Numerical study of a gas coupled VM-PT hybrid cryocooler using 3He as the working fluid

Jue Wang[1, 2], Changzhao Pan[1], Liubiao Chen[1,2], Junjie Wang[1, 2], Yuan Zhou[1,2]

1 CAS Key Laboratory of Cryogenics, Technical Institute of Physics and Chemistry, Beijing, 100049, China

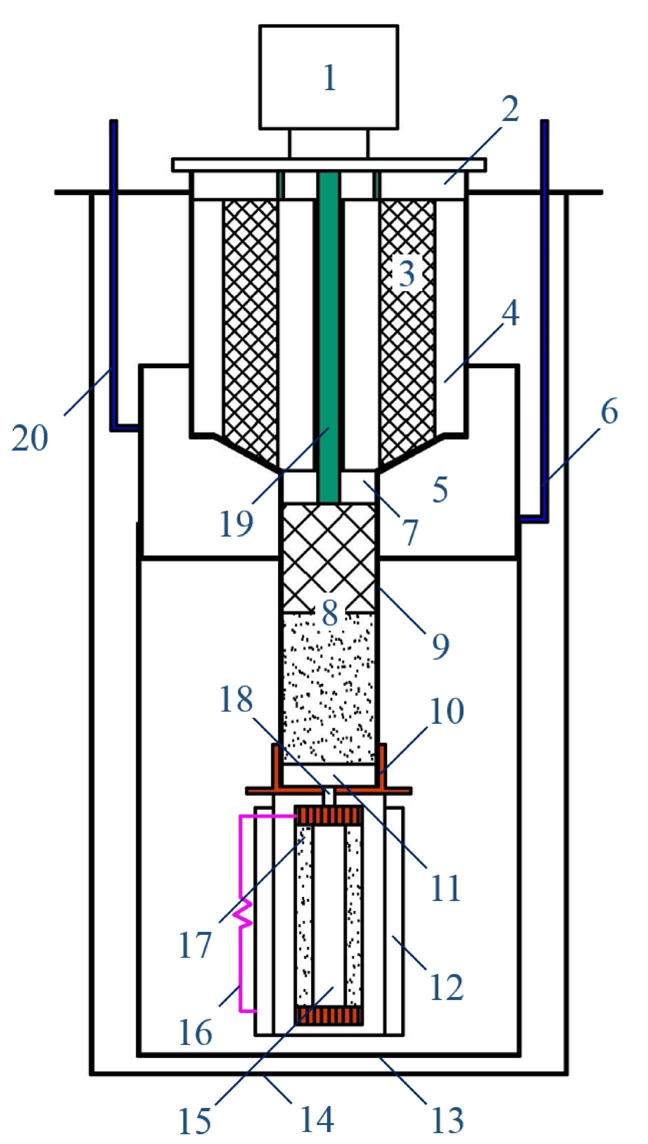
2 University of Chinese Academy of Sciences, Beijing, 100049, China

C2PoK-10

Introduction

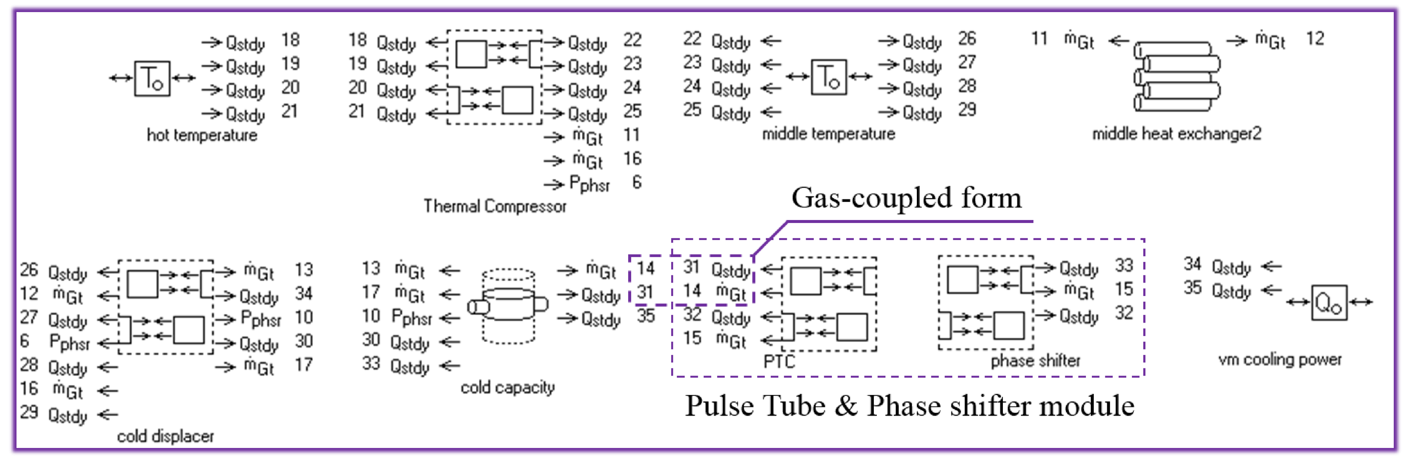
The two stage Vuilleumier gas-coupling pulse tube cryocooler (VM-PT) is one kind of novel low-frequency cryocoolers. The Gas-coupled form intends that the single stage Vuilleumier cryocooler serves as both pressure wave generator and cooler for a coaxial pulse tube cryocooler. Compared with the most commercialized GM and GM pulse tube cryocooler, the two stage VM-PT cryocooler is characterized by its high stability, more compact size and thermal actuation which are indispensable for space application. ^{3}He as a more potential substitution of ^{4}He, has better physical properties to enlarge the cooling power and efficiency, a numerical study on the specific performance of two stage VM-PT cryocooler using ^{3}He is carried out in present study though Sage software, meanwhile, the comparison of performance with ^{4}He is carried out.

Structure diagram and simulation model

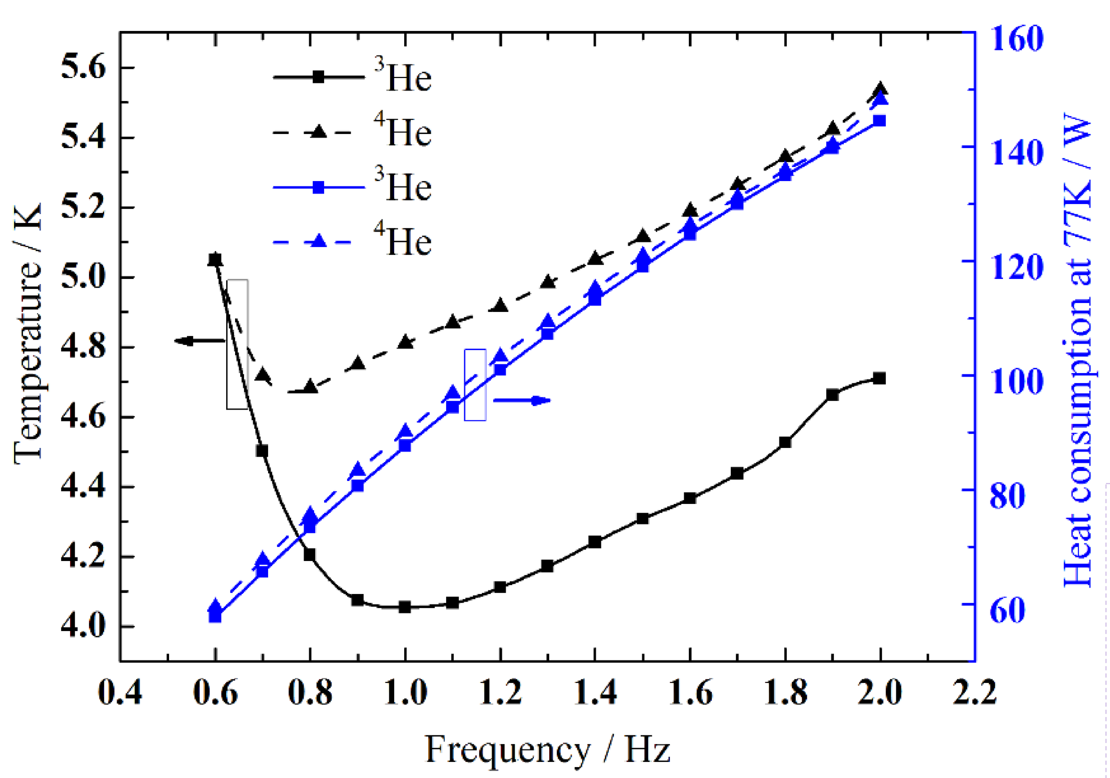


1. Motor
2. Hot cavity
3. Hot regenerator
4. Hot displacer
5. Liquid nitrogen tank
6. Liquid nitrogen pipe
7. Intermediate cavity
8. Cold regenerator
9. Cold displacer
10. VM cold end
11. Cold cavity
12. Reservoir
13. Radiation shield
14. Vacuum cabin
15. Pulse tube
16. Pulse tube regenerator
17. Capillary
18. Connecting tube
19. Guide rod
20. Liquid nitrogen pipe

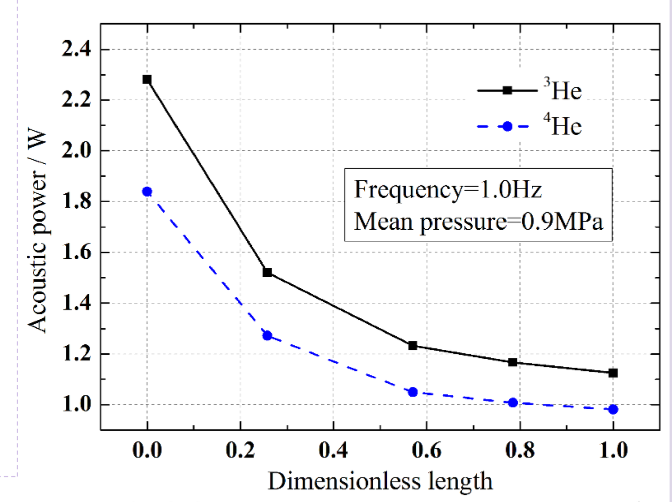
	Components	Parameters	
VM 1st stage	Hot displacer	Φ96*165	stroke: 32 mm
	Hot regenerator (Annular)	Φ23&45*128	80# SS
	Cold displacer	Φ95*190	stroke: 20 mm
	Cold regenerator	Φ95*190	200# SS + lead sphere
PT 2nd stage	Regenerator (Annular)	Φ8.9&15.9*70	Er_3Ni sphere &$HoCu_2$ sphere
	Pulse tube	Φ8.5*70	



Frequency optimization

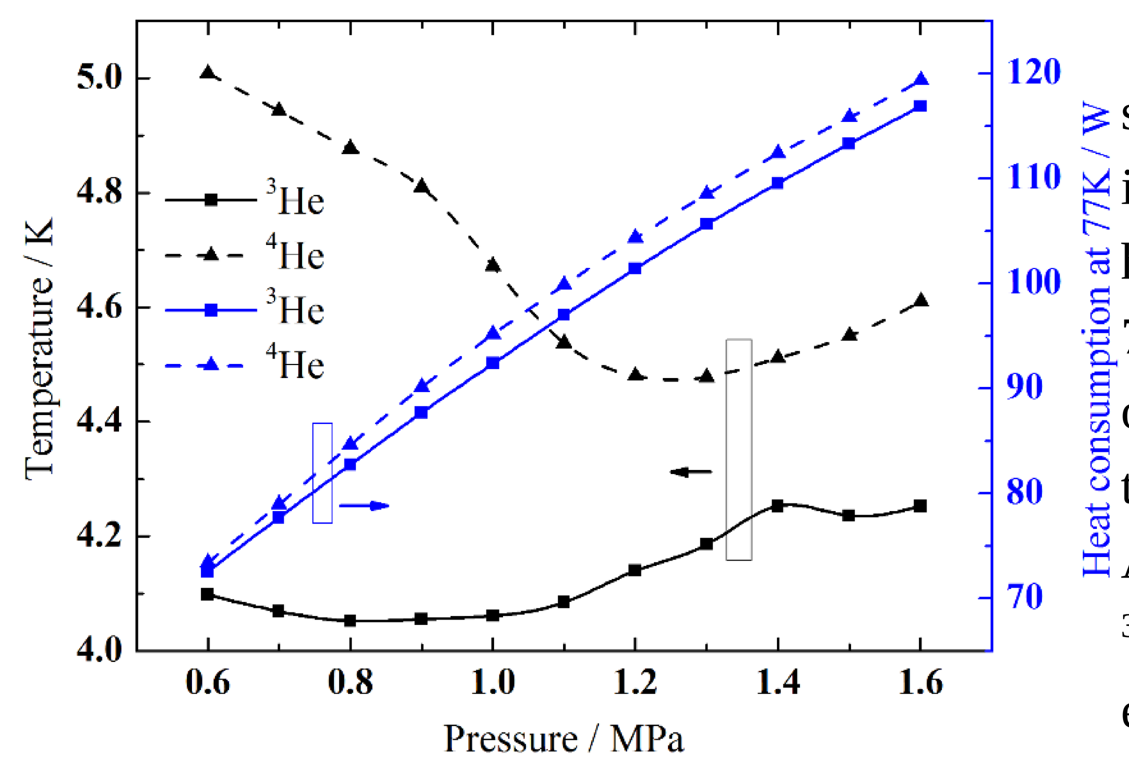


Using ^{3}He obtains the lowest 4.68K with 50mW load at 0.8Hz while ^{3}He get the lowest 4.06K with 50mW load at 1.0Hz. Overall, using ^{3}He provides lower temperature than ^{4}He with similar input power.

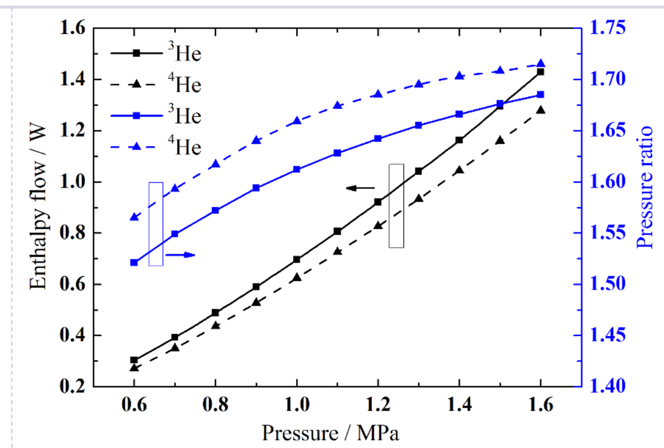


Although the acoustic power dissipates 0.297W more compared with ^{4}He along regenerator, the input and output acoustic power of ^{3}He are both higher than using ^{4}He, which contributes to higher performance and lower cooling temperature by ^{3}He.

Pressure optimization

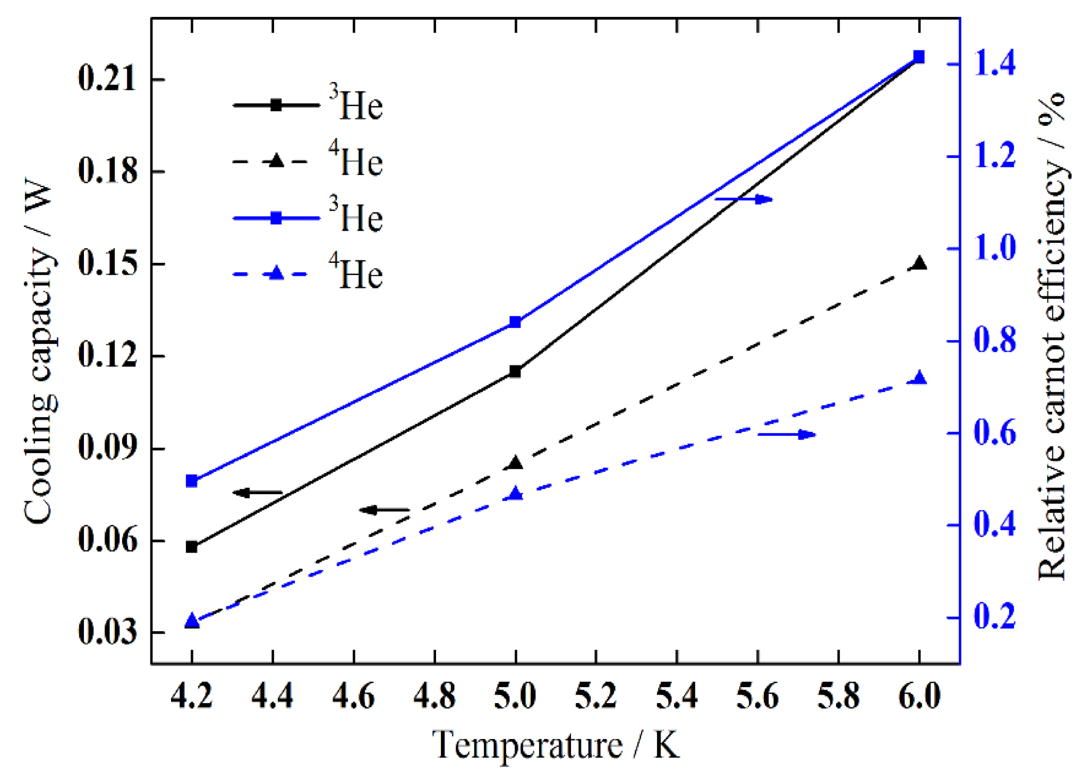


The influence of operating pressure is studied at 1.0Hz. Quite similar with influence of working frequency, the heat consumption of using two fluids at 77K are similar. The optimal pressure of ^{3}He is around 0.8-0.9MPa, lower than that of ^{4}He, around 1.2-1.3MPa. At the optimal pressure, the usage of ^{3}He is about 0.0038kg in this system, equivalent to 30L gas under STP.



Using ^{3}He makes both lower pressure ratio and large enthalpy flow out of PT regenerator than ^{4}He with the change of working pressure.

Performance & efficiency



The both cooling power curves and efficiency curves increase with the increasing of cooling temperature, and growth rate of using ^{3}He is bigger than ^{4}He. At 4.2K, the cryocooler with ^{3}He can offer 58mW cooling capacity, but it with ^{4}He can only offer 33mW, nearly half of the former. The relative Carnot efficiency of charging ^{3}He and ^{4}He are 0.49% and 0.19% respectively. At 5K and 6K, the VM-PT with ^{3}He can provide 115mW and 217mW cooling power, and the input power are all less than 1000W. In the field of relative Carnot efficiency, the ^{3}He must be an ideal substitution of ^{4}He for two stage VM-PT hybrid cryocooler.

Conclusion

Working at the frequency of 1.0Hz and the pressure of 0.8MPa, the two stage VM-PT cryocooler with ^{3}He obtains 50mW@4.06K. The usage of ^{3}He is 0.0038kg, about 30L gas under STP. At 4.2K, using ^{3}He can obtain 58mW cooling power and 0.49% relative Carnot efficiency, about 1.6 times higher than using ^{4}He. It can be included that using ^{3}He can further develop the performance of two stage VM-PT hybrid cryocooler.

If you have any questions , please contact me with e-mail: wang_56102@sina.cn panchangzhao@mail.ipc.ac.cn

This work was supported by the Postdoctoral Innovation Talent Support Program of China (Foundation No. BX201600173)