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# Performance of a scroll compressor with vapor-injection and two-stage reciprocating compressor operating under extreme conditions

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A B S T R A C T

The current paper presents a comparative study between a scroll compressor with vapor-injection (SCVI) and a two-stage reciprocating compressor (TSRC) operating under extreme conditions. The present work is divided into two parts: in the first part, both compressors are compared in terms of compressor efficiency, volumetric efficiency, coefficient of performance (COP), and cooling capacity with R407C refrigerant; in the second part, the seasonal performances of both compressors working in cooling and heating modes are estimated and analyzed. Results show that the SCVI presents better efficiency and COP than the TSRC for pressure ratios below 7.5. This compressor can be used in air conditioning systems and heat pumps which work under moderate temperature conditions. For higher pressure ratios, the TSRC has better efficiency which subsequently gives higher COP. This type of compressor is more suited to be used in sanitary hot water systems operating in harsh climates and in low-temperature freezing systems (under −20°C).



# Performance d’un compresseur à spirale avec injection de vapeur et d’un compresseur à piston bi-étagé fonctionnant sous des conditions extrêmes

*Mots clés :* Compresseur à spirale ; Compression bi-étagée ; Compresseur à piston ; Injection de vapeur ; Conditions extrêmes

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**Nomenclature**

| | |
|---|---|
| h | enthalpy [kJ kg$^{-1}$] |
| H | number of bin hours |
| $\dot{m}$ | mass flow rate [g s$^{-1}$] |
| P | pressure [bar] |
| $P_a$ | compressor consumption [kW] |
| $P_r$ | pressure ratio |
| $Q_c$ | cooling capacity [kW] |
| $Q_{econo}$ | economizer capacity [kW] |
| $Q_h$ | heating capacity [kW] |
| SCOP | seasonal coefficient of performance |
| SCVI | scroll compressor with vapor-injection |
| T | temperature [°C] |
| TSRC | two-stage reciprocating compressor |
| $\dot{V}$ | swept volume [m$^3$ h$^{-1}$] |

*Greek symbols*

| | |
|---|---|
| ρ | density [kg m$^{-3}$] |
| $\eta_c$ | compressor efficiency |
| $\eta_v$ | volumetric efficiency |

*Subscripts*

| | |
|---|---|
| c | condensing |
| cond | condenser |
| e | evaporating |
| econo | economizer |
| evap | evaporator |
| inj | injection |
| int | intermediate |
| s | isentropic |
| 1 | compressor inlet |
| 2 | compressor outlet [first stage] |
| 3 | compressor inlet [second stage] |
| 4 | compressor outlet [second stage] |
| 5 | condenser outlet |
| 6 | economizer outlet [evaporator line] |
| 7 | economizer inlet [injection line] |
| 8 | economizer outlet [injection line] |
| 9 | evaporator inlet |

## 1. Introduction

Refrigeration and heat pump units working with a single-stage vapor compression system significantly reduce their efficiency when there are large differences between evaporating and condensing temperatures. These systems have several limitations, as described below.

- High compressor discharge temperature. The high temperature can induce thermal instability in the lubricating oil.
- Cooling/heating capacity loss. The volumetric efficiency decreases significantly when the compressors work with higher pressure ratios. Therefore, the cooling/heating capacity is reduced.
- Low COPs. Carnot and compressor efficiencies decrease dramatically at high temperature lifts. This behavior places heat pump systems at a great disadvantage compared with conventional heating boilers.
- Large compressor displacement is needed. The volumetric efficiency decreases rapidly with high pressure ratios. This means that to obtain a given capacity, the compressor displacement has to increase, with a subsequent impact on compressor cost.

In order to overcome these limitations, the most widely used solution is the two-stage compression with vapor injection. This technique comprises the injection of vapor refrigerant into the intermediate location of the compressor. It has several advantages, the most important of which are as follows.

- Capacity improvement in harsh climates (heating at less than 0°C and cooling at more than 35 °C of ambient temperature).
- The system capacity can be varied by controlling the injected refrigerant mass flow rate, which permits some energy savings by avoiding the intermittent operation of the compressor.
- The compressor discharge temperature of a vapor injection cycle is lower than that of a conventional single-stage cycle (Xu et al., 2011).

The scroll compressor with vapor-injection (SCVI) is one of the most frequently used compressors in heat pump systems with the vapor injection technique. Ma et al. (2003) performed an experimental investigation of air-source heat pumps for cold regions using an SCVI with an internal heat exchanger (economizer). The prototype was able to work smoothly under ambient temperatures as low as −15 °C, the heating capacity and COP were improved, and the discharge temperature was steady and remained below 130 °C in these temperature conditions; similar studies were conducted by Ding et al. (2004) and Ma and Chai (2004).

Bertsch and Groll (2008) simulated, designed and constructed an air-source two-stage heat pump using an SCVI working with R410A as the refrigerant. They tested the heat pump and verified that it was able to operate at ambient temperatures as low as −30 °C to 10 °C and supply water temperatures of up to 50 °C in heating mode. At the same ambient temperature, the two-stage mode operation approximately doubled the heating capacity compared with the single-stage mode operation. The discharge temperatures of the compressors in the two-stage mode stayed below 105 °C. Ma and Zhao (2008) compared the heating performance of a heat pump with a flash tank coupled to an SCVI and a system with an economizer cycle using R-22. The heating capacity and COP of the flash tank cycle were higher by 10.5% and 4.3%, respectively, than those of the economizer cycle at air temperatures of 45 °C in the condenser and −25 °C in the evaporator. Wang et al. (2009a) suggested a model