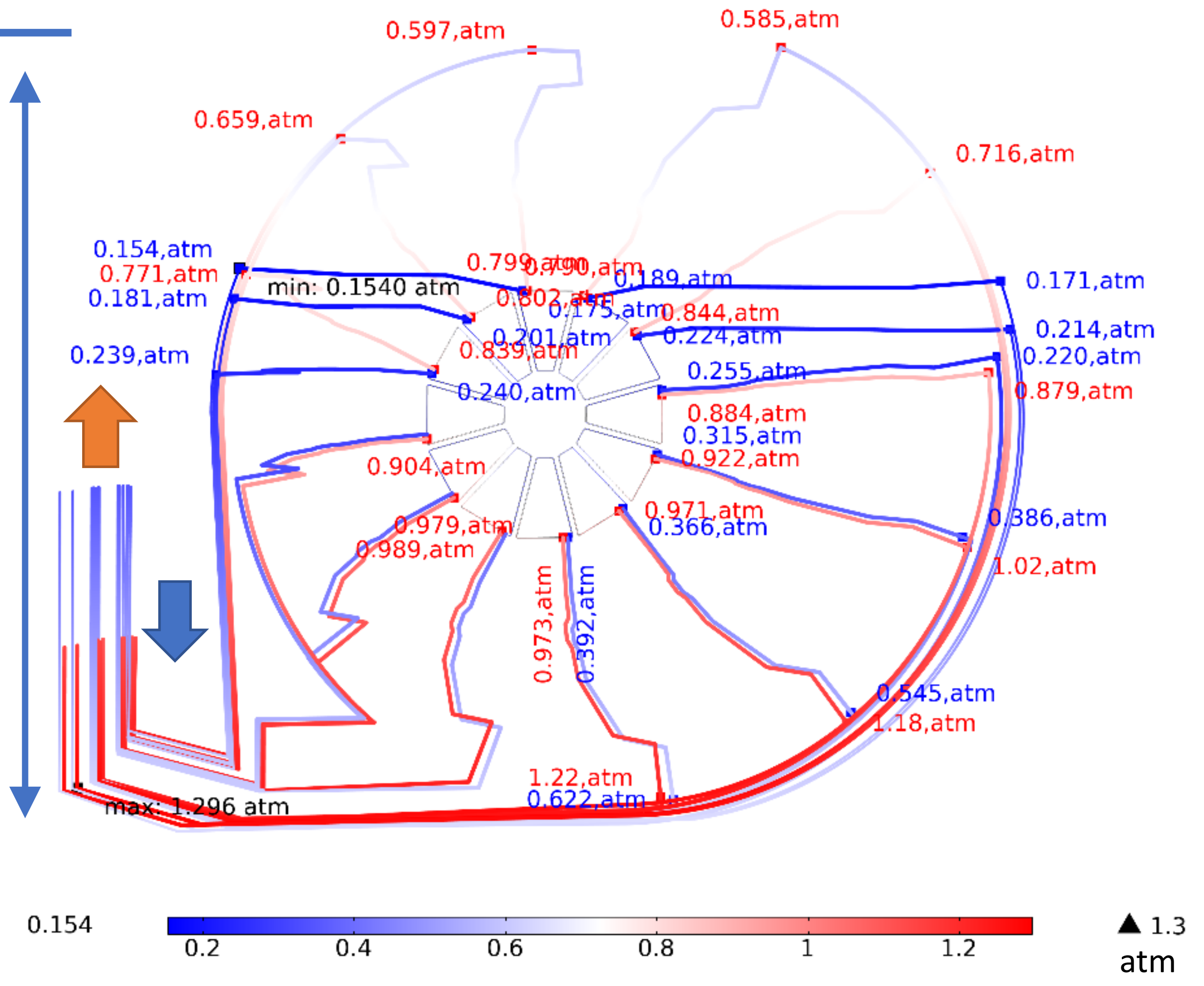
$$\begin{cases} \dfrac{\partial \vec{u}}{\partial t} + (\vec{u}\cdot\nabla)\vec{u} = -\dfrac{\nabla P}{\rho} - \dfrac{1}{2} f \dfrac{|u|\vec{u}}{D} + \vec{g} \\ \dfrac{\partial \rho}{\partial t} + \nabla\cdot(\rho\vec{u}) = 0 \\ \dfrac{1}{\sqrt{f}} = -2\log\left(\dfrac{\varepsilon}{3.7D} + \dfrac{2.51}{\mathrm{Re}\sqrt{f}}\right) \end{cases}$$

Δh = 8 m

$\Delta p = \rho g \Delta h \approx$ 0.8 atm

Leakless achieved! We found:

1. Pump flow and pressure conditions;
2. Vacuum tank pressure;
3. Pipe diameters;
4. Pipe tracing enhancements.

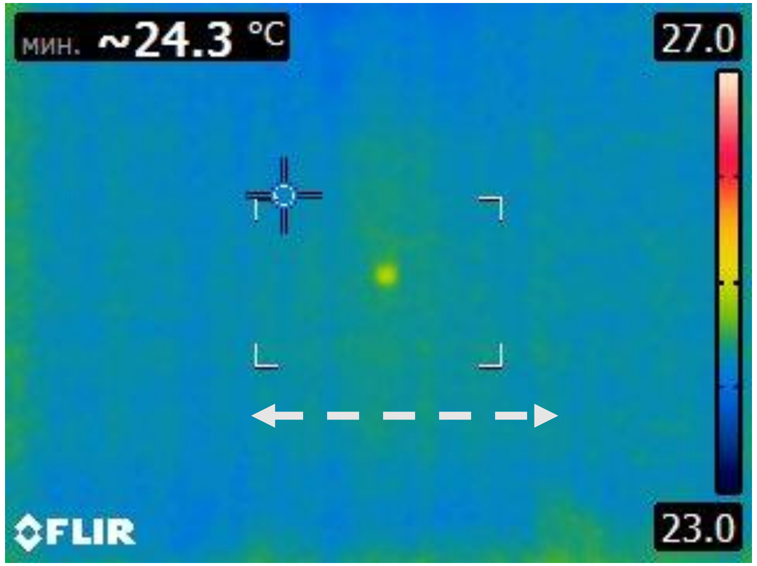


Example of pressure distribution in ROC cases

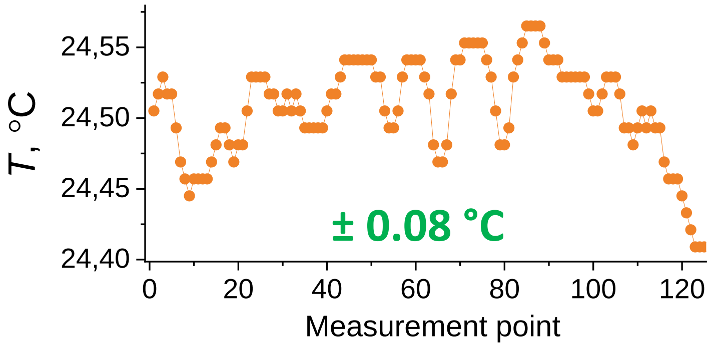
Hydraulic experiments - Done

Element	SAMPA	ECAL	Frontal thermal screen	Outer thermal screen	LVDB	ROC case	FPGA
q, m^3/h	0,55	0,12	0,08	0,91	0,1	0,1	0,27
ΔP_{exp}, atm	0,47	0,16	0,15	0,41	0,5	0,5	0,52
ΔP_{sim}, atm	0,50	0,18	0,15	0,38	0,5	0,5	0,55

Thermal stabilization of pad plane



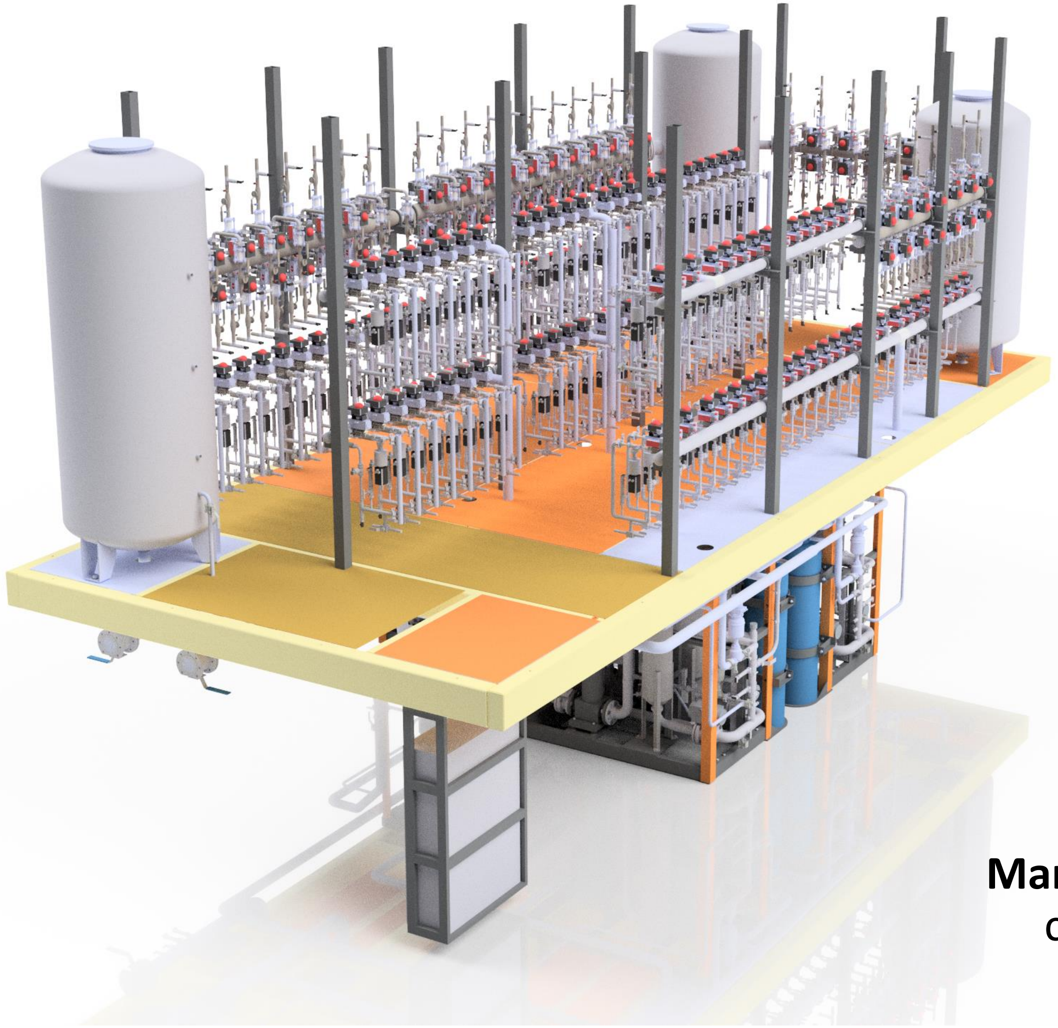
Pad plane with ROC input water heating T = 23 °C

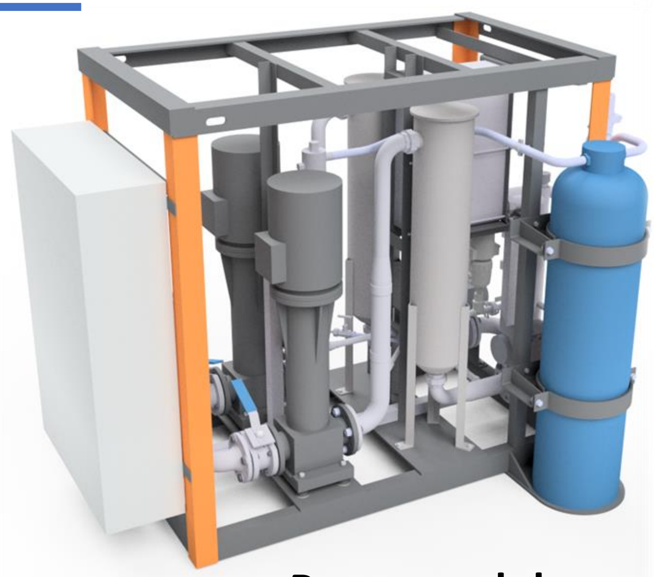


Installation of Vacuum tanks, Pump modules, Manifolds

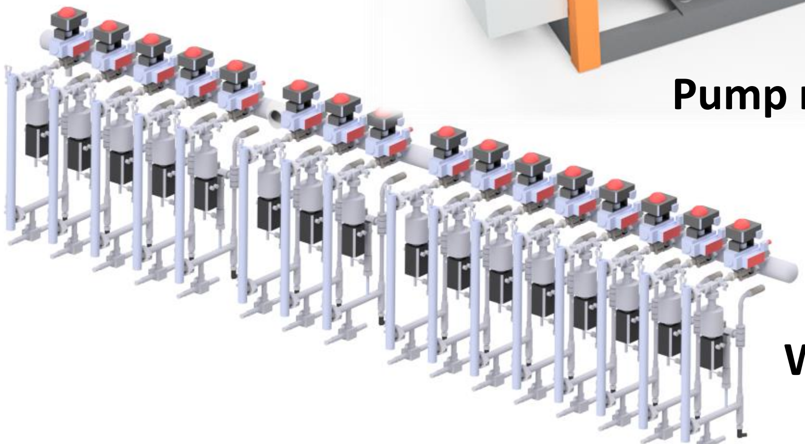
Water plant

Assembled at platform





Pump module



Manifolds: redistributes water from the contour line to the individual sub-contours

Water Tank: An airtight reservoir that contains water below atmospheric pressure. Tested for leaks at 0.2 atm and 10 atm.

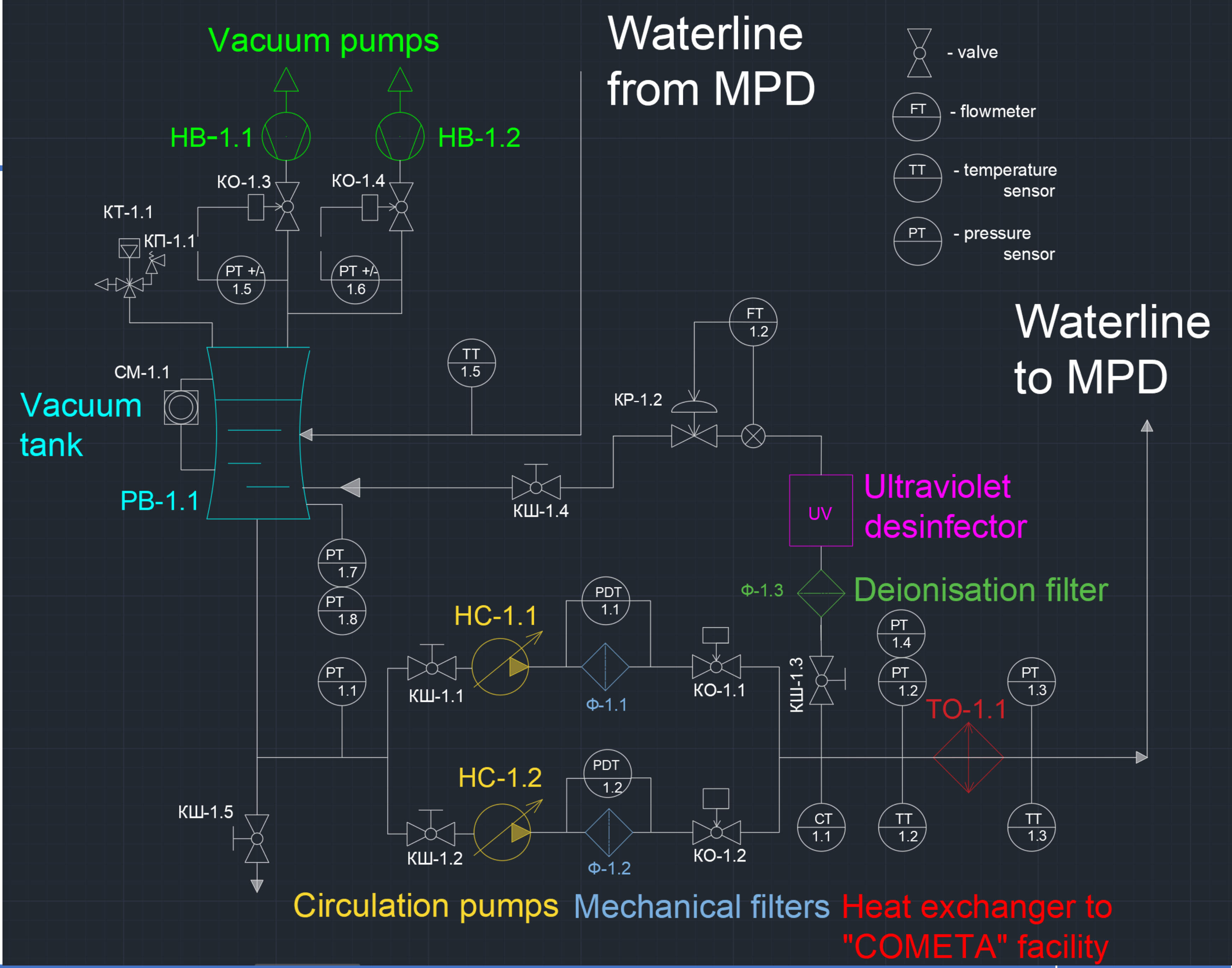
Scheme

<u>The pump module & vacuum tank</u>

- provides circulation,
- maintains low pressure,
- filters,
- thermally stabilizes

water before entering MPD

Principal scheme of water plant:



Pump module – main equipment

aquaPro UV- 12GPM-HT
ultraviolet sterilizer *

Heat exchanger “Ridan” XB95BR
removes heat to “COMETA”

Jetex V-VS 32-03
circulation pumps x2

Filter MVN- 07-02
removes > 20 μm particles x2

Ion-exchange CWO filter FSD1315
removes charged impurities

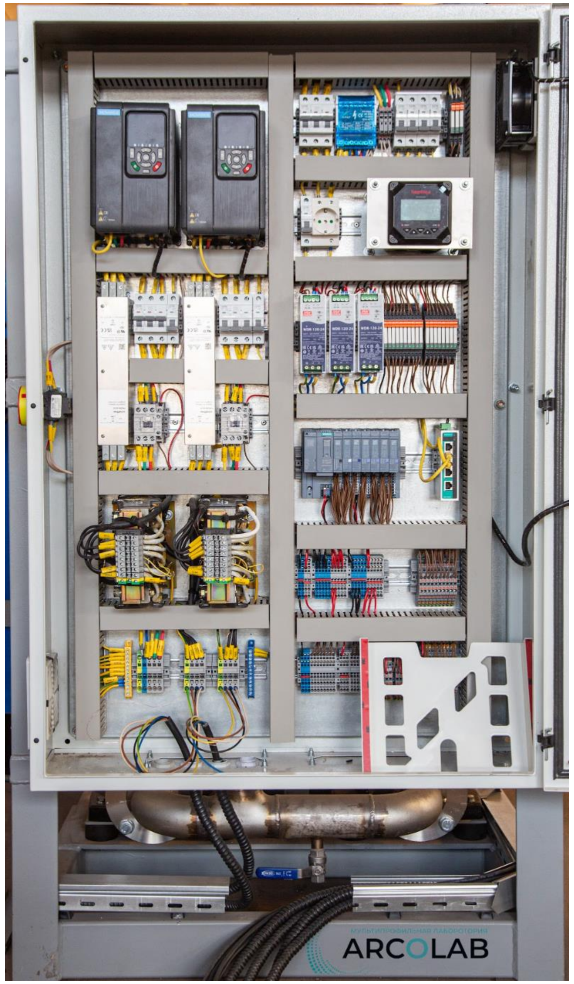
Pump module – control equipment

Frequency converter

EMC input filter

Automatic switches

N Bus zero



Automation cabinet

PLC Siemens
I/O modules
Read from sensors,
Control valves

Temgy DN 20 flowmeter
flow measurement

Bürkert 2702 & 2301 pneumatic control valves
controls flow, smoothens transitions

CCT-8930 conductometer
controls ion concentration

Pt-100-B
thermometer

Aplisens pressure sensors
Pressure control

Pump modules - photos

Assembled under 1st floor of platform

Water tanks & manifolds

Heat exchanger and thermal sensor for TPC gas mixture

Thermal stabilization of TPC gas

Motivation

Thermal stabilization ±0.1 K is needed for reliable event reconstruction in $Ar_{0.8}(CO_2)_{0.2}$

Challenges

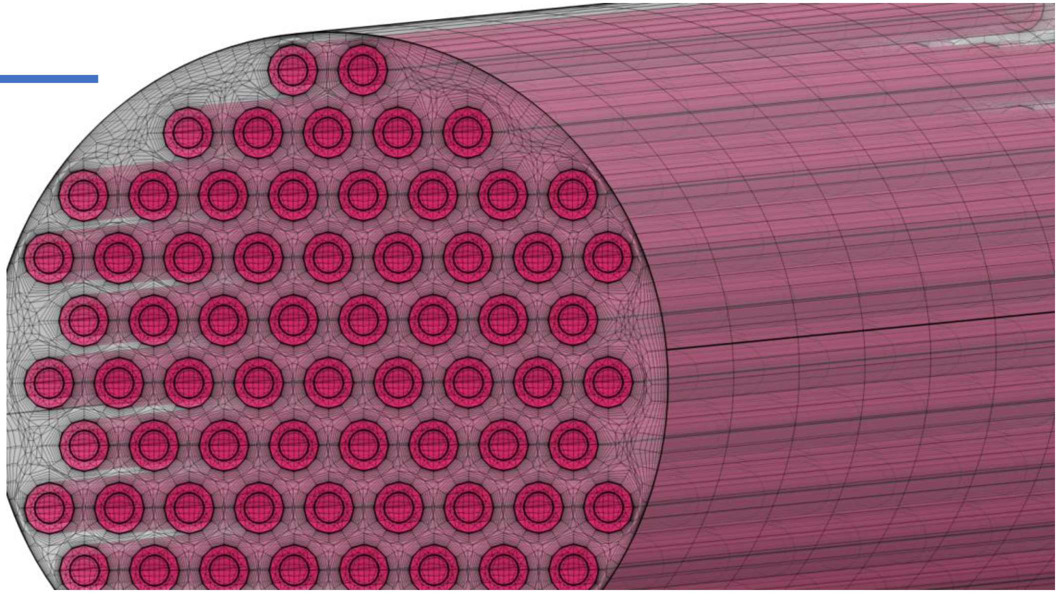
- Measure gas temperature with accuracy better than ±0.1 K
- Prepare gas at a specific temperature to feed into the TPC
- Minimize the influence of the environment on the gas supplied to the TPC

Heat exchanger

Initial concept by I.A. Balaschov

Shell-and-tube heat exchanger:

- Gas flows in small tubes with large surface area;
- Water environment outside of small tubes provides heat exchange



Mesh for computations

Stationary 3D Navier-Stokes equations for gas and water:

$$\begin{cases} \nabla \cdot \vec{u} = 0 \\ \rho_0 (\vec{u} \cdot \nabla)\vec{u} = \nabla \cdot \left[-p\mathbf{I} + \mu_0 \left(\nabla \vec{u} + (\nabla \vec{u})^T \right) \right] + \rho_0 \beta (T_0)(T - T_0) \vec{g} \\ \rho_0 C_{p0} (\vec{u} \cdot \nabla) T = \nabla \cdot \lambda_0 \nabla T \end{cases}$$

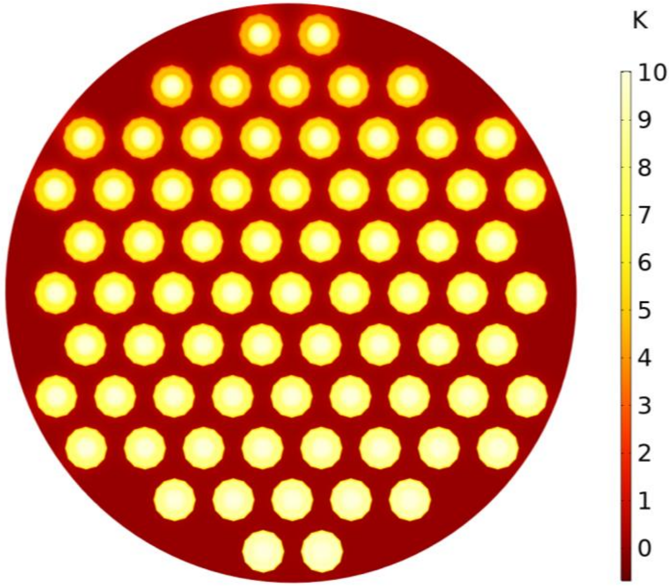
$\vec{u}$ – fluid velocity;
μ – dynamic viscosity;
p – pressure;
$\mathbf{I}$ – identity matrix.
λ_0 – heat conduction coefficient at reference temperature T_0;
C_{p0} – heat capacity at reference temperature T_0;
β – compressibility,
ρ_0 – density at reference temperature T_0.

Heat exchanger

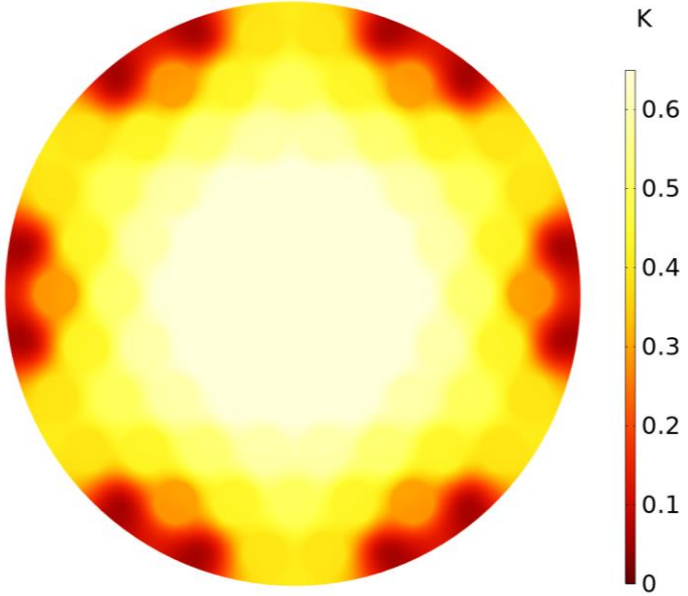
Prototype simulation parameters:

ΔT decreased by 10-15 times

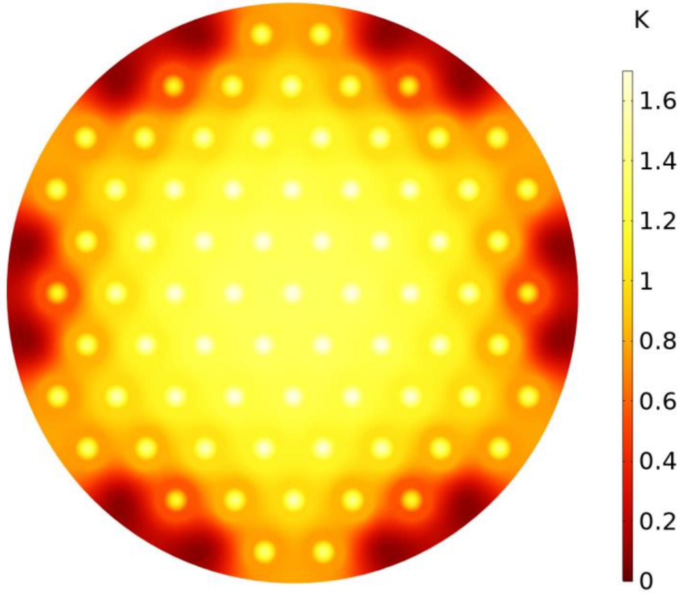
- Length 0.55 meters;
- Inlet gas is 10 K hotter than water;
- Water flow is 0.1 m^3/h;
- Gas flow is 20 — 200 l/min.



At inlet



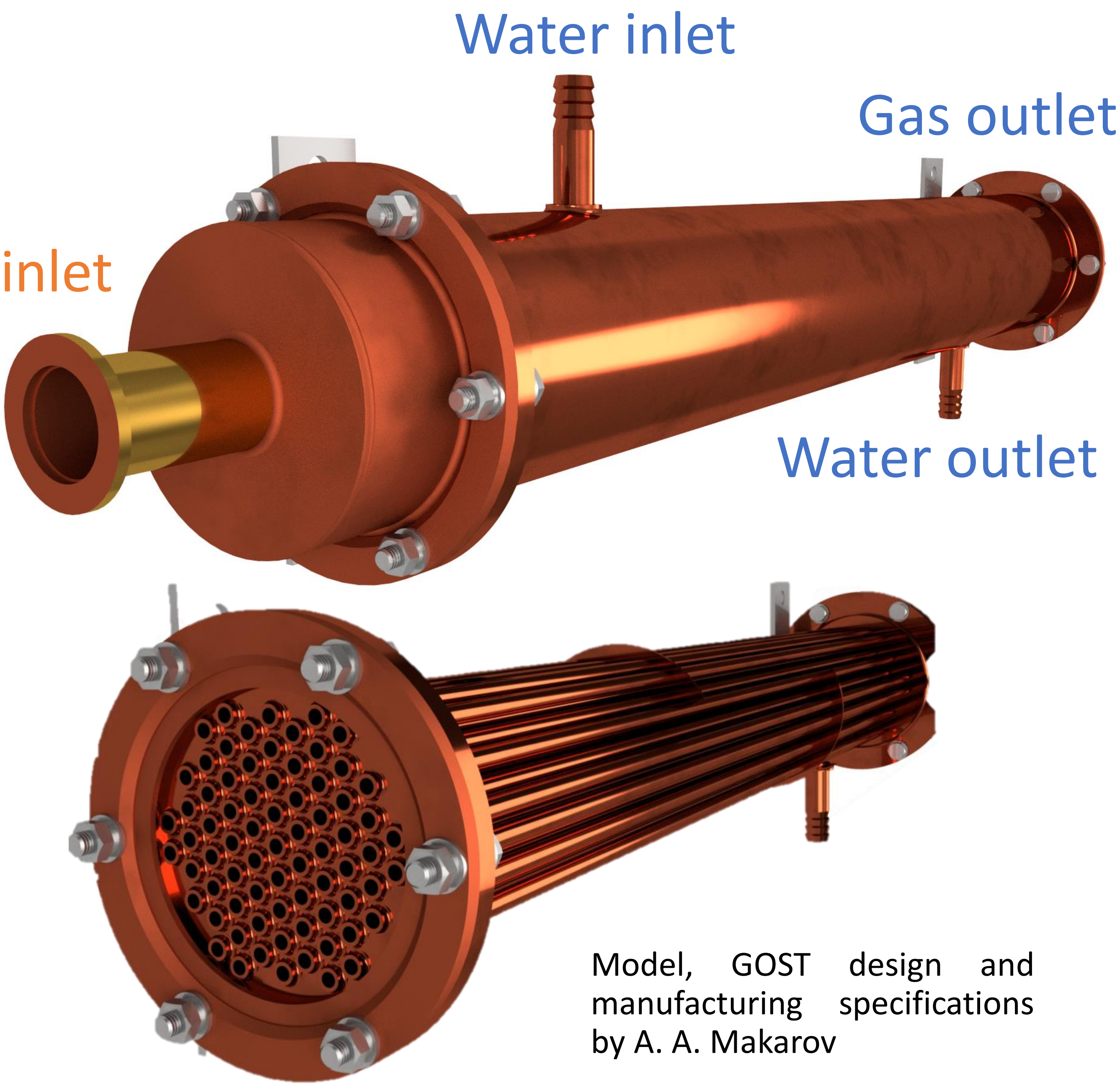
At outlet – 20 l/min



At outlet – 200 l/min

Heat exchanger

Shell-and-tube heat exchanger for gas thermal stabilization:



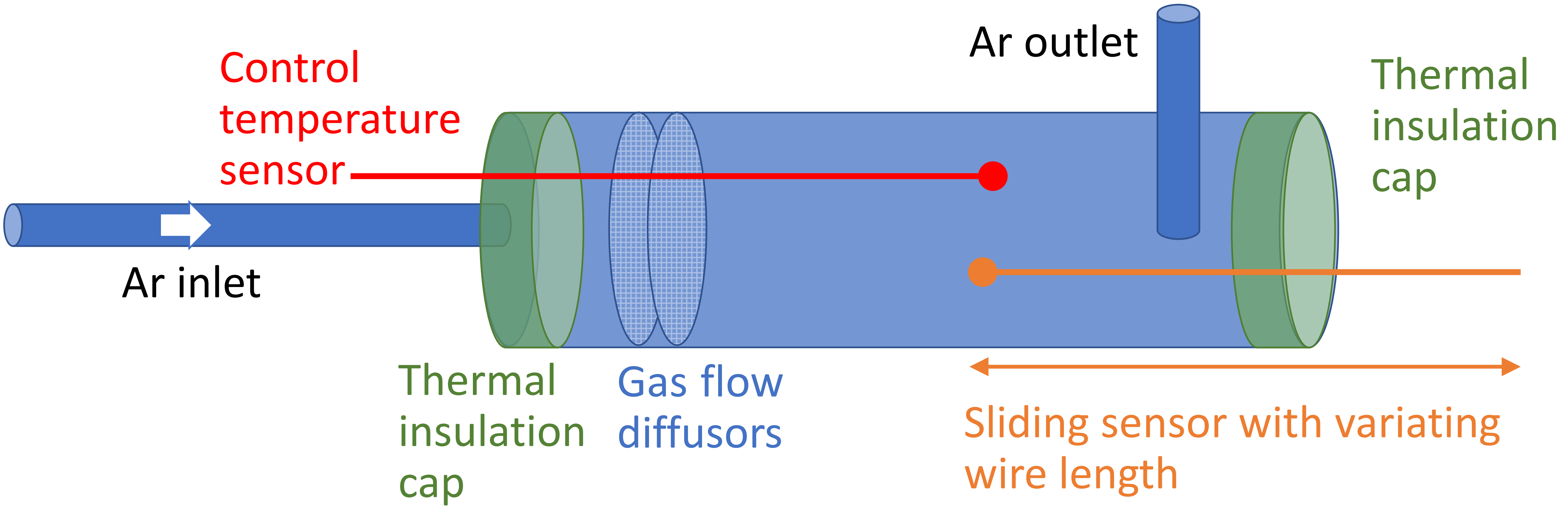
- 74 gas pipes of 6 mm diameter
- ~8 kg weight
- **Being manufactured at LHEP**

Model, GOST design and manufacturing specifications by A. A. Makarov

Gas temperature sensor

The gas volumetric heat capacity is 10^4 less than that of liquids and solids

To measure temperature of gas (not a wire or a wall) a sensor must be drown deep in gas

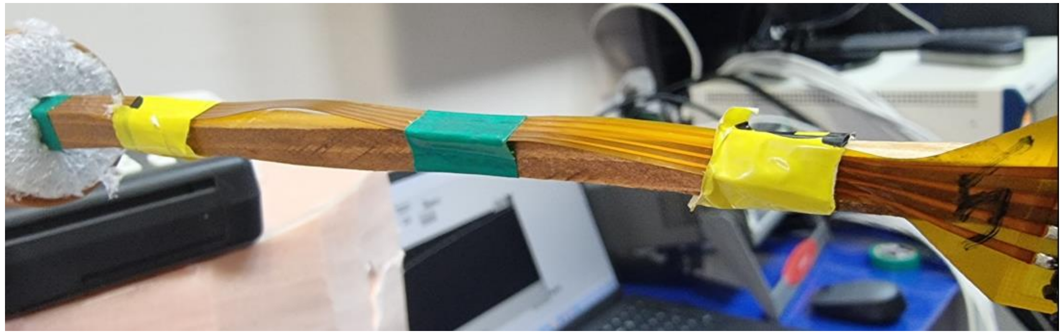


Gas temperature sensor

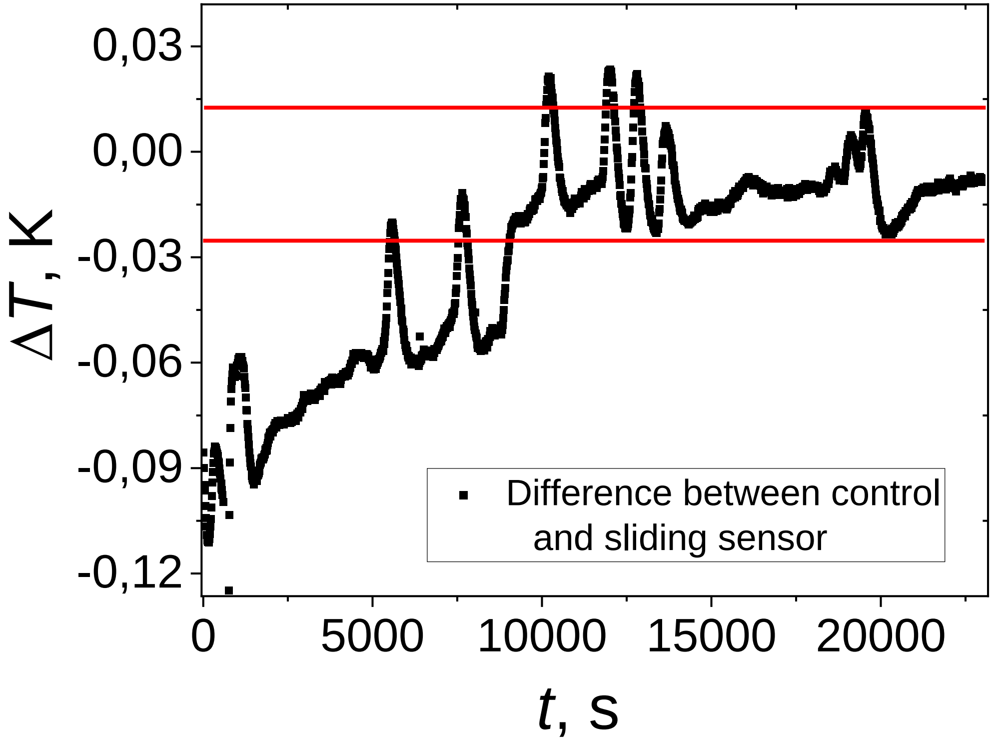
Experiment was motivated by Gleb Meshcheryakov

- Argon flow ≈ 800 cm^3/min;
- Water jacket is around testing tube;
- Pt100 RT + NI Controller;

Testing tube with sensor fully in



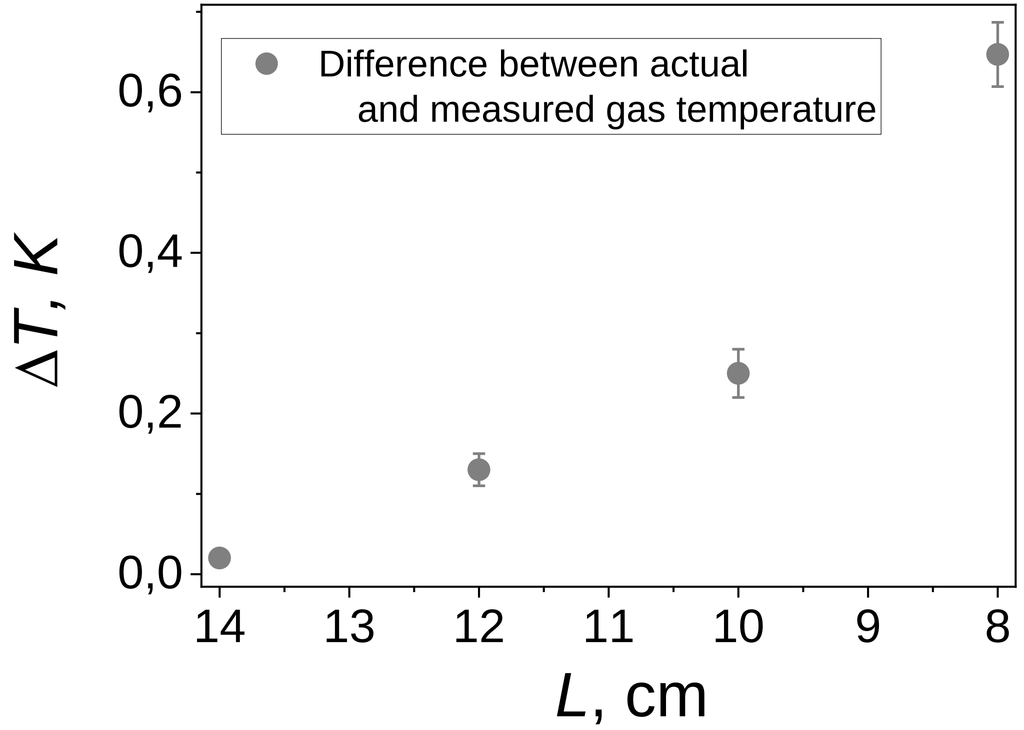
Sliding sensor almost out of tube



Time dependence of ΔT between the control and the full-drawn sliding sensor

<0.03 K gradient is achieved inside the testing tube with gas about 15 °C and room temperature 21 °C

Gas temperature sensor



Difference between control and sliding sensor temperature on the length of wires inside gas

Prototype of gas temperature sensors with swagelok and wire support

Conclusions

- Pumping modules, vacuum tanks, and collectors have been delivered and installed on the platform;
- A shell-and-tube heat exchanger for the thermal stabilization of the flowing gas has been developed. The prototype is being manufactured in the LHEP workshops;
- Prototypes of temperature sensors for the flowing gas have been proposed and manufactured, with an expected measurement accuracy of 0.03 K;
- Experiments conducted have shown the necessity of thermal stabilization of the gas line using a water jacket.

Event	Date
Finalizing of platform pipes installation for MPD cooling system	November 2024
Assembling of temporary scheme for pipe washing and testing	November 2024
Connecting of pump modules for testing	November 2024
Continuation of assembling	December 2024

Co-authorship and gratitude

Research was directly conducted by

Institute for Nuclear Problems of Belarusian State University:

Ilya Zur

ArcoLab:

Alexander Shish,

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Alexander Galuza,

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JINR:

Alexander Fedotov,

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Alexander Ryubakov,

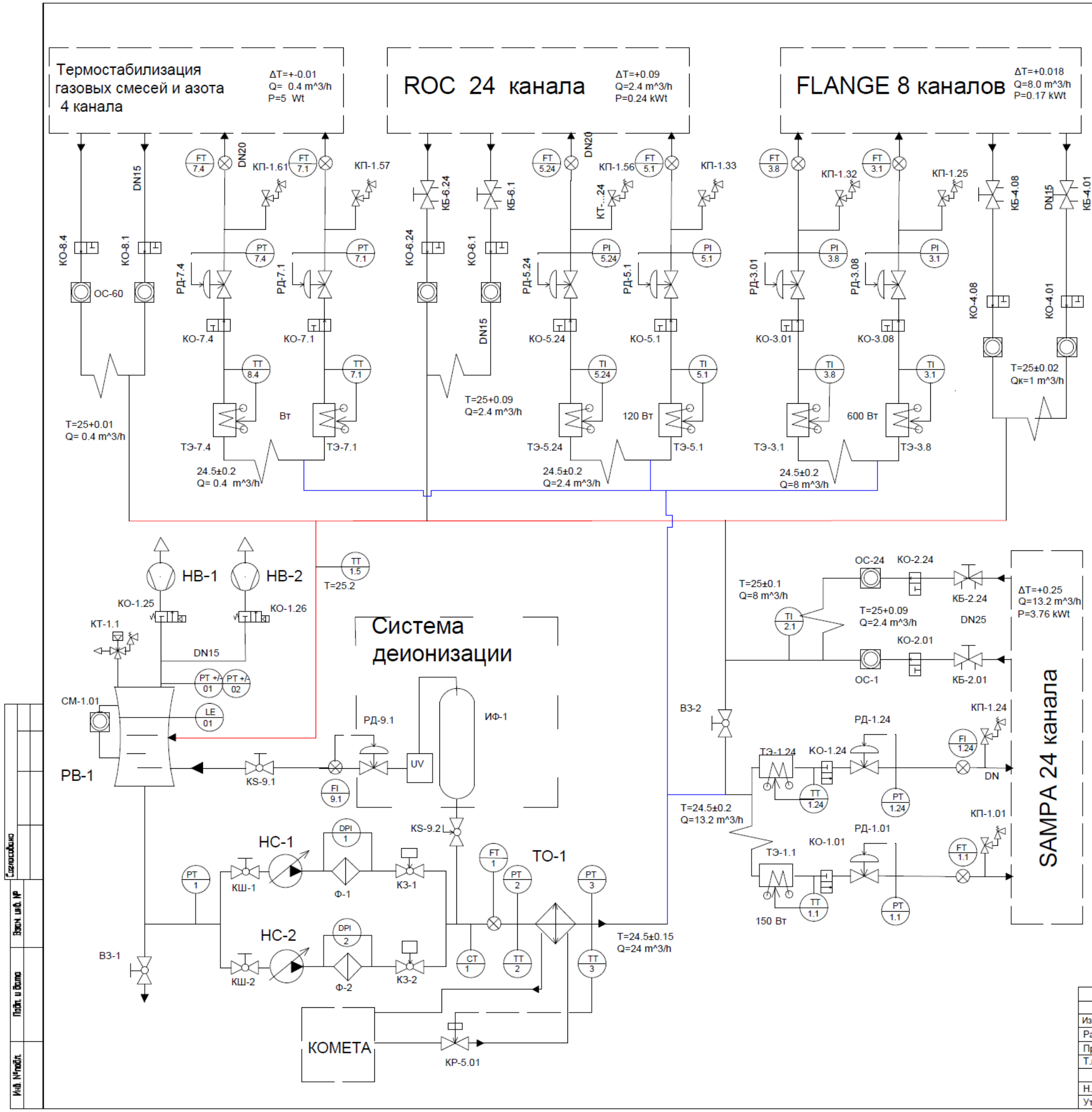
Alexander Makarov,

Igor Balaschov,

Alexey Butorin,

Nelli Pukhaeva (NOSU)

Схема Cu-TS замкнутого контура



Обозн.	НАИМЕНОВАНИЕ	кол.	Примечание
Ф-1...2	Фильтр 10...30 мкм	2	40 м^3/h
НВ-1...2	Вакуумный насос KNF N 026 ANE	2	1.3m^3/h @P=0.1Bar
РВ-1	Резервуар вакуумный	1	V=1500L P=0.1Bar
КР-5.01	Регулятор (Buerkert 2301+8692+ST20)	1	Kv13 DN40
НС-1.1	Насос GRUNDFOSS CRN 32-3 (30m^3/h@35m@4kWt)	2	24 m3/h DN 65
КЗ-1...2	Кран с пневмоприводом Burkert 8805	2	DN 65
ТО-1	Теплообменник (Danfoss/Ридан XB12)	1	3.8 m^2 & 22 kWt
РД-8.1...4	Регулятор давления (Buerkert 2301+8692+8323)	4	Kv 0. DN15
РД-1.1...24	Регулятор давления (Buerkert 2301+8694+8323)	24	Kv 0.64 DN15
РД-3.1..08	Регулятор давления (Buerkert 2301+8694+8323)	8	Kv 1.6 DN 15
РД-5.1..24	Регулятор давления (Buerkert 2301+8694+8323)	28	Kv 0.16 DN15
КБ-2.1...24	Кран балансировочный Vexve 240	28	Kv=? DN 20
КБ-4.1...8	Кран балансировочный	32	Kv=? DN 20
К0-1.1..24	Кран шаровой с пневмоприводом Burkert 8805 тип А	60	DN 20
К0-2.1..24	Кран шаровой с пневмоприводом 8805 тип В (НО)	60	DN 20
К0-4.1..08	Кран шаровой с пневмоприводом	8	DN 20
ТЭ-1.1..24	ТЭН	24	N=150 Wt
ТЭ-3.1..8	ТЭН	8	N=600 Wt
ТЭ-5.1..24	ТЭН	24	N=120 Wt
КШ-1.1...2	Кран шаровой Vexve 232 (BURKERT TKU001)	2	DN65
ВЗ-1...2	Кран шаровой Vexve 232 (Burkert 2657)	2	DN15
КТ-1.1	Кран трехходовой с пневмоприводом Burkert	1	1/2"
КТ-1...56	Кран трехходовой	56	1/2"
КП-1...60	Клапан предохранительный D7C-S LORCH	60	7мм 2Бара
ОС-1...60	Смотровое стекло END-Armaturen SG30021	60	DN20
РД-9.1	Регулятор расхода (Buerkert 2301+8694+8035)	1	Kv 1.6 DN 15
ИФ-1	Фильтр деионизационный	1	2 м^3/h
UV	Кварцевая лампа	1	
	КИП		
TI-...39	Термопара PT100	39	
PI-01...50	Преобразователь давления	32	
FI-01	Расходомер BURKERT 8035	1	12. m^3/h DN50
FI-03...27	Расходомер ультразвуковой (Burkert)	24	0.25 m^3/h DN15
FI-28...36	Расходомер ультразвуковой (Burkert)	8	0.5 m^3/h DN15
FI-37...61	Расходомер (Burkert)	24	0.1 m^3/h DN15
CT-1.1	Датчик электропроводности	1	5-7

Изм.	Дата	Лист	№док	Подпись	Дата
Разраб.		Новиков			
Проверил		Галуза			
Т.контр.					
Н.контр.		Сенкевич			
Утвердил		Левков			

Термостабилизация TCP
Медная подсистема

Схема комбинированная принципиальная

Литера	Лист	Листов
О		

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