

J-PARC Target Helium Cooling System Upgrade

23 October 2019, 11th International Workshop on
Neutrino Beams and Instrumentation (NBI2019) @ Fermilab

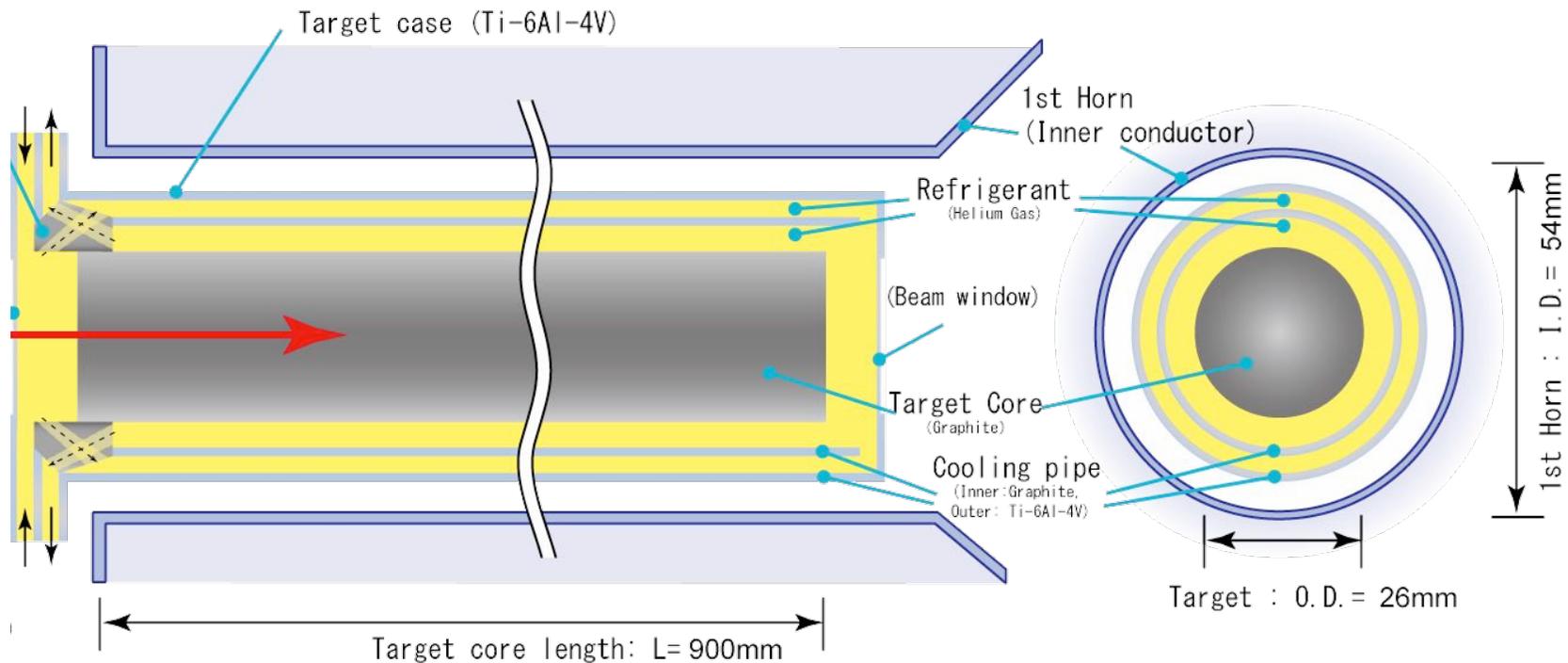
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Outline

- Introduction of current system
- Upgrade for 1.3 MW beam power
- Design of vacuum insulated pipe, replacing 1st heat exchanger
- Estimation of pressure drop at the vacuum insulated pipe
- Summary & prospects

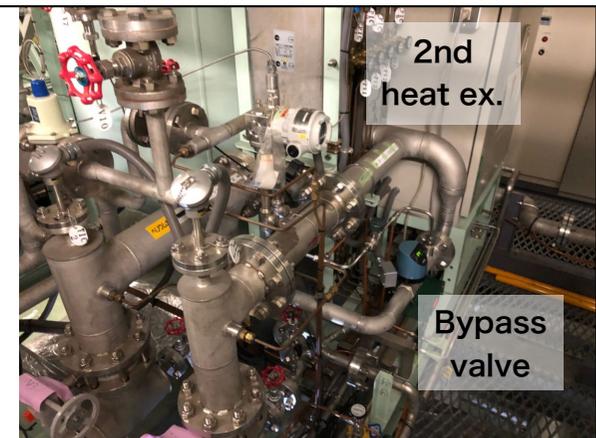
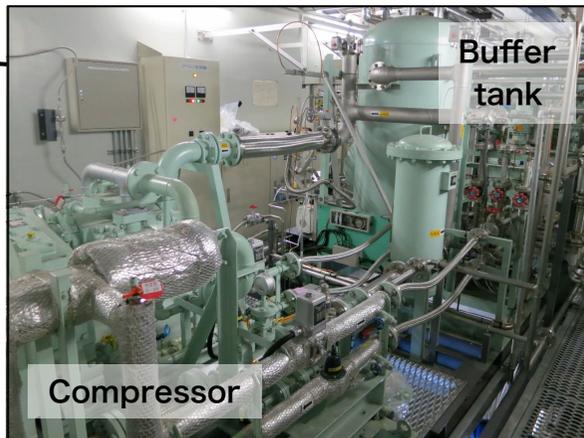
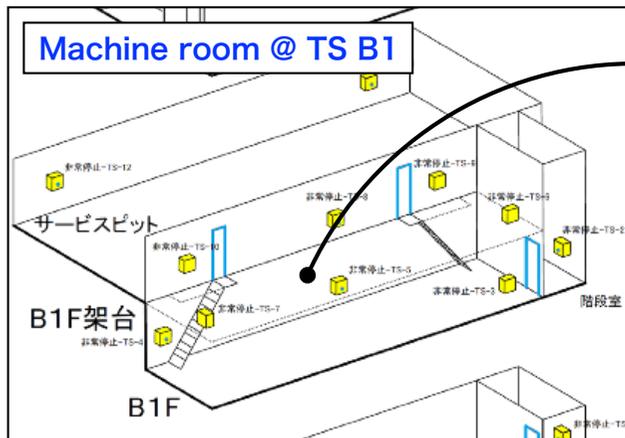
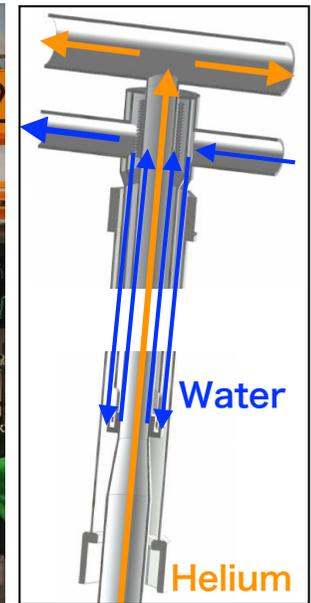
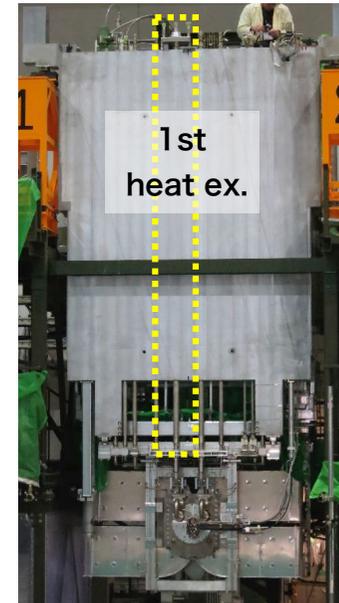
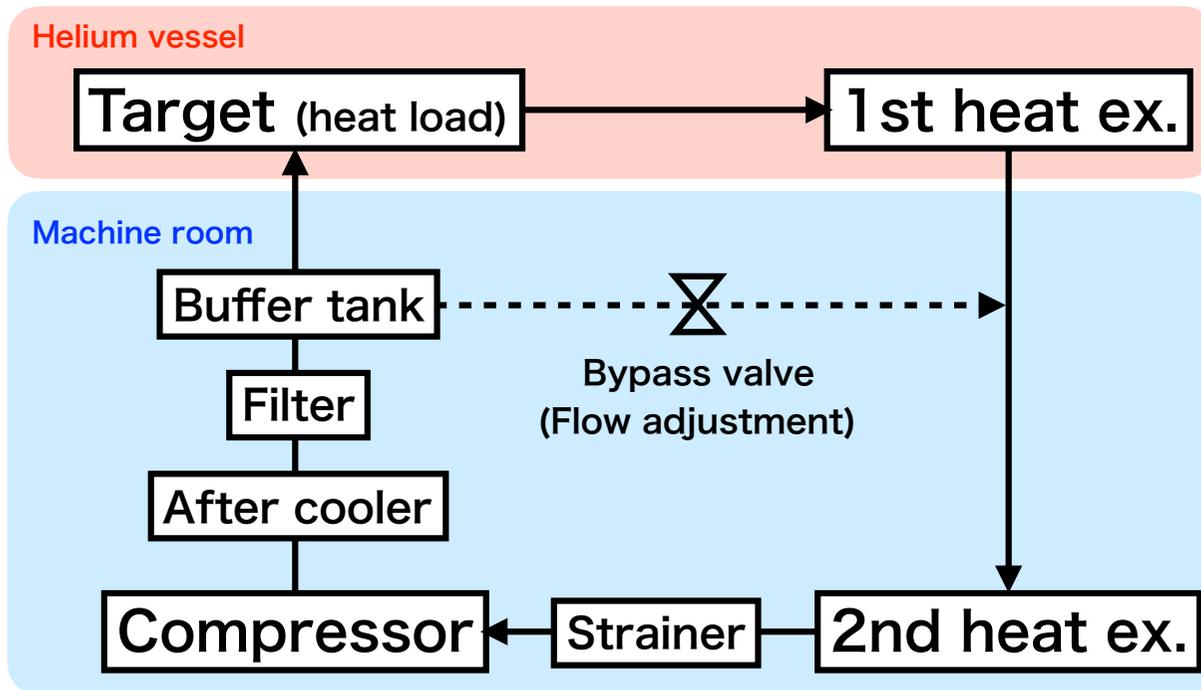
Target

- Isotropic graphite (IG-430) with rod structure of 2.6 cm Φ & 90 cm long
- Inner graphite tube & outer tube (Ti-6Al-4V) for the Helium cooling
- Enable to detach from the 1st horn for maintenance



Helium cooling system

Helium gas from the target return to the compressor via 2 heat exchangers



Upgrade for 1.3 MW beam power

Current target design

- Design intensity : 3.3×10^{14} ppp \rightarrow 3.4×10^{14} ppp is no problem
- Cooling capacity : 750kW + 20% margin = 900 kW \rightarrow **Need upgrade**

Upgraded design

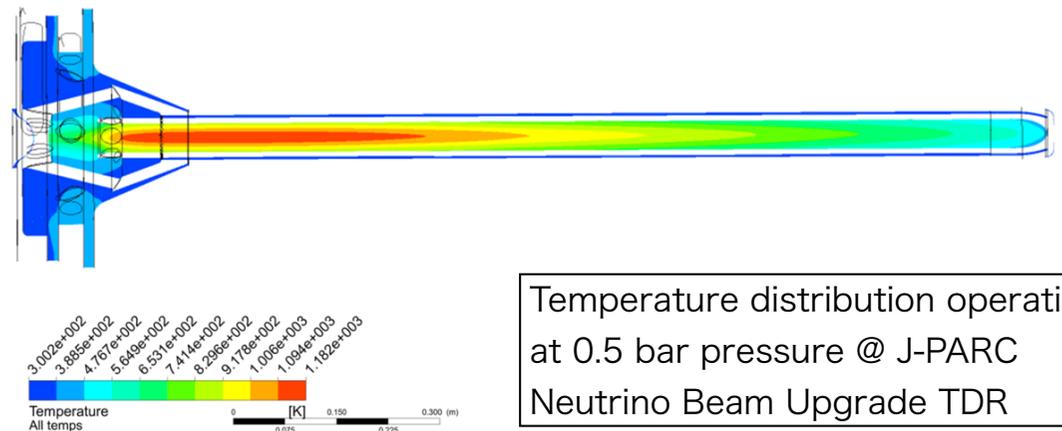
- **High flow rate** to accept x1.7 of heat load (24 kW @ 750 kW \rightarrow 41 kW @ 1.3 MW)

Requirement

- **High pressure tolerance** (“0.16 MPaG \rightarrow 0.5 MPaG” is our target)

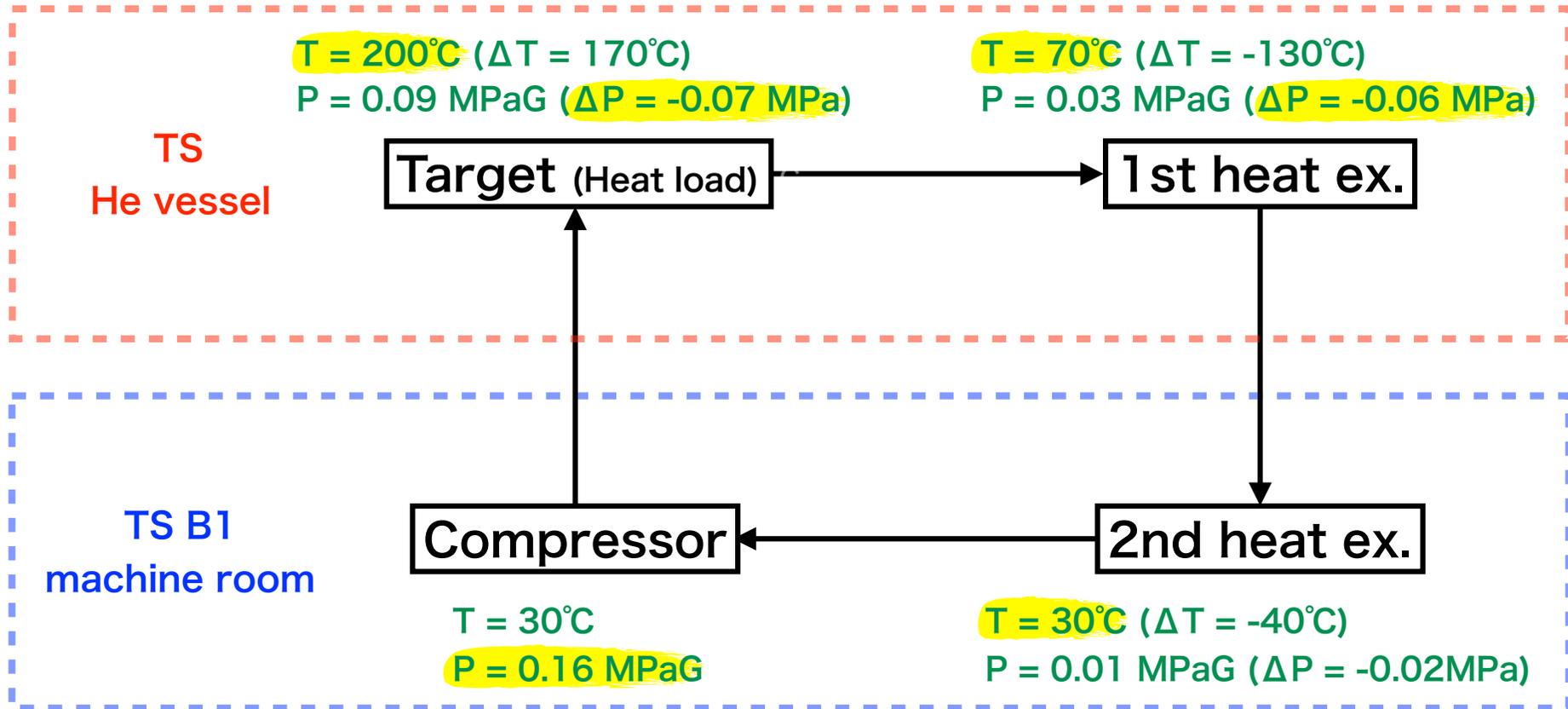
Equipments to be upgraded

- 1st heat exchanger
- Compressor (< 0.9 MPaG)
- Pipes at service pit



Current system

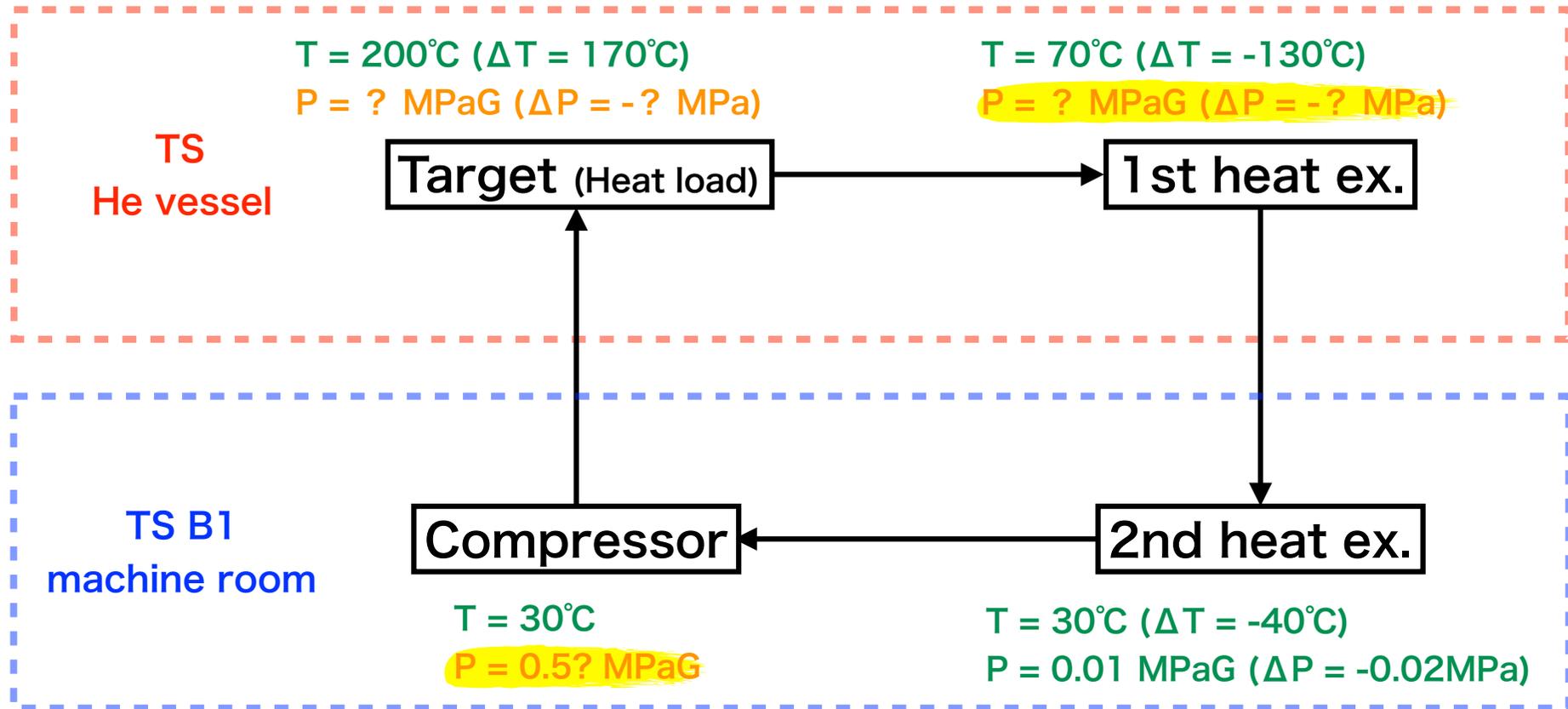
- Cooled by 1st (2nd) heat ex. to 70°C (30°C) from 200°C at the target



- Control pressure for the current compressor is 0.16 MPaG
- Comparable with sum of pressure loss in the target & 1st heat ex.

Upgrades of cooling capacity for 1.3 MW

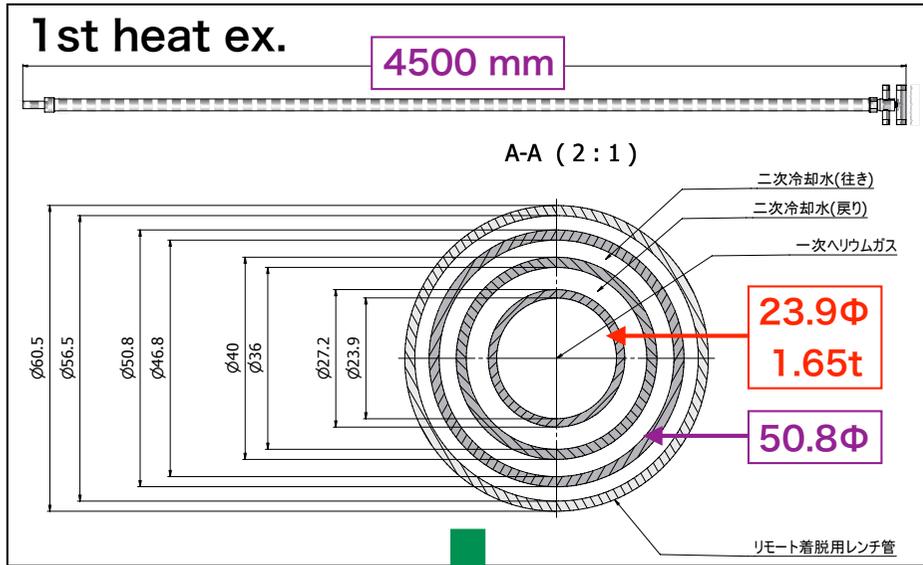
- Cooled w/ high flow rate **by high pressure** keeping helium temperature



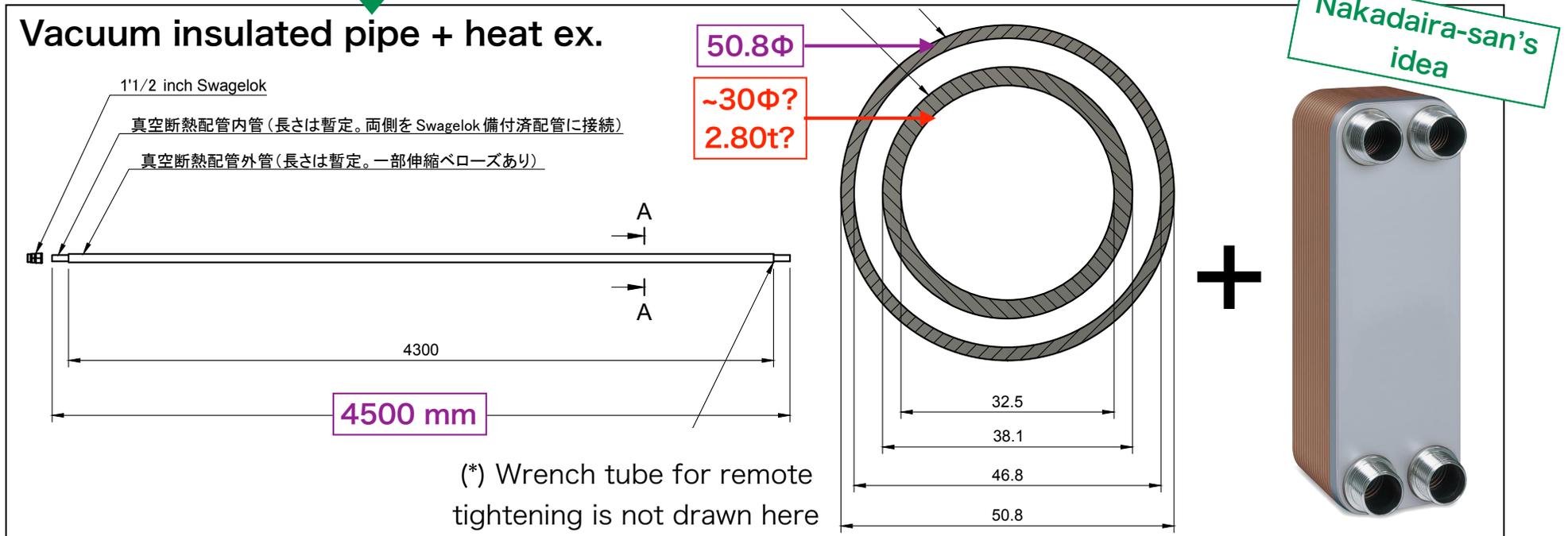
Issues are in current 1st heat exchanger

- **Pressure tolerance** is not enough after the upgrade
- **High pressure drop** requires higher discharge pressure by compressor

An idea : Vacuum insulated pipe



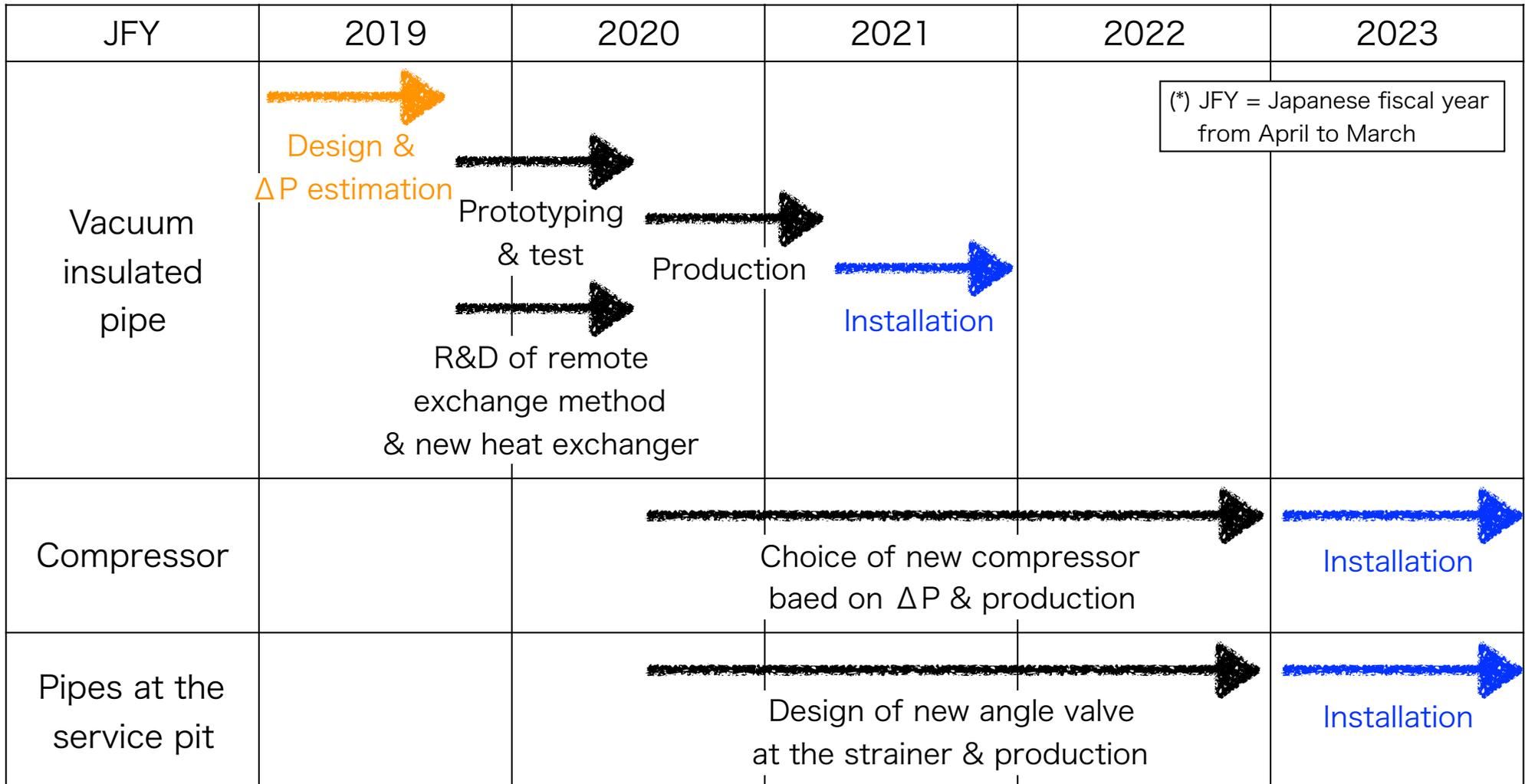
- Thicker pipe thickness (5S to 10S)
→ Pressure resistance
- Triple to double co-axial pipe with heat insulated in the pipe
→ Low ΔP by bigger inner diam.
- Outer diameter is kept
- Same as 2nd heat ex. on the top



Rough timeline

Need to upgrade by 2023 to accept > 1 MW

- Upgrade to vacuum insulated pipe during horn exchange in JFY 2021
- Upgrade of compressor/pipes in the machine room in JFY 2023



Design of vacuum insulated pipe

Contacting to two companies

- Enoah Co., Ltd.
- KEIYO PLANT ENGINEERING Co., Ltd.



<https://www.enoah.co.jp/>



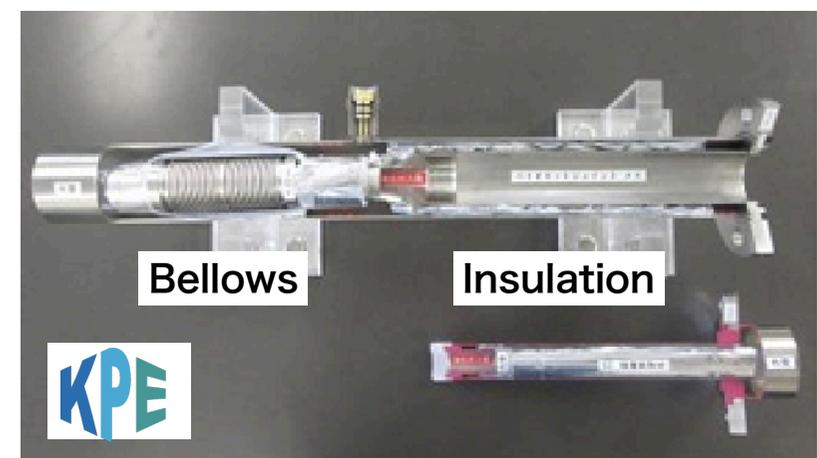
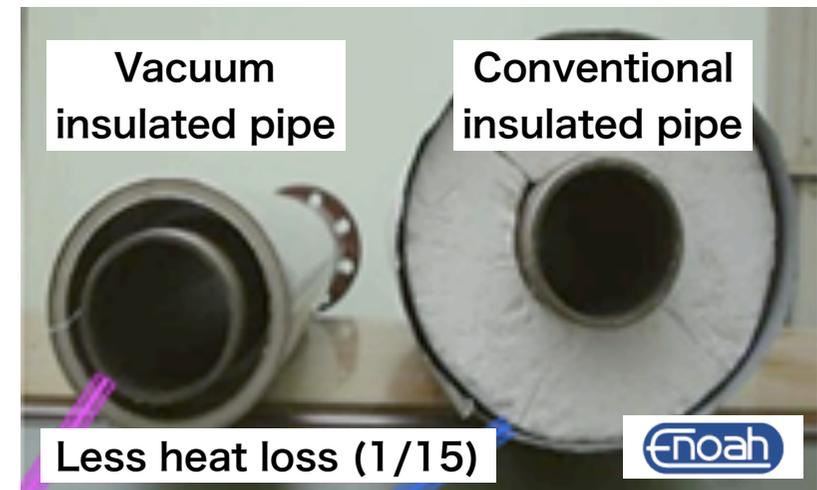
<http://kpeng.co.jp/>

Common design

- Two pipes keeping vacuum in between
- Insulation to reduce radiant heat
- Choice of pipe thickness & length
- Bellows inside
- Proven long-term operation
(More than 7 years at least)

Main differences

- Different materials in insulation
- Experience of high temperature

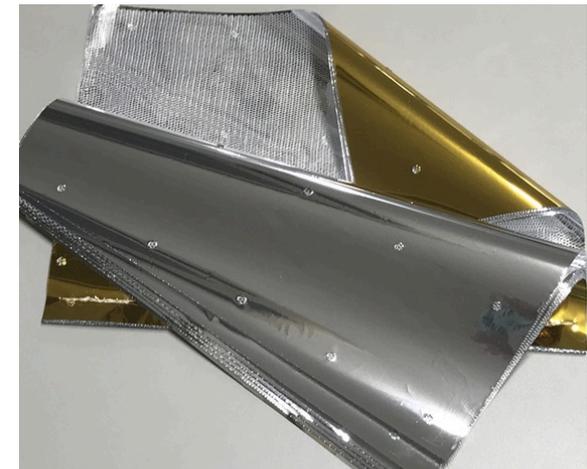
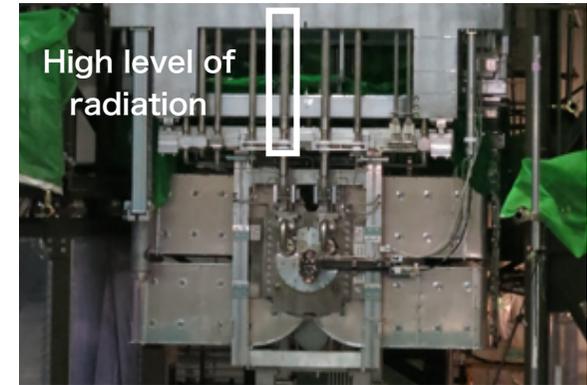


Design choice

Those are related with heat insulation performance

Materials for the heat insulation

- Super insulation by Kaneka Co. Ltd. [KPE]
 - Al-evaporated polyimide film
 - Heat tolerance (~200 degree)
 - Radiation tolerance grade
(but we need a valve for evacuation of out gas due to radiation damage)
- Al only insulation [Enoah]
 - No solvent is used. Adsorbent is placed



<https://makesat.com/ja/products/multi-layer-insulation-mli-super-insulation-si>

Experience of high temperature

- Degree of vacuum may degrade due to out gas
 - Can be mitigated by a baking process
- Experience to provide pipes with high temperature operation [Enoah]

Current status of the design

No critical issue is found for the upgrade

- Asking for realistic design & quotation
- Planning to develop short prototype without bellows to test heat insulation performance

Estimation of pressure drop is ongoing in parallel

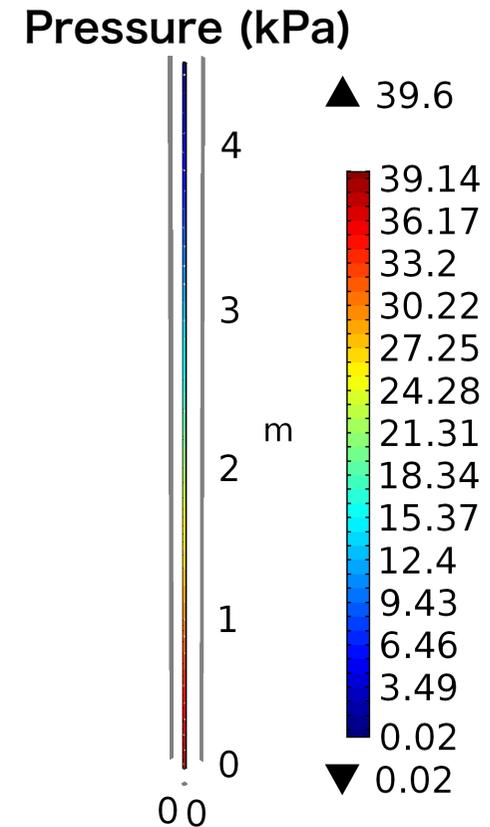
- Important to know required specifications of the upgraded compressor
- FEA simulation is performed to see the impact of bigger diameter for the inner pipe

ΔP estimation by COMSOL @ Present

Simulation input

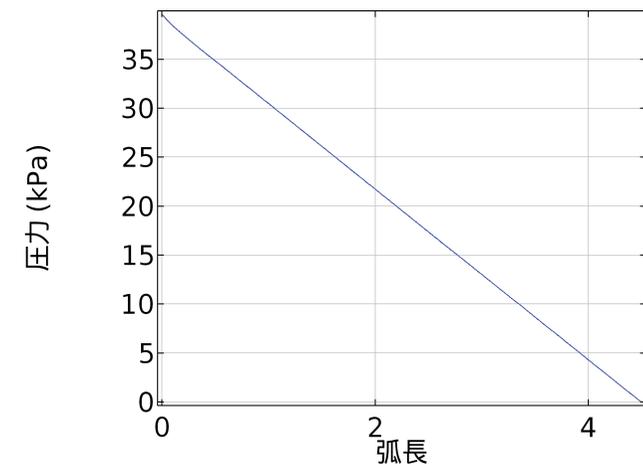
- Physics : Turbulent flow
- Shape : $d = 23.9$ mm、 $l = 4.5$ m
- Boundary : Bottom to enter, Top to exit
x-sectional average flow velocity
 $U_{in} = 408.7$ m/s
- Material : Fluid density $\rho = 0.103$ kg/m³
Viscosity coefficient $\mu = 0.027$ cP
@ 1 atm · 200°C
(*) No roughness applied

Flow rate
= ~32 g/s



Simulation result

- $\Delta P = -0.04$ MPa at 1 atm is estimated
→ Comparable with the hand calculation
→ How about ΔP in high pressure?

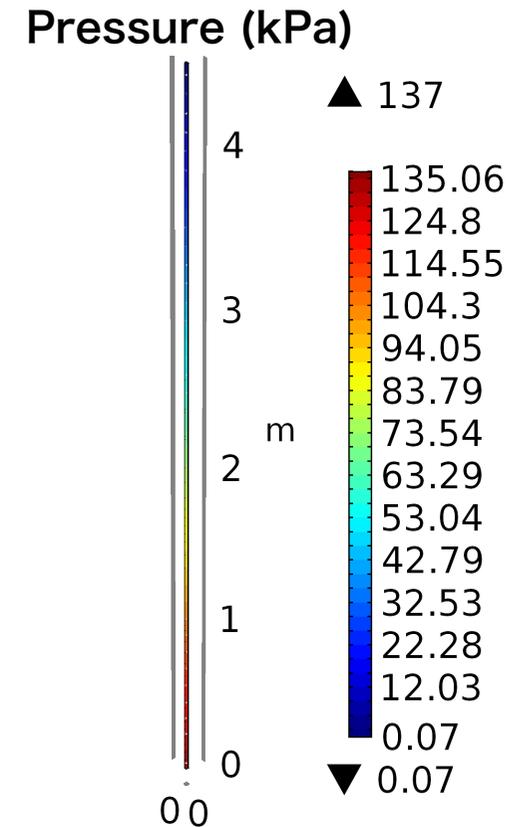


ΔP estimation by COMSOL @ High P

Simulation input

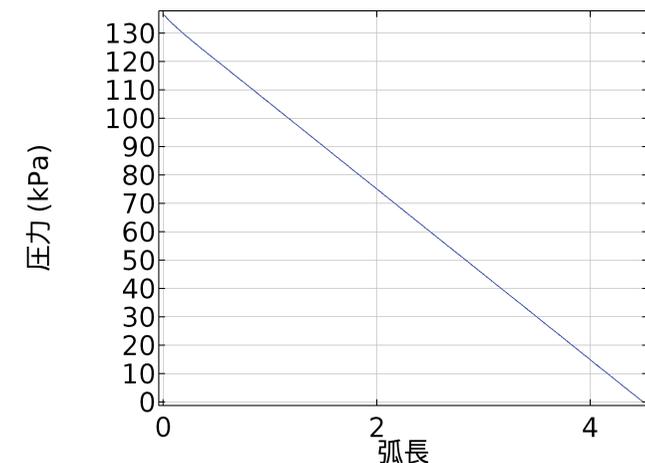
- Physics : Turbulent flow
- Shape : $d = 23.9$ mm、 $l = 4.5$ m
- Boundary : Bottom to enter, Top to exit
x-sectional average flow velocity
 $u_{in} = 408.7$ m/s
- Material : Fluid density $\rho = 0.515$ kg/m³
Viscosity coefficient $\mu = 0.027$ cP
@ 5 atm · 200°C
(*) No roughness applied

Flow rate
= ~60 g/s

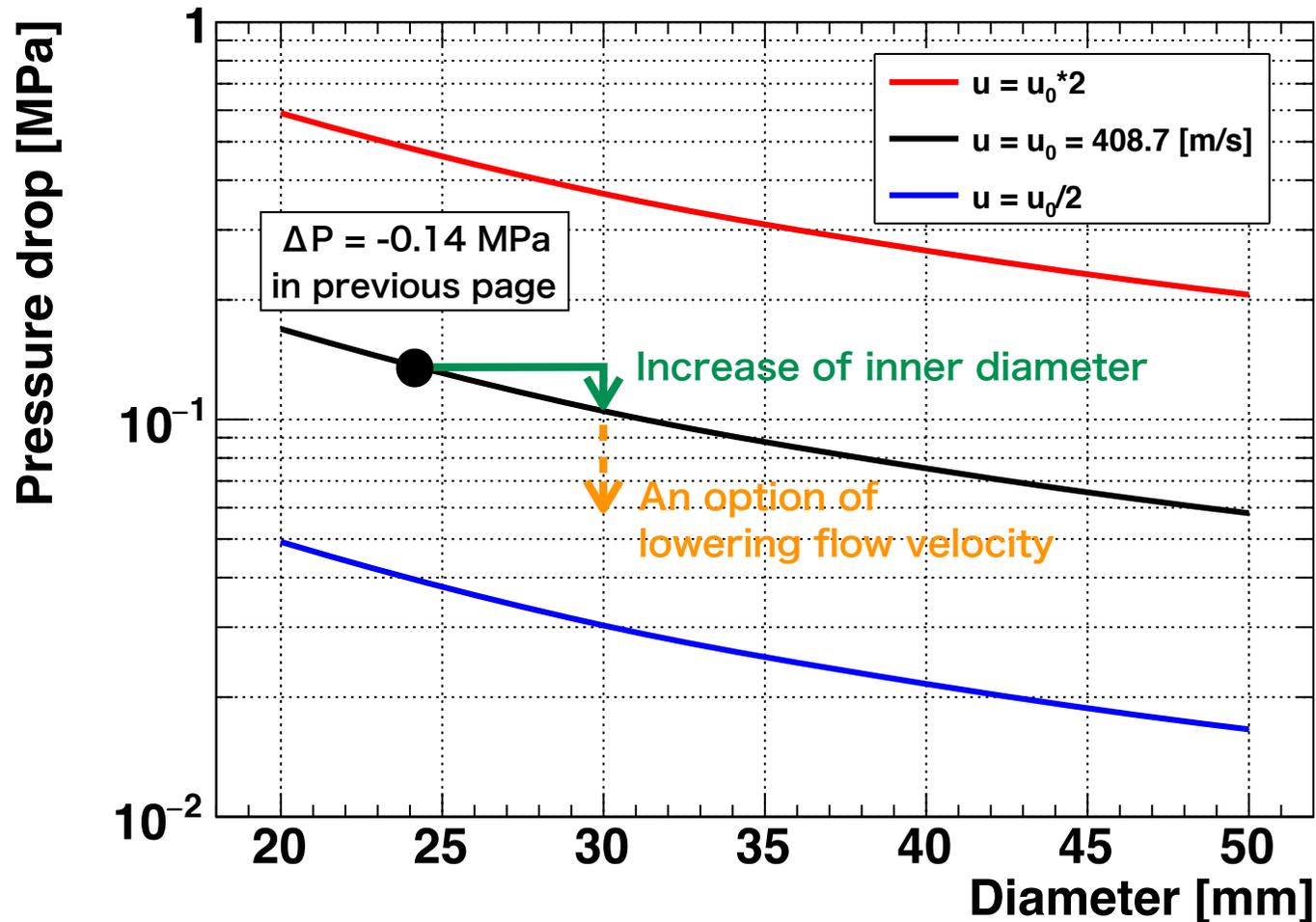


Simulation result

- $\Delta P = -0.14$ MPa at 5 atm is estimated
→ How about different d & u_{in} ?



If different inner diameter & flow velocity



Parameters related with the pressure loss is roughly understood

→ Contacting to a company of vacuum insulated pipe for more realistic simulation w/ expected flow rate & downstream pressure

Summary & prospects

Target Helium cooling system will be upgraded for 1.3 MW

- Idea is to provide high flow rate by increasing pressure
- Vacuum insulated pipe is newly used, replacing 1st heat ex.

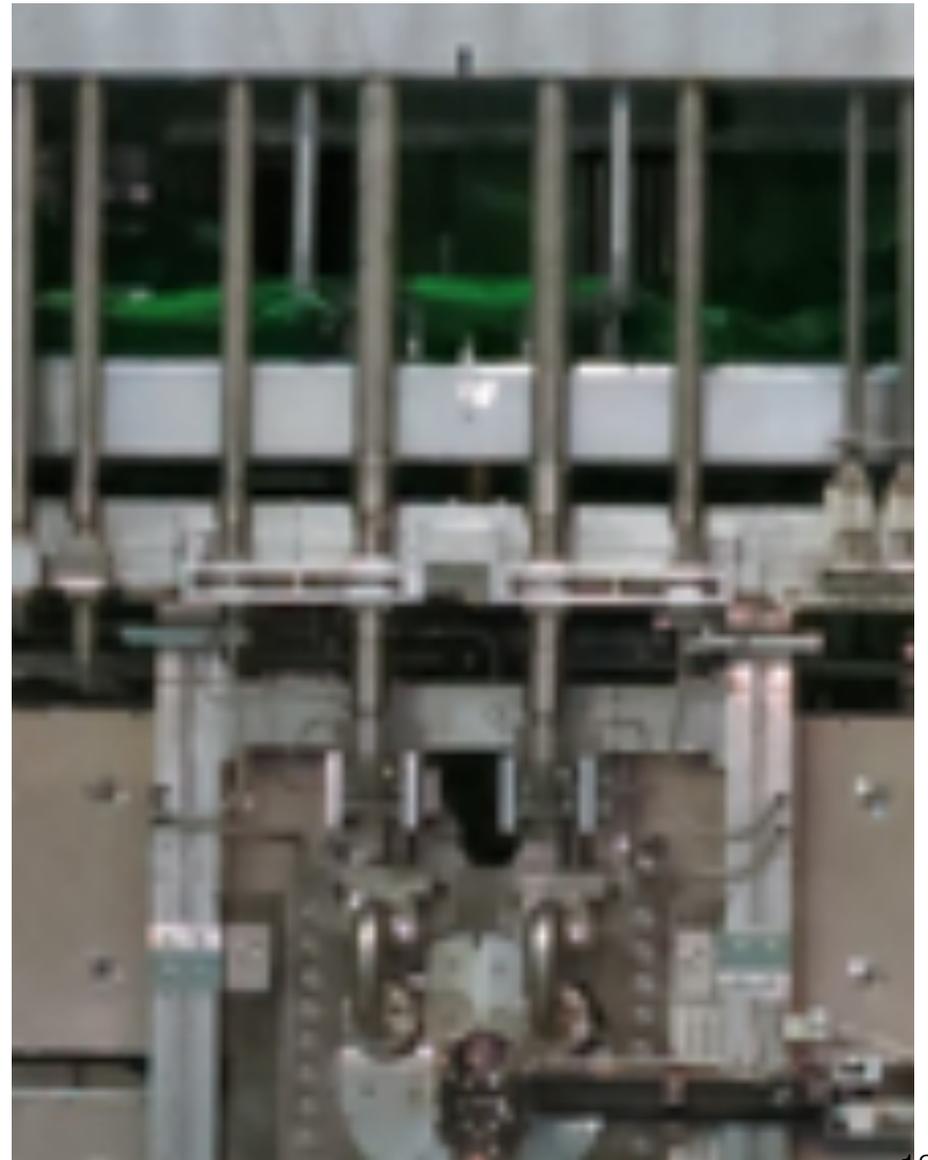
Status

- Designing the vacuum insulated pipe with two companies
- Initial estimation of pressure drop was performed

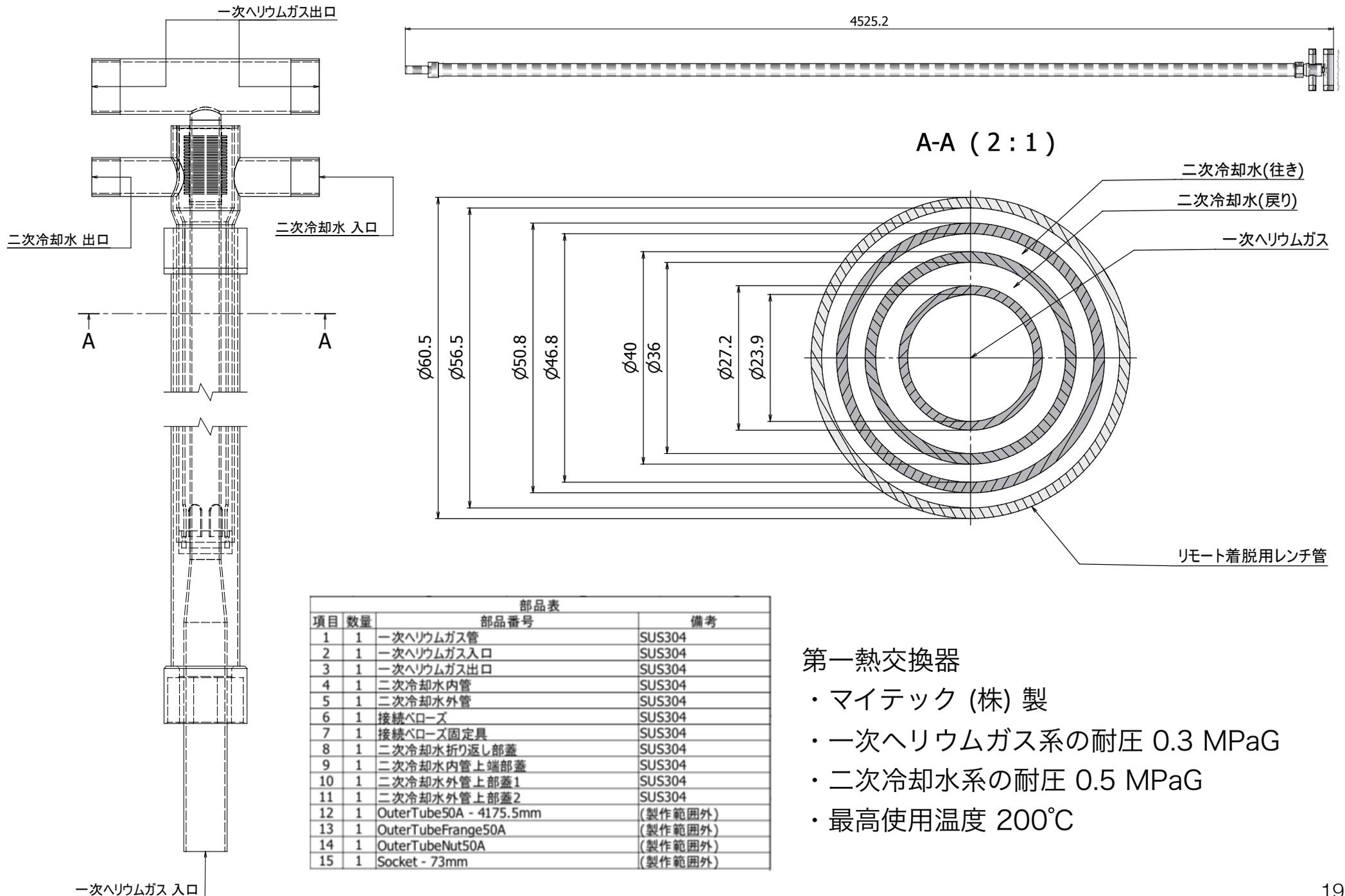
Prospects

- Prototyping & heat insulation tests ASAP
- R&D of exchange method & new heat exchanger toward upgrade of the vacuum insulated pipe in 2021
- Upgrades of compressor & angle valve are foreseen in 2023

Backup



Details of 1st heat exchanger



| 部品表 | | | |
|-----|----|-------------------------|---------|
| 項目 | 数量 | 部品番号 | 備考 |
| 1 | 1 | 一次ヘリウムガス管 | SUS304 |
| 2 | 1 | 一次ヘリウムガス入口 | SUS304 |
| 3 | 1 | 一次ヘリウムガス出口 | SUS304 |
| 4 | 1 | 二次冷却水内管 | SUS304 |
| 5 | 1 | 二次冷却水外管 | SUS304 |
| 6 | 1 | 接続ベローズ | SUS304 |
| 7 | 1 | 接続ベローズ固定具 | SUS304 |
| 8 | 1 | 二次冷却水折り返し部蓋 | SUS304 |
| 9 | 1 | 二次冷却水内管上端部蓋 | SUS304 |
| 10 | 1 | 二次冷却水外管上部蓋1 | SUS304 |
| 11 | 1 | 二次冷却水外管上部蓋2 | SUS304 |
| 12 | 1 | OuterTube50A - 4175.5mm | (製作範囲外) |
| 13 | 1 | OuterTubeFrangle50A | (製作範囲外) |
| 14 | 1 | OuterTubeNut50A | (製作範囲外) |
| 15 | 1 | Socket - 73mm | (製作範囲外) |

第一熱交換器

- ・マイテック (株) 製
- ・一次ヘリウムガス系の耐圧 0.3 MPaG
- ・二次冷却水系の耐圧 0.5 MPaG
- ・最高使用温度 200°C

Details of other system

Compressor

- ・オイルフリーコンプレッサ
- ・堀技研工業(株)製 2640TD

2nd heat exchanger

- ・ブレイジングプレート式熱交換器
- ・日阪製作所(株)製 BXC-724-PU-30
- ・伝熱面積：5.6 m²

Other circulation system

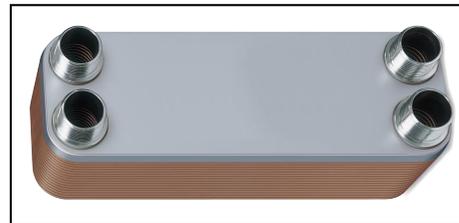
- ・アイハラ (株) 製



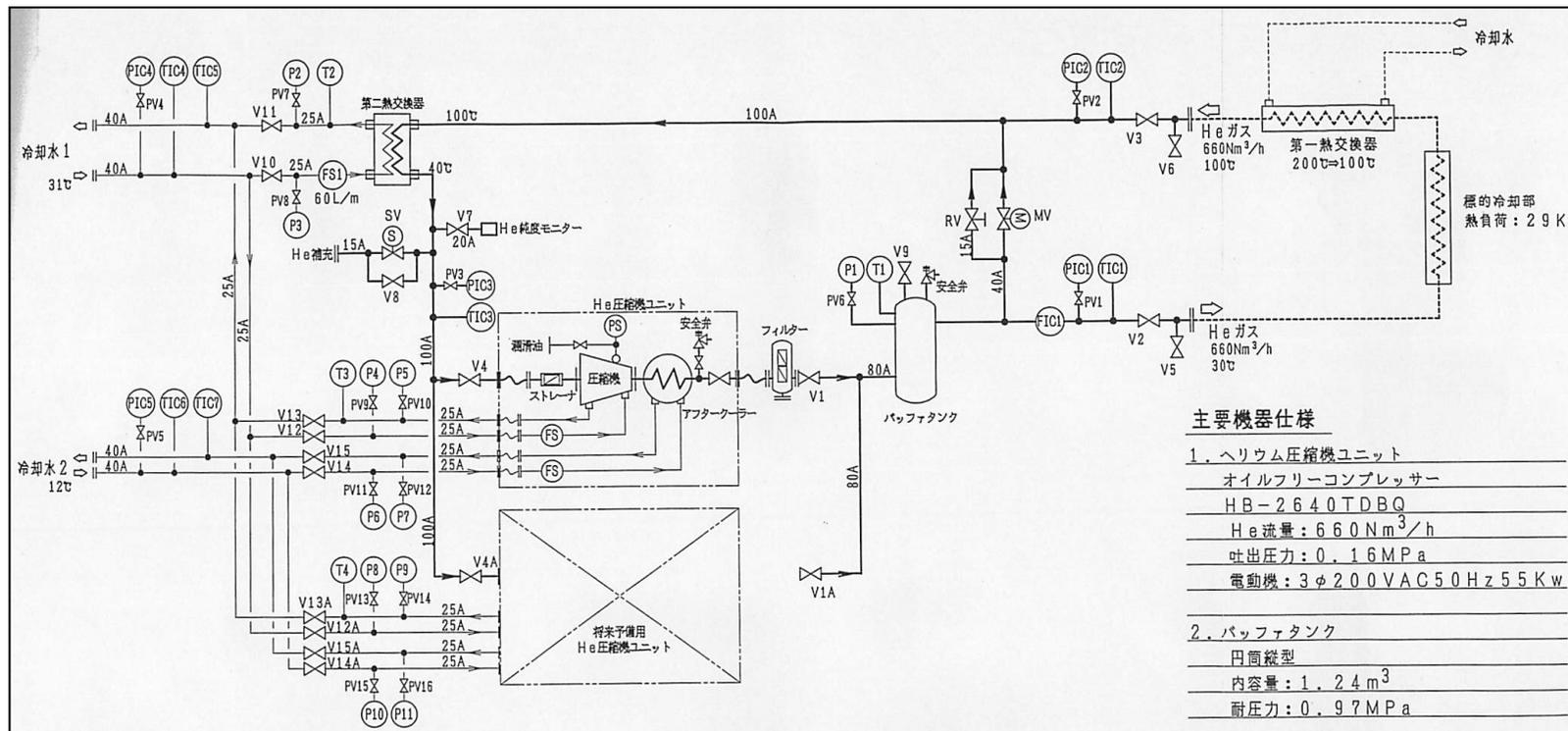
型式
HC-2026GWDQ

用途
ガスエンジンへの供給用

仕様
流 体：都市ガス 13A
流 量：1250 Nm³/h
吸入圧力：0.20 MPaG
吐出圧力：0.51 MPaG



(*) 圧縮熱はアフタークーラーによって除熱
 (*) バッファタンク (1.24 m³、耐圧0.97MPa) でガス貯蔵
 (*) バッファタンクには0.3 MPaGの安全弁が備え付け
 (*) 流量はおよび圧力は、循環系へのガスの充填量とバッファタンクからコンプレッサに戻るバイパス流量を調整することにより制御
 (*) コンプレッサ吸入口には圧縮部への異物混入を防ぐストレーナ (~数百μm以上)、コンプレッサ吐出口には標的部への異物混入を防ぐHEPAフィルタ (1μm以上)



ΔP estimation by hand calculation

Darcy–Weisbach equation relates ΔP for steady flow in a circular pipe as:

$$\Delta P = \lambda \times \frac{l}{d} \times \frac{\rho \times u^2}{2} = -0.036 \text{ MPa}$$

| | | | |
|-----------|-----------------------|-------------------------|--|
| λ | Friction loss factor | 0.022 | From Moody diagram with Reynolds number & ϵ/d (See below) |
| l | Length | 4.5 m | From drawing |
| d | Diameter | 23.9 mm | From drawing |
| ρ | Density of the fluid | 0.103 kg/m ³ | @1 atm, 200°C, From $\rho (K, P) = 0.1785 \times 273.2/K \times P/101.3$ |
| u | Average flow velocity | 408.7 m/s | From $u = Q/(\pi \cdot (d/2)^2)$ & Flow rate $Q = 660 \text{ Nm}^3/\text{h}$ |
| μ | Viscosity | 0.027 cP (=mPa · s) | @1 atm, 200°C, From $\mu (K) = 0.0186 \times (K/273.2)^{2/3}$ |

Details of friction loss factor

- Calculated Reynolds number to know Laminar or turbulent flow

$$Re = \rho \times u \times d/\mu = 37263$$

where, $\mu = 0.027 \text{ cP (= mPa} \cdot \text{s)}$ at 1 atm · 200°C is used

- If $Re > 2000$ in steady flow, it becomes turbulent flow. Colebrook equation gives Darcy's friction loss factor. Conventionally, Moody diagram from the equation is used. The λ can be estimated with Re & roughness
- Here, λ is obtained assuming no roughness. Relative pipe roughness (ϵ/d) is $\epsilon/d = 0.001252$ assuming seamless SS pipe without any degradation. Then $\lambda = \sim 0.025$ (+20%) is obtained from the right diagram

