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Research Paper

# Comparison of transcritical $CO_2$ refrigeration cycle with expander and throttling valve including/excluding internal heat exchanger: Exergy and energy points of view

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## HIGHLIGHTS

- Exergy–energy analysis of four $CO_2$ refrigeration cycles is conducted.
- Shown that the use of heat exchanger in cycle with expander is favorable.
- Shown that the use of heat exchanger in cycle with throttling valve is unfavorable.

## ARTICLE INFO

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## ABSTRACT

The article compares four compression evaporative refrigeration cycles from energy and exergy points of view where carbon dioxide is considered as the working fluid. The four cycles are: (1) the cycle with expander, (2) the cycle with expander and internal heat exchanger, (3) the cycle with throttling and (4) the cycle with throttling and internal heat exchanger. In the cycles, effect of evaporation temperature and exhaust temperature of gas cooler on Coefficient of Performance (COP) and exergy efficiency are taken into consideration. From the energy and exergy points of view, the results indicate that using heat exchanger reduces COP and exergy efficiency of the cycle with expander while the use of heat exchanger in the cycle with throttling valve enhances the COP and exergy efficiency. The comparison between the four cycles reveals that the cycle with expander and without internal heat exchanger has the highest COP and exergy efficiency.



## 1. Introduction

Chlorofluorocarbons (CFCs) used in refrigeration systems as refrigerants cause major environmental damage. Global warming, ozone depletion, greenhouse gases emissions and air pollution have made international organizations to use natural refrigerant in lieu. At the end of 20th century in Montreal protocol [1] countries agreed to gradually replace CFC and Hydrofluorocarbons (HFCs) with new refrigerants harmless for ozone layer. The Kyoto Protocol [2] presented a list of HFCs as the main hazards for ozone layer including chlorine atoms. These substances continuously combine with each other and cause separation of stratospheric ozone molecules and long term erosion. Carbon dioxide is among the natural refrigerants having high cooling capability without harmful effects to our environment. The studies conducted during the last decade indicate that carbon dioxide has turned to the most important natural refrigerant [3,4]. No surprise because it is non-flammable, non-toxic, accessible and cheap. In addition, it has high volumetric refrigeration capacity [4] and good heat transfer properties as well as no recycling problems [3,5]. More importantly, there is a huge potential of production of carbon dioxide from waste e.g. landfill gas that eliminates the need for carbon dioxide production in many cases. Hence, using carbon dioxide in refrigeration cycles reduces environmental negative impacts. However, the only drawback of this refrigerant is relatively higher power at high temperature in comparison with CFCs. As a result, applying CFCs was privileged to carbon dioxide for a while.

More recently, Lorzen et al. [5], Neksa [6] and Peterson [7] undertook a research on application of carbon dioxide in thermal pumps and car ventilation systems. Lorzen and Peterson [8] built a lab sample of a saturated refrigerant i.e. compressed carbon dioxide. They used the standard refrigerants of R-12 and R-134a in the car ventilation system and indicated that the optimal use of refrigerants requires

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refrigerants that are compatible with the pressure of cooling and ventilation systems. Moreover, the carbon dioxide refrigerant requires high and transcritical pressure and cannot be applied in conventional vapor compression cycles and thus, evaporative compression transcritical cycle should be replaced [9]. Neksa et al. [10] by making a thermal pump system using saturated carbon dioxide, indicated that carbon dioxide cycle is suitable for thermal pumps in water piping. Chen and Perasad [11] investigated Coefficient of Performance (COP) and the exergy loss of HFC134 and CFC12 cycles. Applying the second law of thermodynamics in a carbon dioxide refrigeration cycle including intermediate heat exchanger, Fartaj et al. [12] showed that the highest level of exergy loss is associated with compressor and condenser. Fangtian et al. [13] proposed the use of throttling valve in carbon dioxide refrigeration cycle and concluded that exergy losses are reduced by 25% and the COP is increased by 30%. Wan Houa et al. [14] investigated exergy loss in a condenser with forced flow for carbon dioxide two-stage refrigeration cycle and increased the COP by optimizing the condenser geometry. Robinson et al. [15] presented a detailed literature review of carbon dioxide and concluded that the use of an internal heat exchanger in conjunction with a work recovery device tends to reduce the COP of the transcritical carbon dioxide cycle by up to 8%. Further, they reported that the use of an internal heat exchanger in conjunction with an expansion valve increases the COP by up to 7%. Aprea et al. [16] indicated that by using an internal heat exchanger, the COP is grown by 10%. Based on Zhang et al. [17], by increasing IHE, ejector entrainment ratio and ejector efficiency increase, also the pressure recovery value drops under the same gas cooler pressure. Torrella et al. [18] reported that, making a maximum increment in refrigeration capacity (about 12%) causes an increment in the efficiency of the plant up to 12%. According to Zhang et al. [19], an IHE addition does not always improve the system performance in the refrigeration cycle with expander. The throttle valve cycle with IHE provides 5.6–17% greater COP compared to the basic cycle. For the ideal expander cycle with IHE, the maximum COP is approximately 12.3–16.1% lower than the maximum COP of the cycle without IHE. Syro Oprea et al. [20] concluded that the rate of exergy loss in the refrigeration cycle with carbon dioxide refrigerant is reduced when carbon dioxide refrigerant is replaced by R-134a.

In this paper, the use of expander and throttling valve in conjunction with internal heat exchange in a transcritical $CO_2$ refrigeration cycle is studied. In this respect, comparison is made between four cycles: (1) The cycle with expander, (2) the cycle with expander and internal heat exchanger, (3) the cycle with throttling and (4) the cycle with throttling and internal heat exchanger. From the energy and exergy points of view, the comparison between the four cycles shows that the cycle with expander and without internal heat exchanger has the highest COP and exergy efficiency among all.

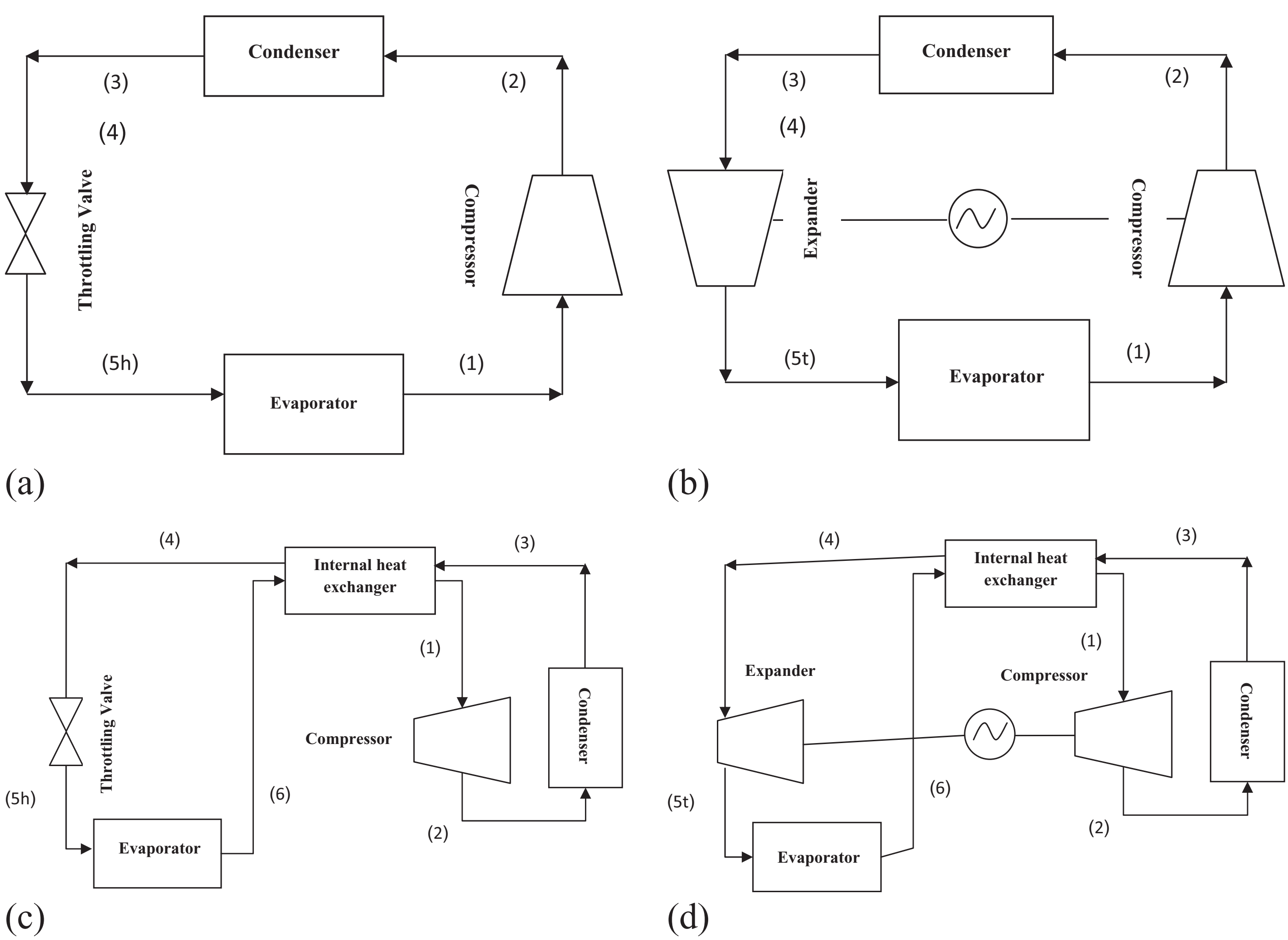


**Fig. 1.** (a) Refrigeration cycle with a throttling valve. (b) Refrigeration cycle with an expander. (c) Refrigeration cycle with a throttling valve and an internal heat exchanger. (d) Refrigeration cycle with an expander and an internal heat exchanger.