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2015臭氧气候工业圆桌会议

自然工质CO₂跨临界循环 制冷与热泵的关键技术

The Key Technology on Transcritical Refrigeration and Heat Pump Cycle with Natural Refrigerant CO₂

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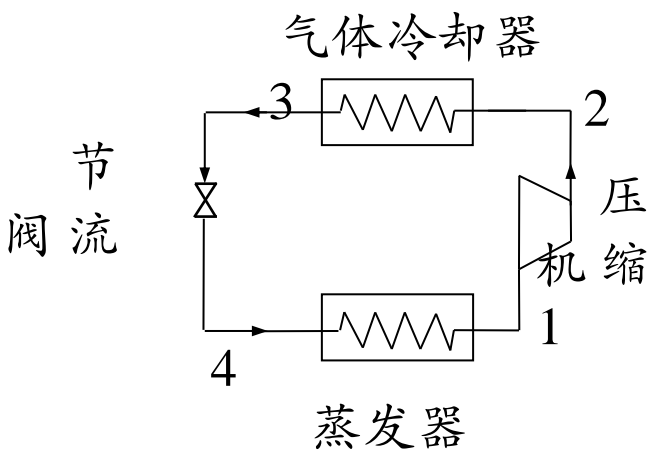
前言 Introduction

- CO₂是零ODP、极低GWP的自然工质。如果大量应用，是制冷工质的最后希望。CO₂ is a natural refrigerant with zero ODP and very low GWP. It is the final hope for refrigerants.
- 人们较早注意CO₂跨循环的原理，进行基础研究和应用基础研究。 Fundamental and application research is paid to more attention on CO₂ transcritical cycle.
- 国际上欧洲、日本已经进行CO₂跨临界循环产品开发研究。 Heat pump and refrigeration production of CO₂ transcritical cycle developed in European and Japan.
- 中国在自然科学基金、博士点基金、863、支撑计划等对CO₂跨临界循环项目给予资助。 The natural science foundation of Chinese, Doctoral Fund of Ministry of Education of China, 863 program, National Key Technology Support Program are supported in this area.
- 我国有若干企业生产CO₂跨临界循环热泵热水机，代替燃煤或燃油锅炉生产生活热水，解决宾馆、饭店、学校、火车站等热水供应。在节能减排中有重要作用。 CO₂ transcritical cycle Heat pumps are produced by several companies in China, which is for hot water to replacement of coal or oil boilers to supply hot water for hotels, restaurants , schools, railway stations and so on.
- 虽然从生产量上看， CO₂跨临界循环热泵的产量还不大，但代表保护臭氧的重要方向。相信“星星之火，可以燎原”。 Although small production of CO₂ transcritical cycle heat pump in our country, it is the direction to protection to ozone layer.

CO₂制冷与热泵循环特点

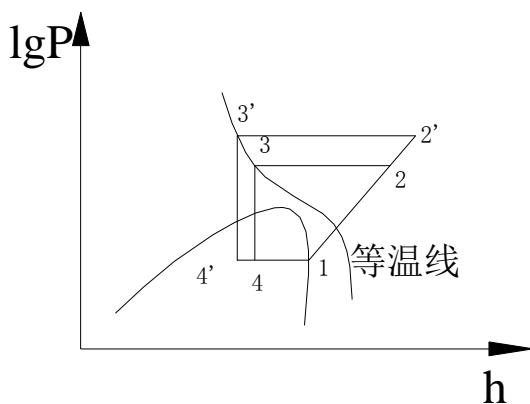
The feature of CO₂refrigeration and heat pump

- 压力高，通常高压高于10MPa，低压也是4、5MPa。 High pressure usually higher than 10MPa, and evaporating pressure is 4 or 5 MPa.
- 放热排温高。 CO₂的温度不断变化，不再是常规循环中的冷凝过程，因此其高压端换热器也不再称为冷凝器（Condenser），而叫气体冷却器（Gas Cooler）。
High temperature of heat releasing process. The temperature of CO₂ is changeable, instead of condensing process of traditional refrigerants. The high pressure heat exchanger is not called as condenser, but gas cooler.
- 循环效率低，在相同外界条件下，比常规工质低25%。 The efficiency of cycle is lower about 25% than traditional refrigerants at the same outside condition.

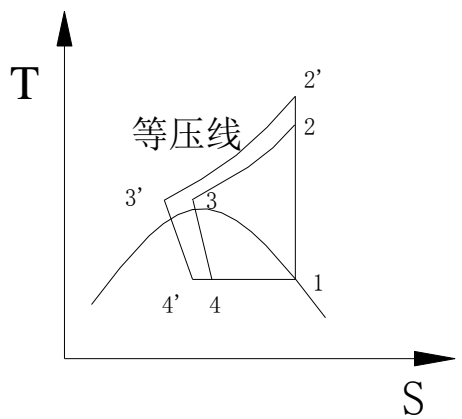


CO₂跨临界循环原理图

The principle of CO₂ transcritical cycle



LgP-h图



T-S图

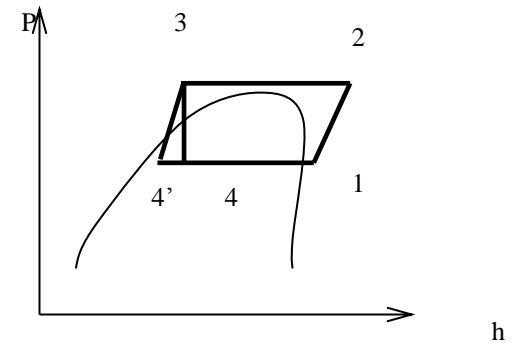
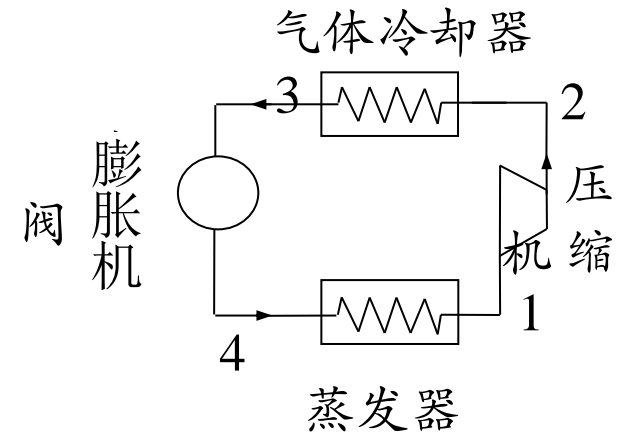
CO₂跨临界热力循环图
CO₂ transcritical cycle

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CO₂制冷与热泵循环特点

The features of CO₂refrigeration and heat pump

- 如果用节流阀，CO₂跨临界循环的节流损失是常规工质的3~5倍，这是其循环效率不高的根本原因。In the cycle with throttling valve, the throttling loss is 3~5 times of traditional refrigerants. This is the reason of low efficiency of CO₂ transcritical cycle.
- 节流损失既消耗了压缩功，还减少了冷量。Throttling loss consumes compression work, but also reduce the refrigeration capacity.
- 对于CO₂跨临界制冷循环，COP下降25~30%。For CO₂ transcritical refrigeration cycle, COP is reduced 25~30%.
- 对于CO₂跨临界热泵循环，COP下降10~15%。For CO₂ transcritical heat pump cycle, COP is reduced 10~15%.
- 所以人们先开发了CO₂跨临界热泵。So CO₂ transcritical heat pump is developed at the first.



用膨胀机代替节流阀的循环

CO₂压缩机需要重新设计

CO₂ Compressor is redesigned

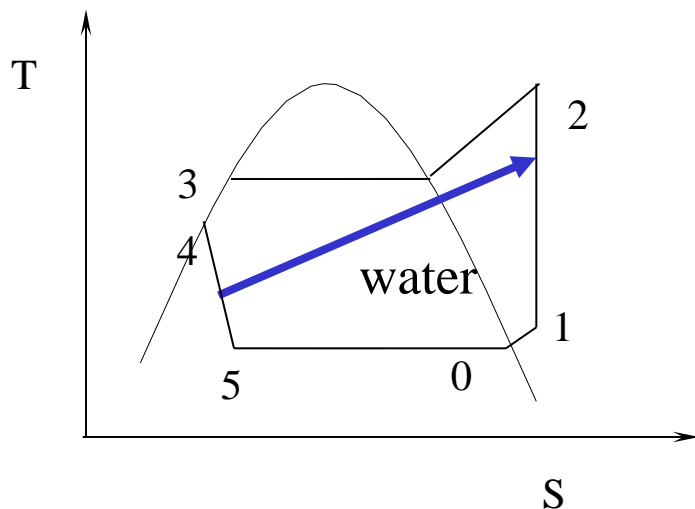
- CO₂压缩过程压比低、压差大，单位容积制冷量大，工作容积小，强度需加强。
In the compressed process of CO₂ cycle, there are low compression ratio, big compression difference and big refrigeration capacity per unit volume.
- CO₂压缩机与常规工质相比外型基本一致。The size and weight of CO₂ compressor is the similar to the traditional refrigerants.
- 目前已有CO₂压缩机容量偏小，有必要研究较大容量，如螺杆式压缩机。To develop big capacity compressor, such as screw compressor.



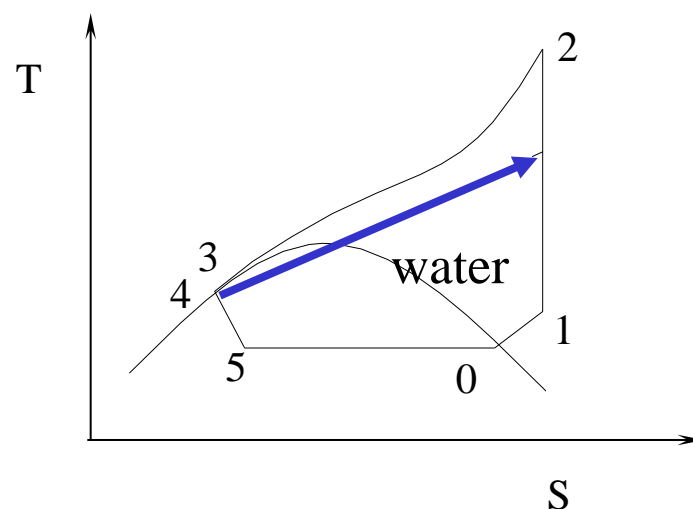
CO₂跨临界循环放热过程温度滑移

Sliding temperature in heat release process of CO₂transcritical cycle

- CO₂跨临界循环由于在气体冷却器中无相变，故放热过程中CO₂的温度是不断变化的，适合用于热泵热水机。There is no phase transformation in gas cooler and the temperature of CO₂ is changeable, and suitable for heating water.



常规工质亚临界循环冷凝器的换热
The sub-critical cycle of
traditional refrigerants

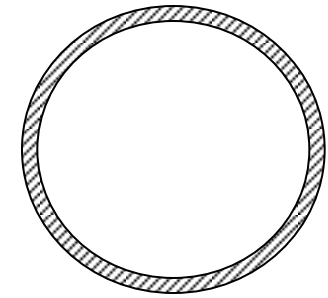


CO₂跨临界循环的换热
CO₂ transcritical cycle

CO₂循环的关键技术

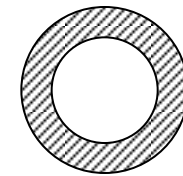
The Key Technology of CO₂ Cycle

- CO₂的高压力并不是大的问题，因为CO₂密度大、粘度低，其换热管道和连接管道比较细，管壁比较厚。It is not big problem for CO₂ high pressure, since high density and low viscosity. Usually the diameter of CO₂ tube is less than the traditional refrigerants and the thickness is bigger than the traditional.
- 考虑另一侧（水或空气）的热阻，当与传统工质在相同容量下比较，两者换热用的材料差不多。In the same heat transfer capacity, the both of weigh of materials is the same.
- 焊接和密封质量要求更高。High quality is requested for weld and seal.



常规工质管道

The tube of traditional refrigerants



CO₂管道

The tube of CO₂

CO₂制冷与热泵循环用膨胀机

The expander of CO₂refrigeration and heat pump

- 如果采用膨胀机代替节流阀，膨胀机的效率可达50~70%，可回收压缩功，并减少了相同数量的冷量损失。 Use expander with 50~70% of efficiency to recovery the compression work and reduce the lose of refrigeration capacity in the same.
- 制冷循环压缩功和冷量同时损失，用膨胀机COP可提高20~25%。 The COP of refrigeration cycle with expander will increase. **20~25%**
- 因制热量不受节流损失的影响，用膨胀机的制热COP提高10~15%。 The COP of refrigeration cycle with expander will increase **10~15%**
- 如果用喷射器代替节流阀，CO₂跨临界循环的效率也会有一定提高。 The COP of refrigeration cycle with ejector will increase than with throttling valve.

节流阀循环的制冷系数：

$$\text{COP}_{\text{Valve}} = \frac{h_1 - h_4}{h_2 - h_1}$$

膨胀机循环的制冷系数：

$$\text{COP}_{\text{Expander}} = \frac{(h_1 - h_4) + (h_4 - h_{4'})}{(h_2 - h_1) - (h_4 - h_{4'})}$$

节流阀循环的制热系数：

$$\text{COPh}_{\text{Valve}} = \frac{h_2 - h_4}{h_2 - h_1}$$

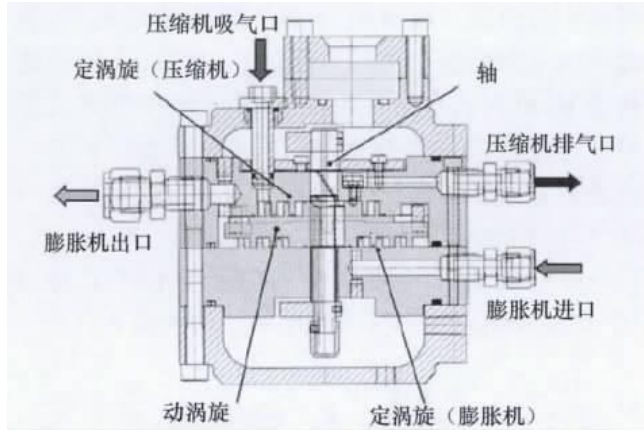
膨胀机循环的制热系数：

$$\text{COPh}_{\text{Expander}} = \frac{(h_2 - h_4)}{(h_2 - h_1) - (h_4 - h_{4'})}$$

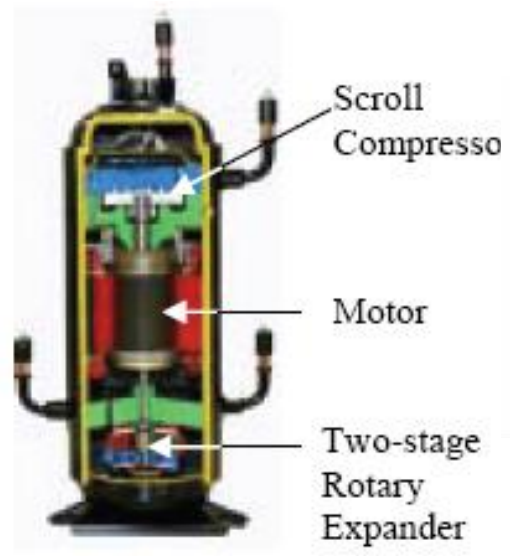
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CO₂ 膨胀机的研究

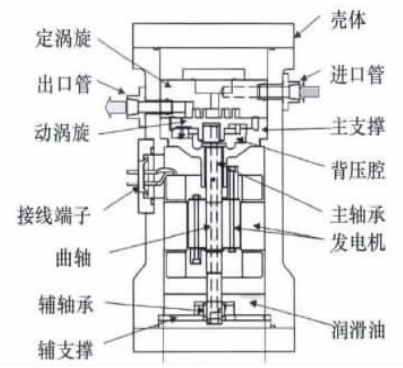
Research on CO₂ Expander



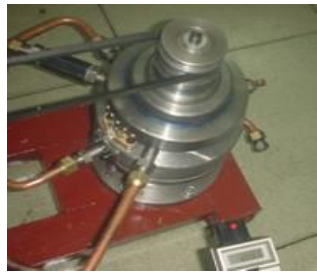
Mitsubishi



Daikin



Hitachi



第一代

第二代

第三代

第四代

2002

2005

2006

2014

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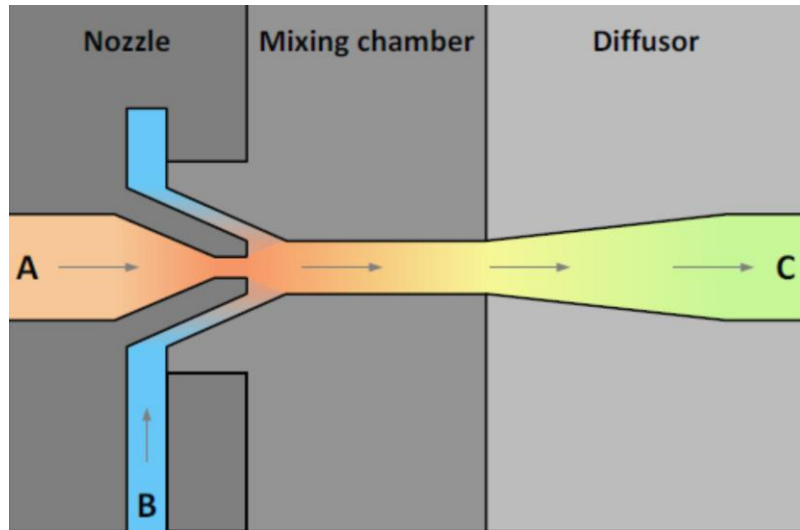
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TERI

用喷射器代替节流阀CO₂制冷循环

Ejector to replacement the throttling valve in CO₂ refrigeration cycle



CO₂跨临界循环的关键技术

The key technology of CO₂ transcritical heat pump cycle

- 压缩机、膨胀机、各种阀门、换热器的承压大大增加，对材料的强度、耐磨性、加工精度、焊接质量、可靠性等提出很高的要求，与传统制冷设备的制造业提升了一个等级。 Because the high pressure, there are very high request for the strength of materials, wearability, machining accuracy, melting quality, and reliability compare with traditional refrigeration system production.
- 由于家用CO₂热泵热水机的气体冷却器是套管式换热器，水在狭小的管道内流动，中国大多地区水质较硬，结垢很快，并不好清除。可降低热水器的出水温度，改变气体冷却器的放热回路等措施，既涉及技术关键，也涉及产品标准的修订。
As the most tap water is hard water in China, which is easy to format scale in the gas cooler which is tube to tube type. Suggest that to reduce the outlet temperature of water, may be involved to revise standard.
- 作为生产、维修、售后服务，各种关于CO₂制冷剂安全操作规程也需要尽快建立。
To make the regulations of production, maintenance and service of CO₂ heat pump.
- 大批量的CO₂制冷剂供应链，提供适合不同场合应用的大中小容量的高压气瓶。
To supply the different volume gas cylinder of CO₂ refrigerant for the market.

结论和建议 Conclusion and Suggestion

- 发展CO₂跨临界循环制冷和热泵对我国减少直接燃煤，改善环境有重要意义。It is important to develop CO₂ transcritical heat pump cycle for reducing direct coal combustion and improve environment in China.
- 开展CO₂跨临界循环制冷和热泵的产学研合作，大力开展相关国际合作，创建CO₂跨临界循环制冷和热泵的新兴产业。Cooperation of research on CO₂ transcritical heat pump cycle between companies and Universities, set up the new CO₂ transcritical heat pump industry.
- 要大力研究CO₂跨临界循环的各种部件，从压缩机、蒸发器、气体冷却器到代替节流阀的膨胀机，形成制冷产品的产业链，并逐步实现容量的增大。To pay more attention to compressor, evaporator, gas cooler, and expander to replace to throttling valve.
- 制定相关标准，是长久之计。To make standards of CO₂ transcritical refrigeration and heat pump cycle.

谢谢！
Thanks！