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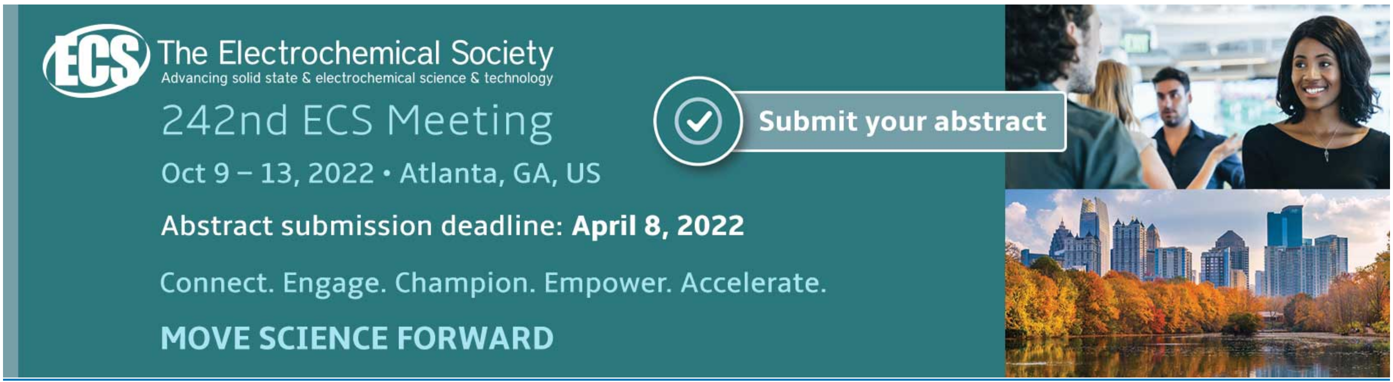

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Ejector refrigeration: perspectives and comparative analysis

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Abstract. Within the broader discussion regarding the decarbonisation of the household sector, ejector refrigeration is attracting a growing attention. This communication contributes to the present day discussion concerning the performances and the perspectives in ejector refrigeration systems. Based on a very large dataset, gathered from the previous literature (encompassing a wide range of system design, operating conditions and refrigerants), this paper proposes a comprehensive comparative analysis. First, the current trends in ejector refrigeration systems, refrigerants and performances are presented. Second, the relationships between ejector performances, refrigerants and boundary conditions (in terms of non-dimensional temperatures, to ensure generality of the proposed analysis) are presented. In conclusion, this paper is intended to provide guidelines for perspective researchers and practitioners interested in selecting suitable ejector-based systems.

1. Introduction

In the broader framework of reducing the energy consumption of the household-scale, ejector refrigeration systems (*ERSs*) seem a promising alternative to the traditional compressor-based technologies owing to their reliability, limited maintenance needs and low initial and operational costs [1]. In addition, ejector-based systems have no limitation concerning refrigerants, which is beneficial taking into account the cutting-edge discussion regarding refrigerant selection [2, 3]. Nevertheless, ejector refrigeration has not been able to penetrate the market due to its low performance coefficient and severe degradation in performance when not operating under on-design conditions [4]. In particular, this paper contributes to the present day discussion regarding the performances and the perspective in ejector refrigeration. Based on a very large dataset (viz., based on 99 papers collected from the literature, 1293 data points extracted from such papers) the current trends in ejector refrigeration systems, refrigerants and performances are presented. For the sake of brevity and clarity, the reader might refer to ref. [1] for details regarding ejector system nomenclature and details regarding refrigerant properties.

2. Literature survey: performances and perspectives

Figure 1 displays the coefficient of performance (*COP*) for *SERS* is in the range of 0.2 – 0.6, which is lower compared with other system configuration. This result was expected owing to the system configuration (i.e., the absence of a compressor) and the well-known issues in off-design system performances. In general, for the different configurations it is possible to observe rising performance over time, especially for *TEERS* and *CERS* systems; this is, of course, caused by the intense research activities on the topic. Conversely, *SERS-WP* systems have *COP* in the range of 0.2 – 0.3: this range is lower compared with the other systems and remained constant over time. In addition, it is noted that, since the second half of 1990s, ejector refrigeration systems started to be coupled with solar systems. Figure 2 displays that the best performances can be obtained using natural, *HFO* or *HFC* refrigerants. In the case of natural refrigerants, *COP* ranges between

0.2 and 4.0, and higher values are reached with carbon dioxide (viz., *TEERS* system design). Starting from 1990s, *CFC* and *HCFC* were progressively phased out in order to be replaced with more environmental friendly fluids such as *HFO* and refrigerant mixtures. It is also observed that mixtures have *COP* in the range of 0.1 – 1.3, which is lower compared with *HFO*. In the forthcoming years, it is expected a raising interest in natural refrigerants (i.e., R718, R744), R290-based systems and forth generation refrigerants [5].

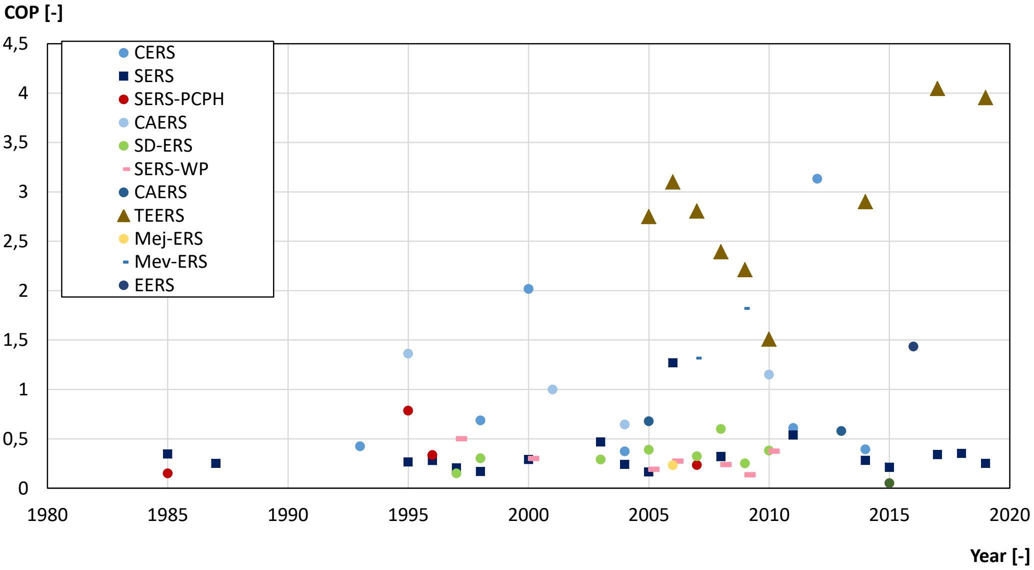

Figure 1. Relationships between *COP*, system layout [1] and time variable.

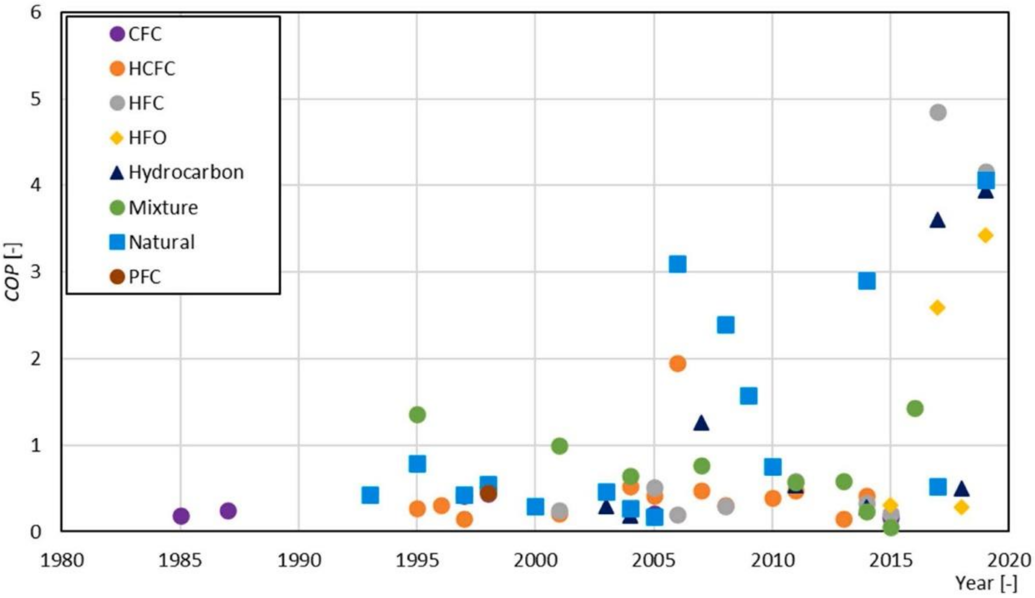

Figure 2. Relationships between *COP*, refrigerant employed and time variable.

Figure 3, Figure 4 and Figure 5 picture the relationships between ejector system performances, refrigerants and boundary conditions (in terms of non-dimensional temperatures, to ensure generality of the proposed analysis). To the authors' best knowledge, this is the very first comparison using non-dimensional temperatures: Figures 3 – 5, thus, can be interpreted as operational maps of ejector based systems. In particular, Figure 3 displays the relationships between *COP* and system design [1], as a function of the the reduced temperature of the evaporator, $T_{R,EVAP}$. As expected, *COP* increases when increasing $T_{R,EVAP}$. Higher *COP* values are obtained for *TEERS* and *CERS* system as a result of the system configuration (i.e. the presence of a mechanical compressor) which allows reaching higher compression ratios. Considering the *TEERS* system layout, *COP* is in the range of 2.5 – 7, when the system operates with a lower reduced temperature; conversely *COP* is in the range of 1 – 4 when the reduced temperature is approximately $T_{R,EVAP}$ = 0.9 – 1. *SERS* and *SERS-WP* have lower *COP* values, while *SD-ERS* are promising solution when the reduced temperature is in the range of 0.6 – 0.7. Figure 4 displays the relationship between *COP* and the reduced temperature of the condenser, $T_{R,COND}$, for the different system configurations. As shown for the reduced temperature at the evaporator, the overall best performances are reached by *TEERS* and *CERS*. For *CERS* system, *COP* is almost constant and approximately equal to 2; conversely for *TEERS, COP* decreases from 4.5 to 1.5 when rising $T_{R,COND}$. Thus, for these systems, it is recommended to operate with a reduced temperature of the evaporator in the range $T_{R,COND}$ = 0.8 – 0.9. When the reduced evaporator temperature is in the range of 0.4 < $T_{R,COND}$ < 0.5, *SERS* systems operate with *COP* = 1, which is higher compared with other system configurations. However, in these systems a slight reduction of $T_{R,COND}$ causes a drastic decrease in the whole system performance. It is worth noting that *SD-ERS* systems are generally used in a limited range of the condenser temperature, i.e. $T_{R,COND}$ =0.6 – 0.7. This can be explained by the fact that the thermal collectors, which are used as generator, should be operated in a narrow temperature range.

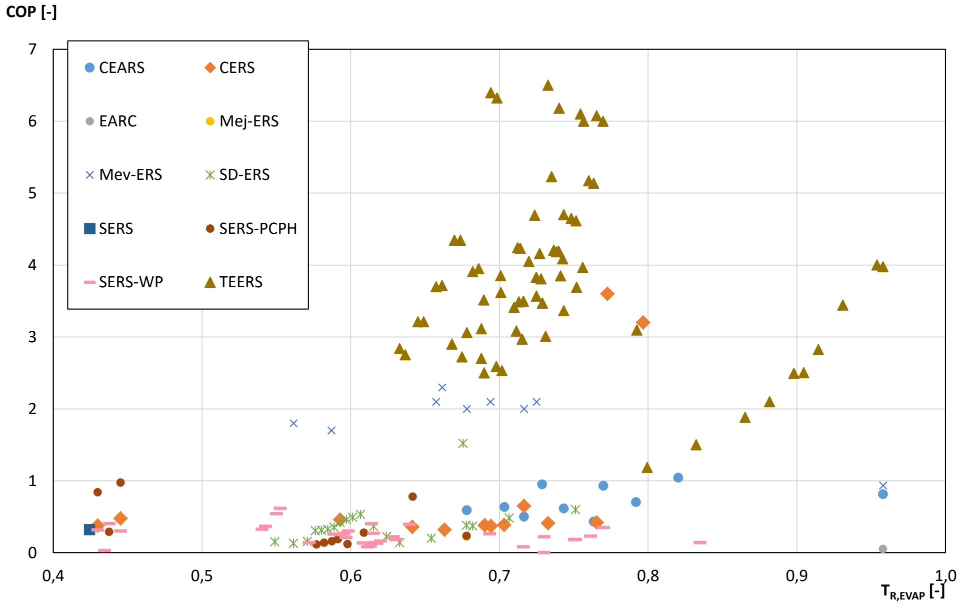

Figure 3. Relationships between *COP*, system layout [1] and reduced temperature of the evaporator, $T_{R,EVAP}$.

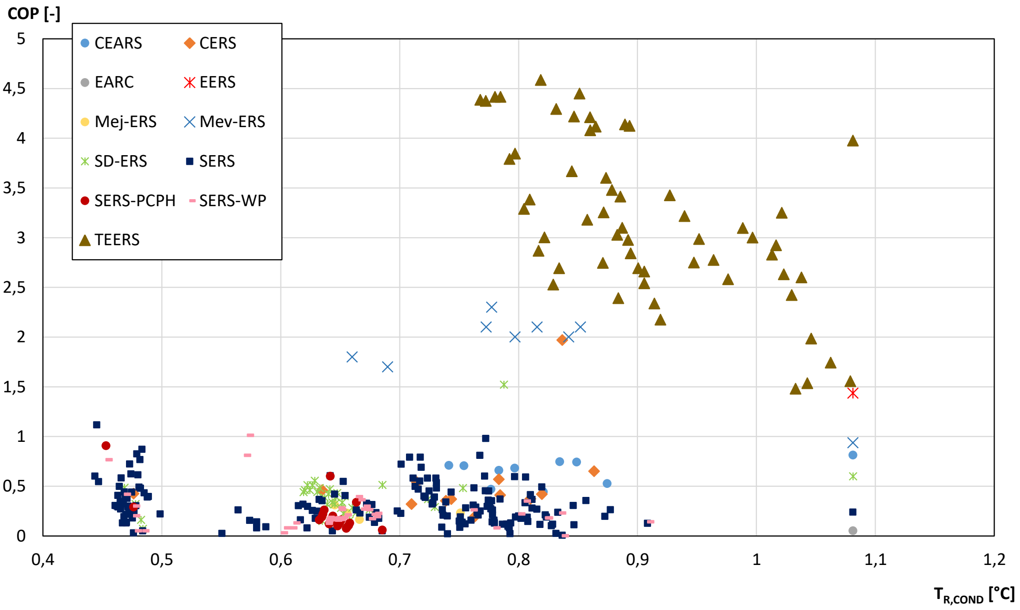

Figure 4. Relationships between *COP*, system layout [1] and reduced temperature of the condenser, $T_{R,COND}$.

Finally, Figure 5 displays the relationship between *COP* with the reduced temperature of the generator, $T_{R,GEN}$. In this analysis, *TEERS* are not taken into account as the generator is not present in *TEERS* design. It is observed that *CEARS*, *SERS-PCPH* and *SD-ERS* systems have interesting performances, owing to their particular configuration that allows a better use of the thermal exchanges with the high-temperature source (viz., high $T_{R,GEN}$). Indeed *COP* value for *CEARS* and *SERS-PCPH* is approximately equal to 1; conversely, in the case of *SD-ERS* systems, COP reaches a maximum value of approximately 1.5. *COP* value for *SERS*, *SERS-PCPH* and *SD-ERS* systems tend to lowers when increasing the reduced temperature of the generator. Thus it is recommended to operate with generator temperature in the range of $T_{R,GEN}$ = 0.6 for *SERS-PCPH* systems, $T_{R,GEN}$ = 0.7-0.8 for both *SERS* and *SD-ERS* systems. Conversely, *CEARS* performances are not strongly influenced by variations in $T_{R,GEN}$.

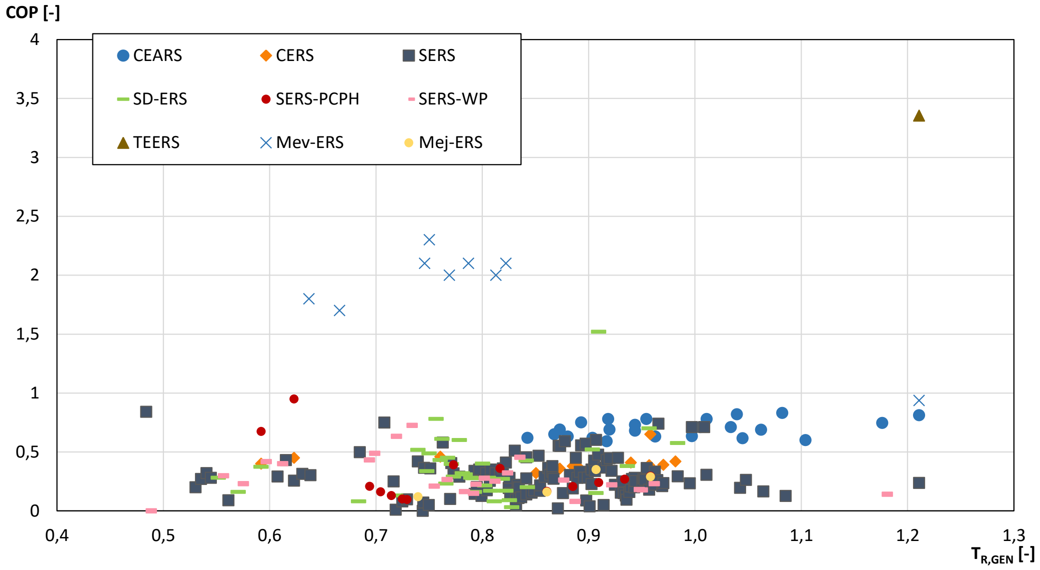

Figure 5. Relationships between *COP*, system layout [1] and reduced temperature of the generator, $T_{R,GEN}$.

3. Conclusions

Ejector refrigeration is a promising technology for producing a cooling effect by using low-grade energy sources with different refrigerants. This paper builds upon a very large dataset, gathered from the literature and encompassing a wide range of system design, operating conditions and refrigerants and proposed a comprehensive comparative analysis. The results presented in Figures 1 – 5 are supposed to be of guidance for perspective researchers and practitioners interested in selecting suitable ejector-based systems.

Acknowledgements

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