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A cryogenic heat exchanger with bypass and throttling and its thermodynamic analysis

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Outline

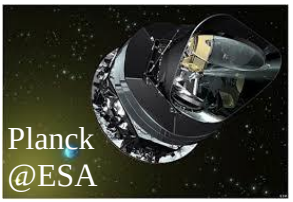
1. Heat exchangers in precooled J-T cycle

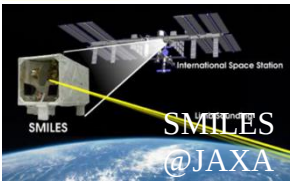
2. A heat exchanger with bypass and throttling

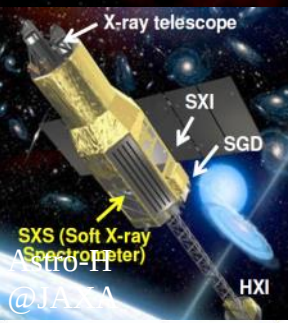
3. Entropy analysis of heat transfer and flow

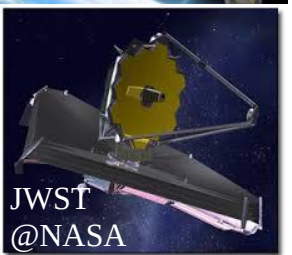
4. Summary

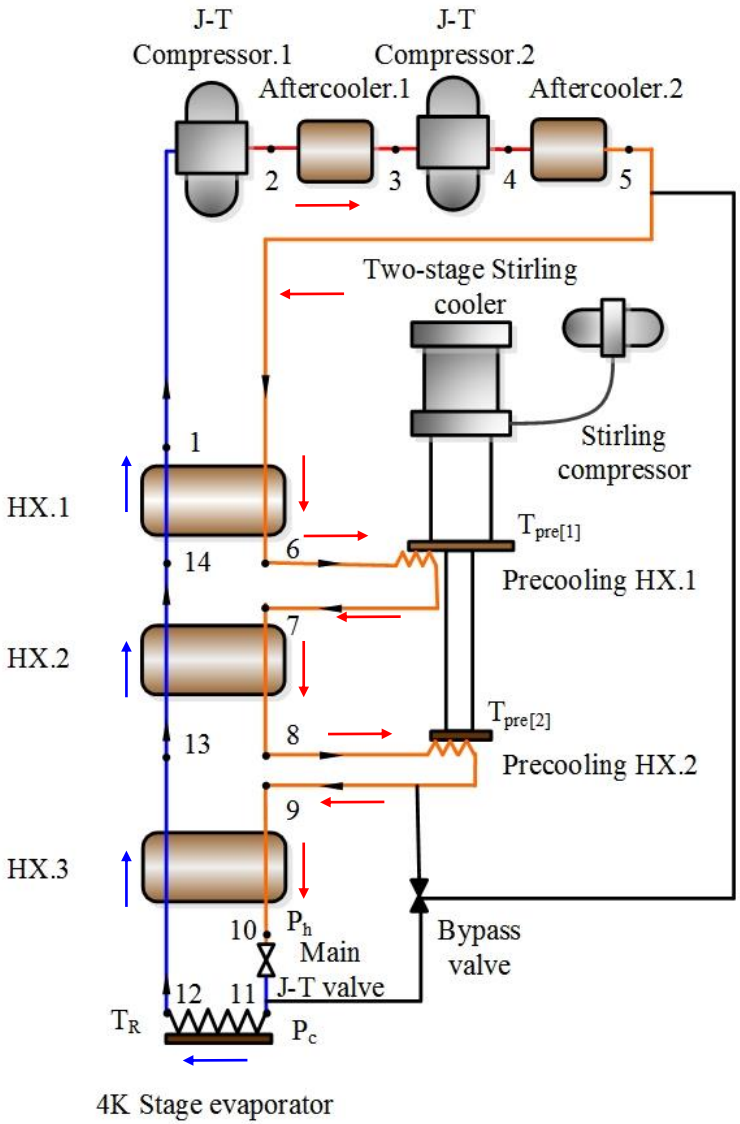
Introduction to the cycle







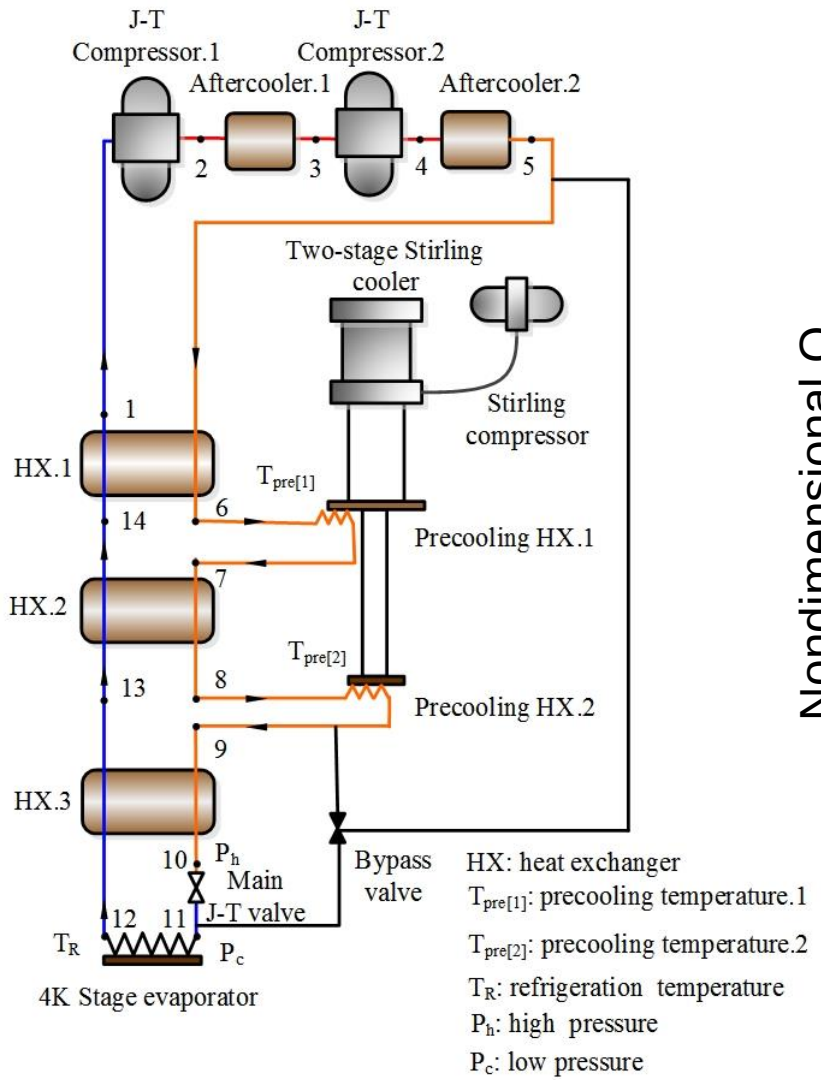


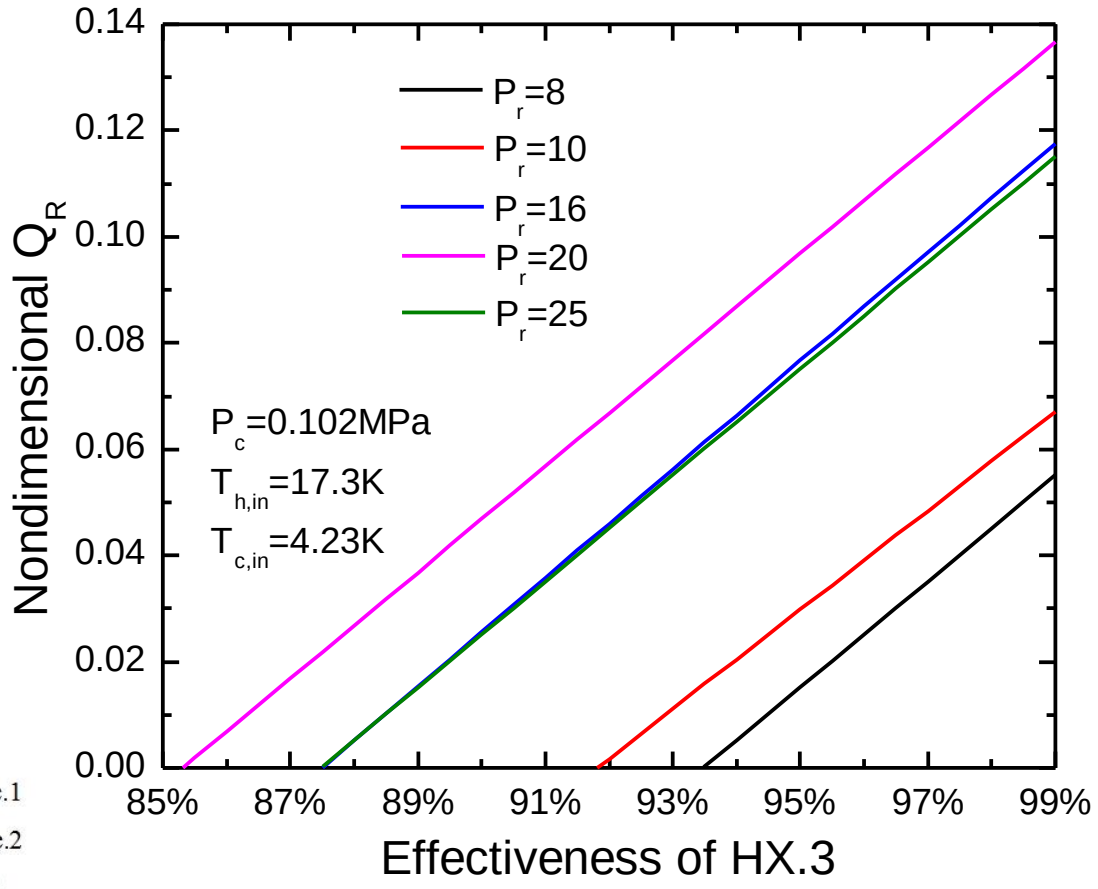


HX: heat exchanger
$T_{pre[1]}$: precooling temperature.1
$T_{pre[2]}$: precooling temperature.2
T_R: refrigeration temperature
P_h: high pressure
P_c: low pressure

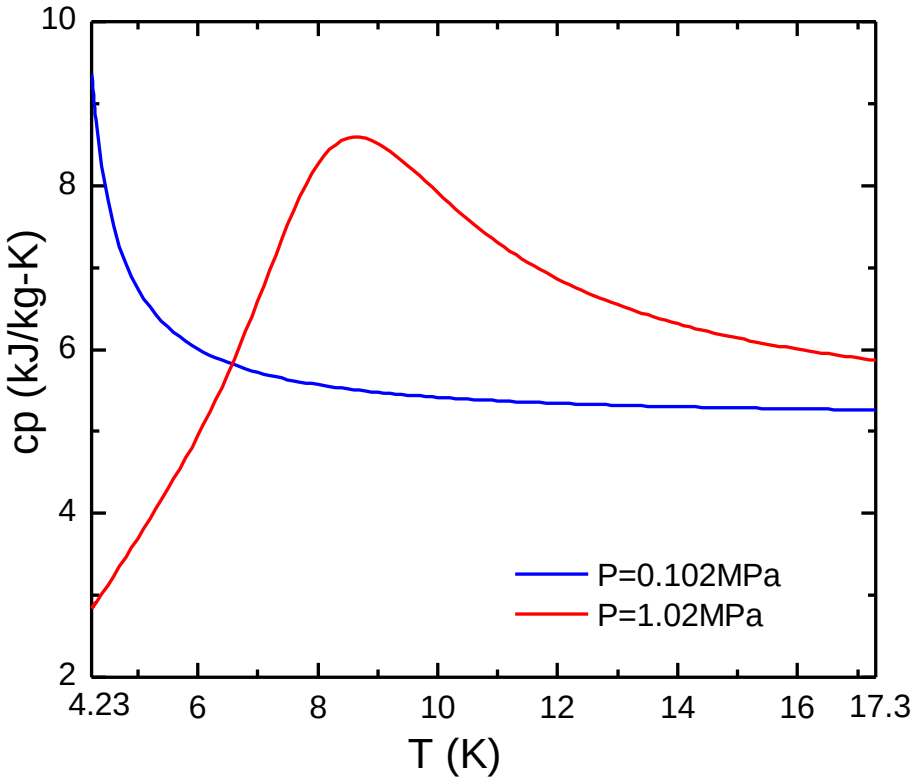
1~100mW
@1~10 K

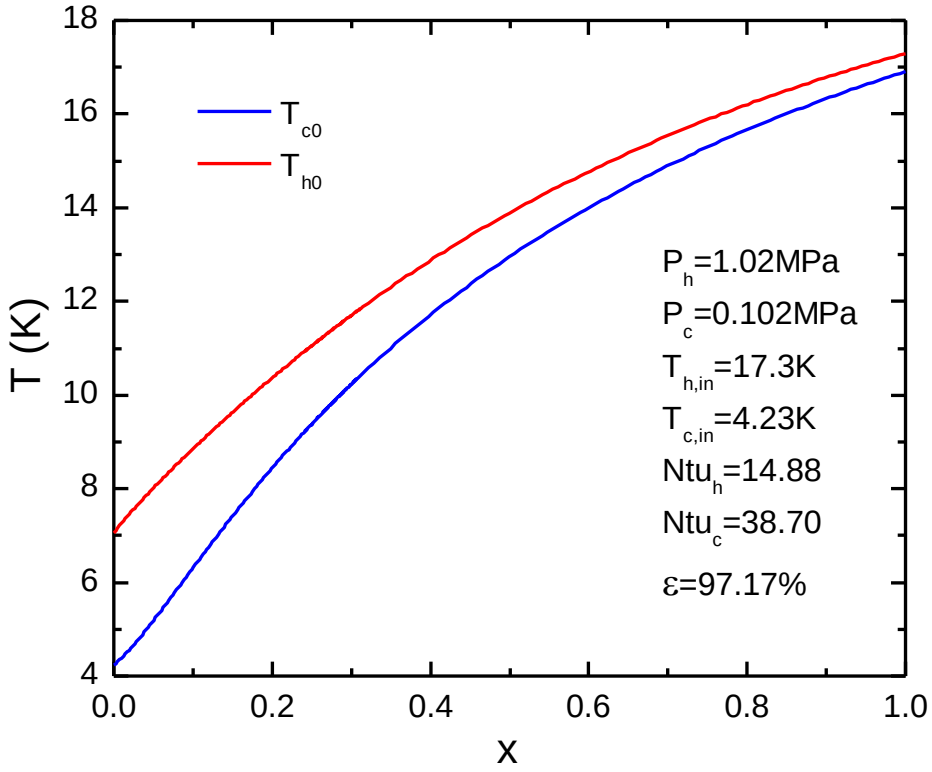
HX.3 is the key component





^{4}He property deteriorates T-L





$$C_{p,h} > C_{p,c}$$

ε=97.17%,
$T_{h,out}$=7.06K,
$\Delta T_{c,end}$=2.83K

ε= 100%,
$T_{h,out}$=6.78K,
$\Delta T_{c,end}$=2.55K

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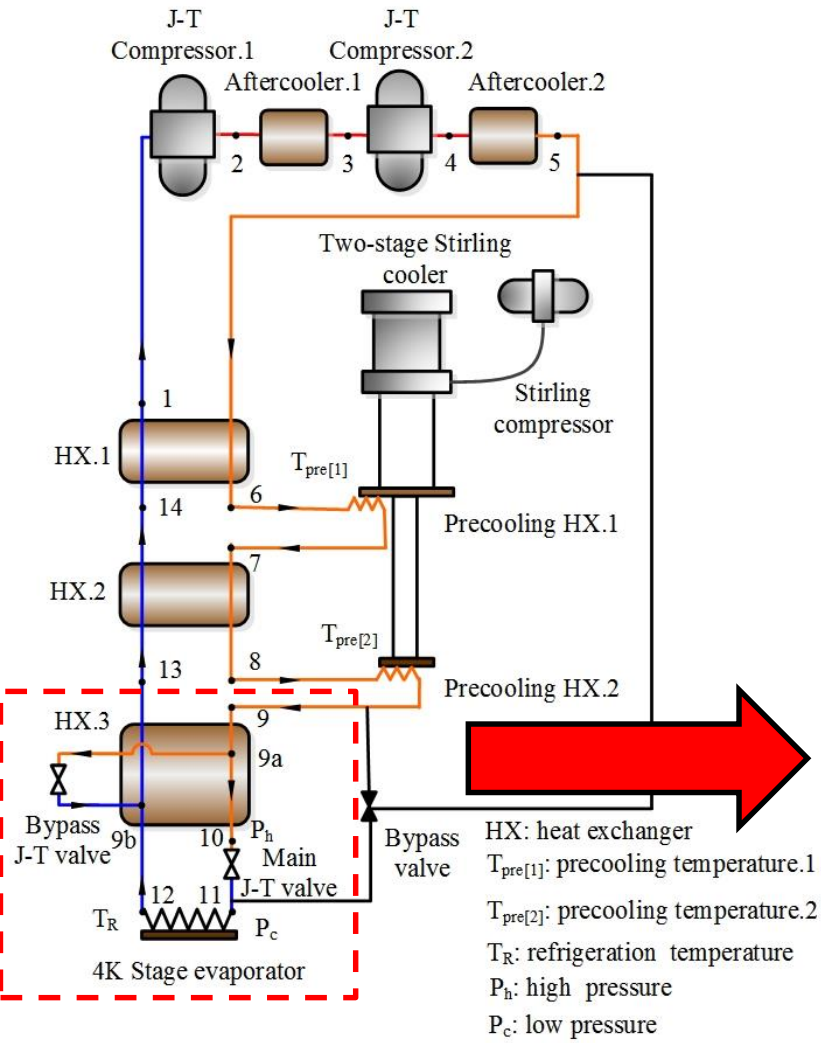
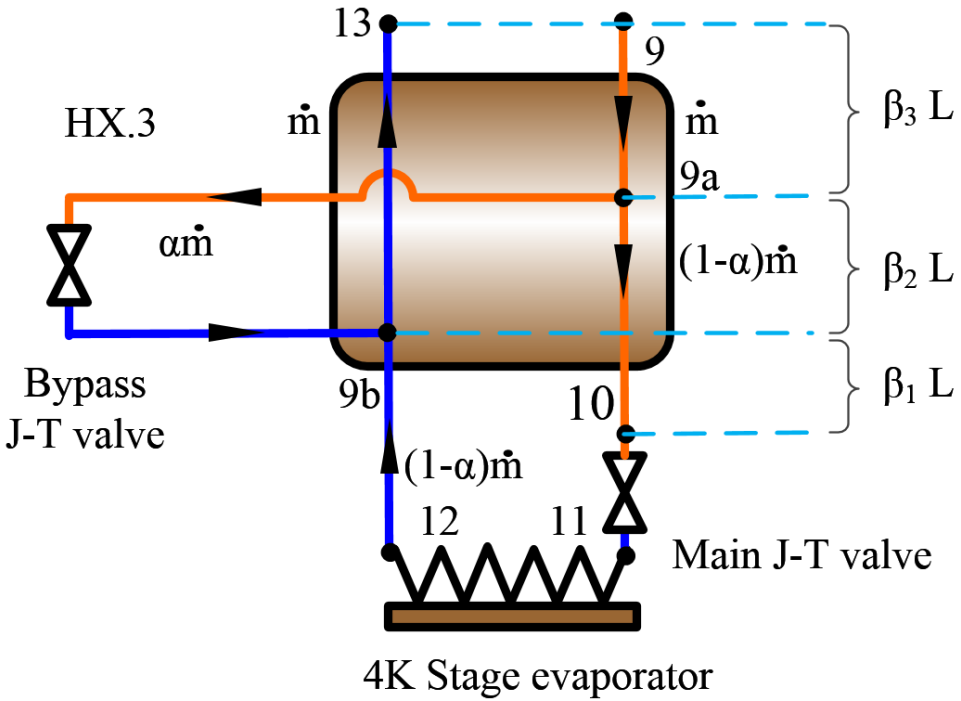
New structure of HX.3

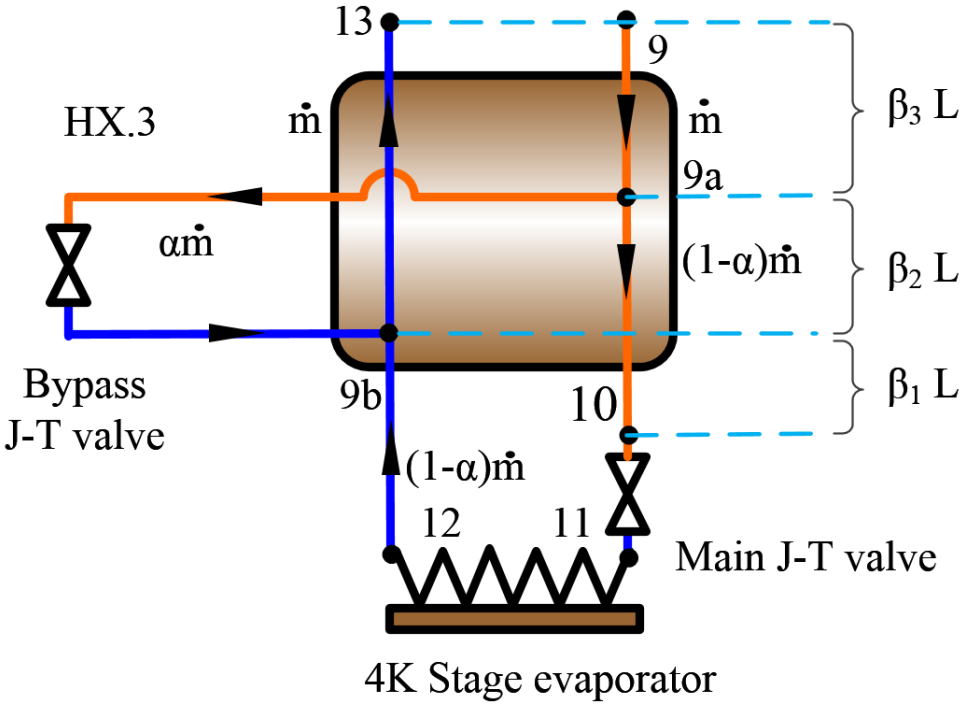
$$c_{p,h}\dot{m} > c_{p,c}\dot{m}$$

$$c_{p,h}\dot{m}(1-\alpha) \sim c_{p,c}\dot{m}$$





New structure of HX.3



Questions

1.Where to locate?

– β

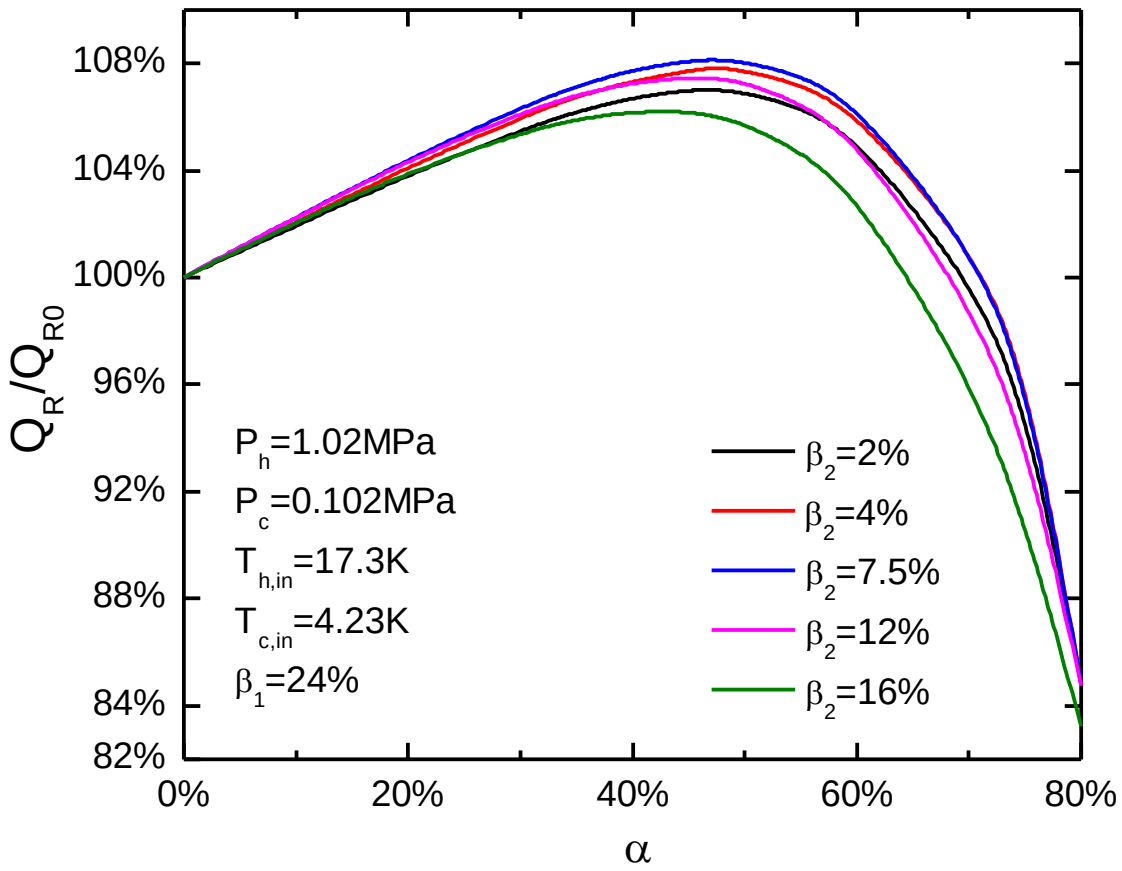
2.How much mass flow to extract?

– α

$$Q_R = \dot{m}(1-\alpha)(h_{c,in} - h_{h,out})$$

Q_R variation

$$Q_R = \dot{m}(1-\alpha)(h_{c,in} - h_{h,out})$$

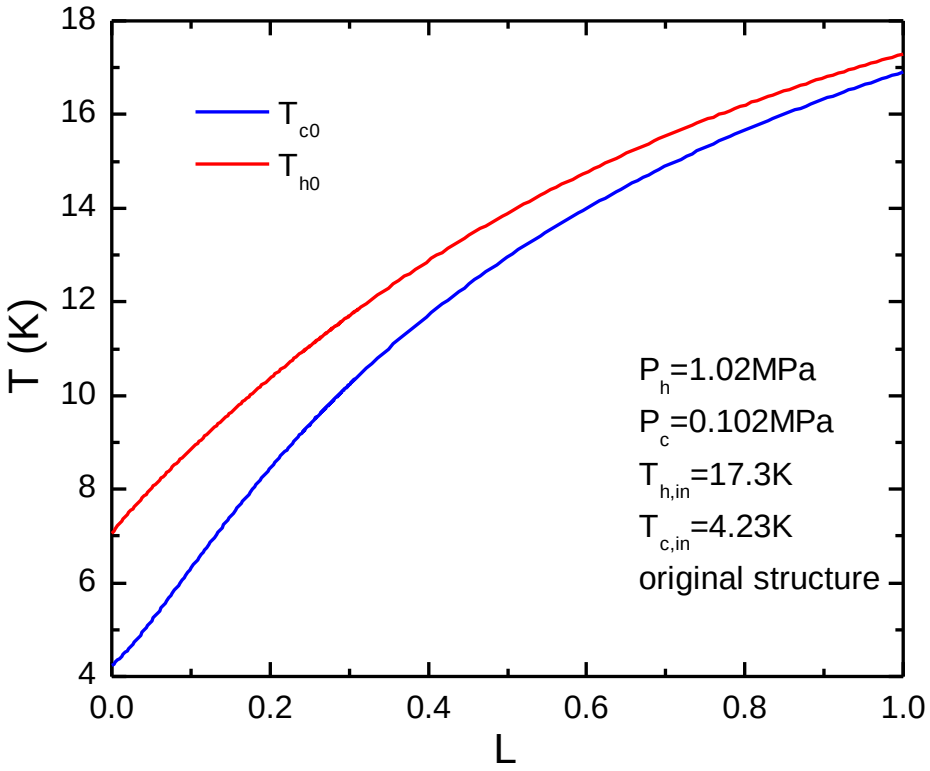


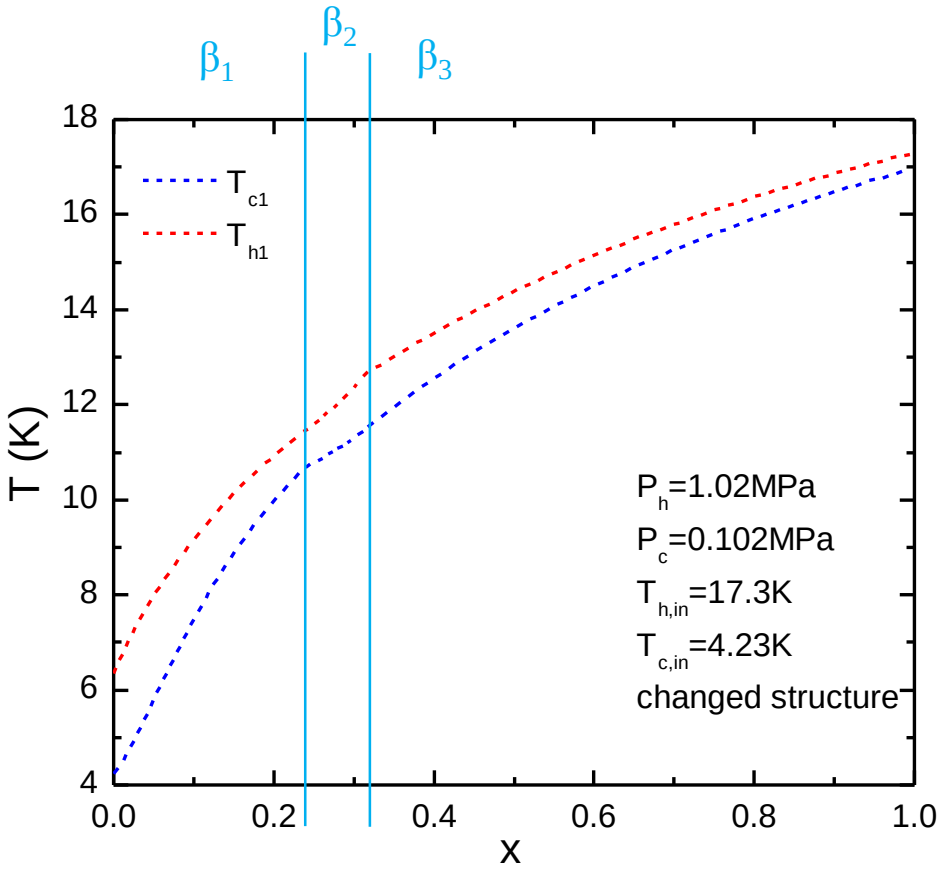
β_2 indicates the position of bypass and throttling
α indicates the amount of bypass mass

β_1=24%, β_2=7.5 %, α=47.5%

$(Q_{R_{max}}-Q_{R_0}) / Q_{R_0}$=8.14%

ΔT decreases





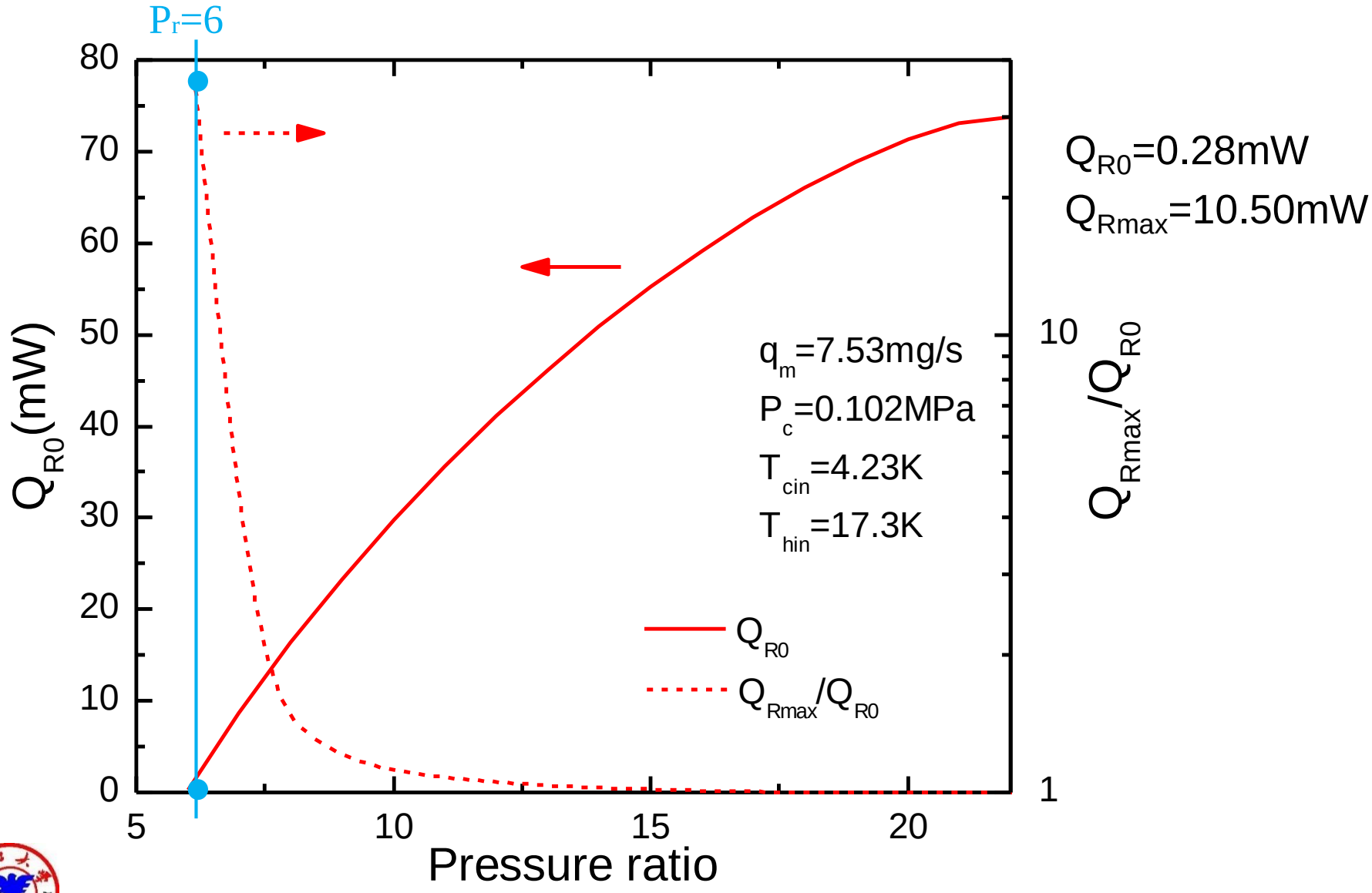
original structure,

$T_{h,out}$=7.06K, $\Delta T_{c,end}$=2.83K

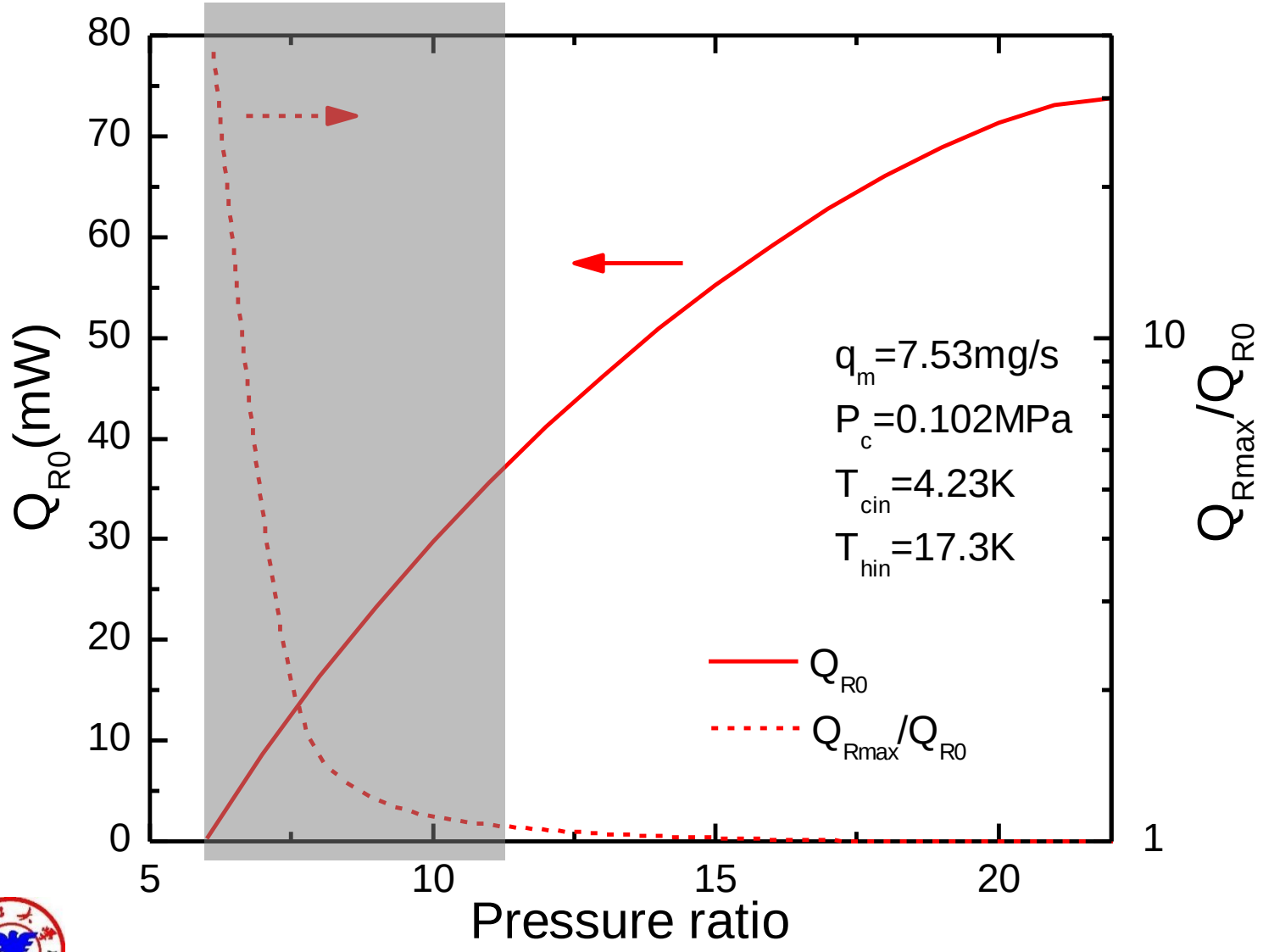
changed structure,

$T_{h,out}$=6.36K, $\Delta T_{c,end}$=2.13K

Effects of changed structure



Effects of changed structure



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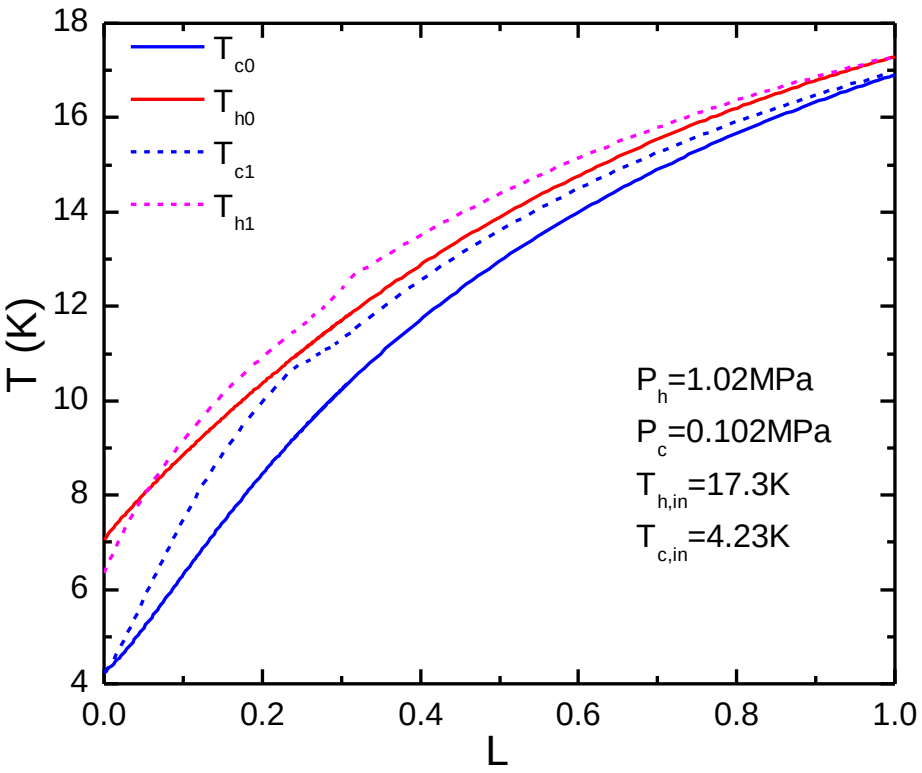
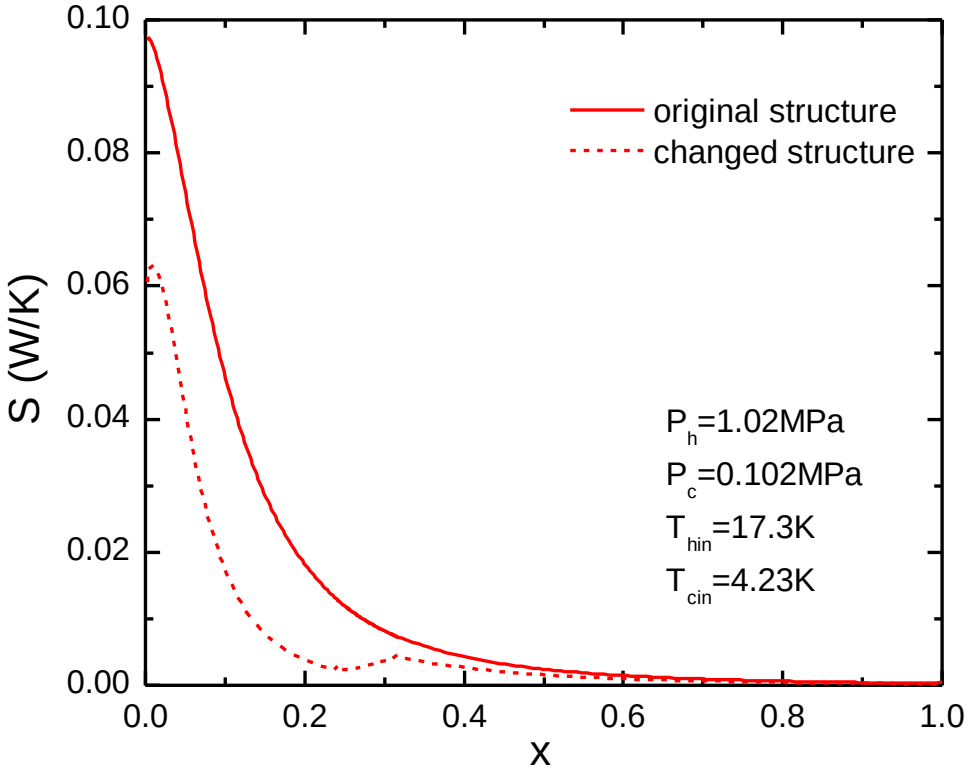
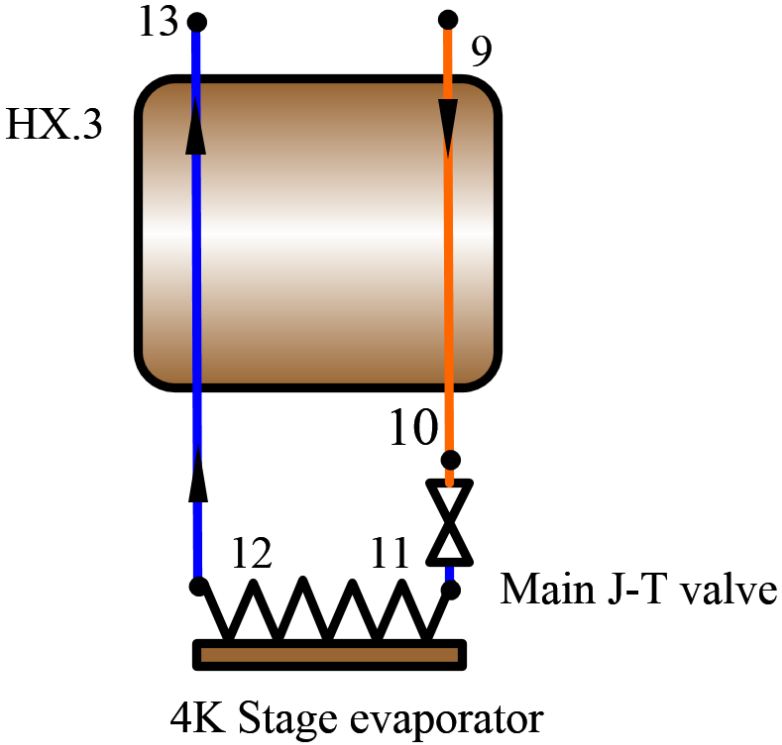
Entropy generation within HX.3

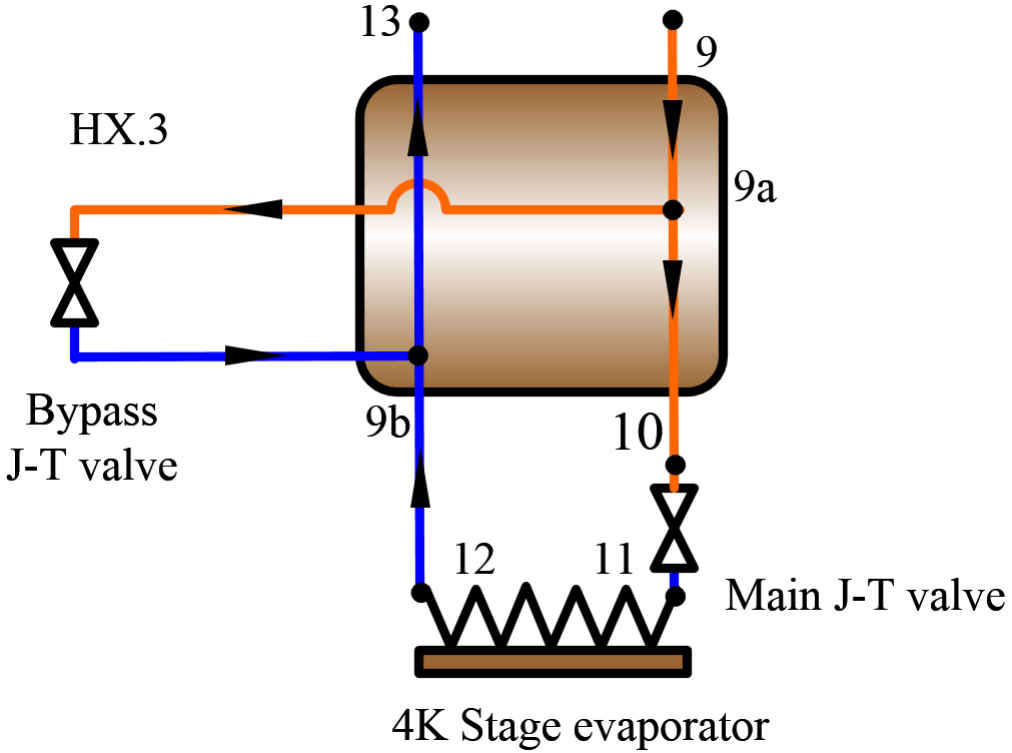




ΔT decreases in the changed structure.
So entropy generation due to heat transfer decreases

Two structures





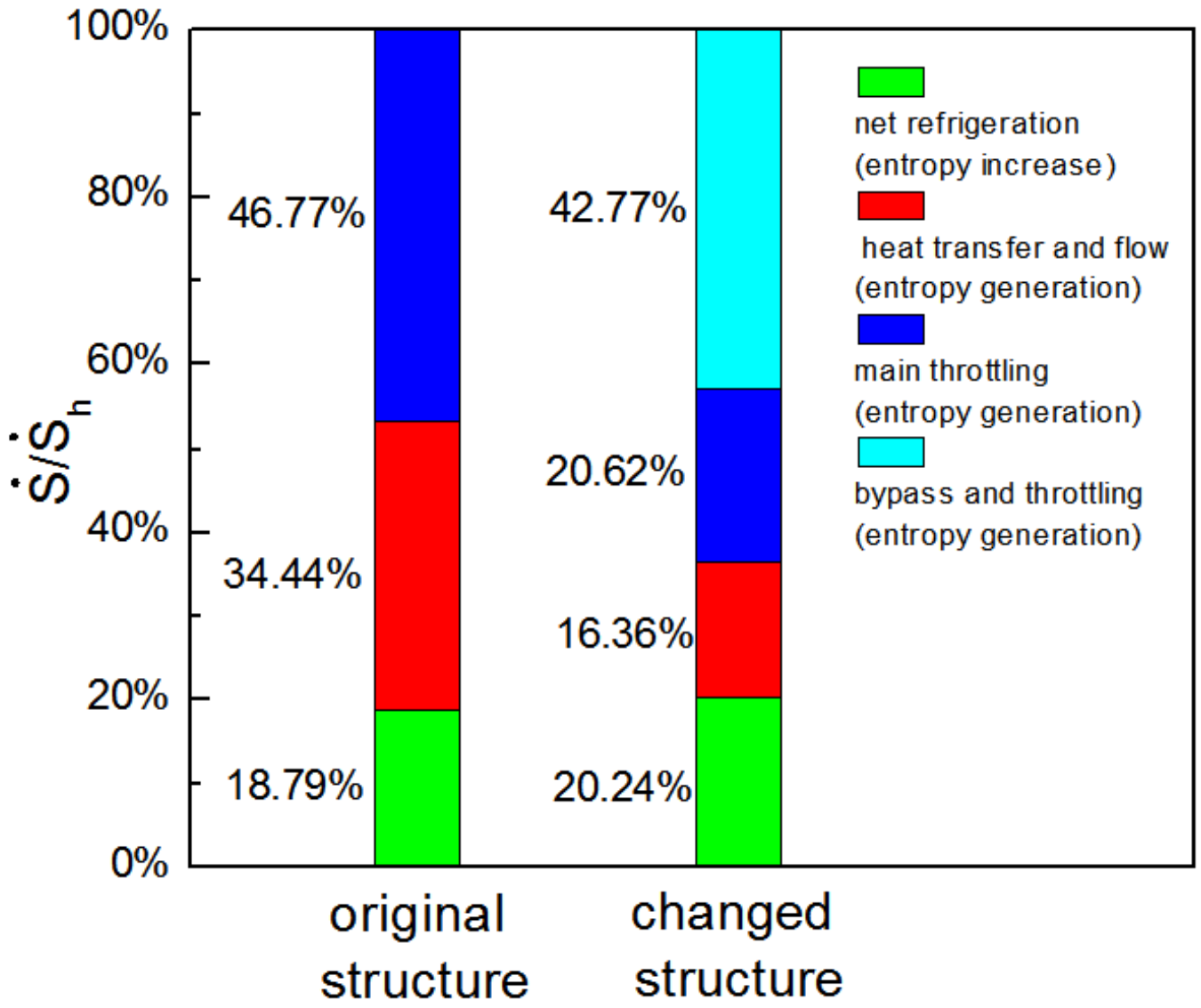
original structure

$$\dot{m}(s_{c,out} - s_{h,in}) = \dot{S}_R + (\dot{S}gen_t + \dot{S}gen_f) + \dot{S}gen_{th1}$$

changed structure

$$\dot{m}(s_{c,out} - s_{h,in}) = \dot{S}_R + (\dot{S}gen_t + \dot{S}gen_f) + \dot{S}gen_{th1} + \dot{S}gen_{th2}$$

Entropy comparison



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Summary

- A cryogenic heat exchanger with bypass and throttling is introduced in this paper.
- The effect of the changed structure is remarkable at low pressure ratio. When the pressure ratio of the J-T cycle is 6, the original structure approximatlely achieves no refrigeration capacity, while the changed structure achieves the refrigeration capacity of 10.5 mW.
- In the changed structure, the entropy generations of heat transfer and flow decrease by a half, the entropy generations of the bypass and throttling is introduced, and the entropy increase of heat absorption increases.

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Thank you !

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