Comparative experimental analysis of two subcritical heat pump boosters using subcooling in order to increase the efficiency of systems with a high water temperature lift

Miquel PITARCH, Emilio NAVARRO-PERIS*, José GONZÁLVEZ-MACIÁ, José M. CORBERÁN

*emilio.navarro@iie.upv.es
Main Characteristics

- Water to water heat pump booster for domestic hot water production:
  - 50kW of nominal capacity.
  - Heating water from 10°C-60°C.
  - Energy recovery from water sources from 10°C-35°C.
  - Uses R290 as refrigerant.
  - Able to heat water up to 90°C.
Theoretical Introduction

• For applications where the heat sink temperature (secondary fluid) is considered constant → Maximum performance is given by reversed Carnot cycle

Subcritical cycle working **without subcooling** and with the **lowest possible condensing temperature**

• Real applications have a temperature lift in the secondary fluid: Finite capacitance rate or given by the application (DHW)

• For a given temperature lift in the secondary fluid
  - Which is the optimal condensing temperature?
  - Which is the optimal subcooling?

Ø Which is the optimal condensing temperature?
Ø Which is the optimal subcooling?
Theoretical Optimal subcooling

- Heating COP depends on the condensing temperature and subcooling.
- The optimum point is given when the two limitations occur at the same time.

![Graph showing theoretical optimal subcooling](image)

Water temperature lift in the condenser: 10°C to 60°C
Optimal subcooling

• COP<sub>h</sub> improves up to 37% respect to the case without subcooling for the DHW application

• Optimal subcooling depends on the condition
Heat pump concepts and design

- Theoretical analysis: Optimal subcooling depends mainly on the external conditions. When heating water from 10°C to 60°C the optimal subcooling is 45 K with 37% of improvement.

- Two heat pump configurations are proposed in order to experimentally study the effect of subcooling in the DHW application:

  **SMC**

  **SMS**
Subcooling in condenser: SMC

- The pressure drop is shared by the throttling and the expansion valve
- Subcooling and superheat can be controlled independently
- The condenser must be able to work efficiently with high subcooling
Designs

Subcooling in subcooler: SMS

- The condenser is used for condensing
- Subcooling is not controlled, depends on the heat transfer at the subcooler
- Subcooler can be optimized for refrigerant liquid (smaller crossflow area)
• Both heat pump designs (SMC and SMS) were built in the same prototype
• The SMS heat pump has 25% more heat transfer area (heat sink)
- Test Rig is able to control all the water inlet & outlet water temperatures
- The measured points have been checked to lie under the limits marked by the norm UNE-EN 14511-3
Performed test

**SMC mode**

- External conditions:
  - Evaporator inlet water temperature ($T_{w,ei}$): From 10°C to 30°C
  - Condenser inlet water temperature ($T_{w,ci}$): From 10°C to 50°C
- Each external condition is measured at different degrees of subcooling → Total number of measured points = 68

**SMS mode**

- External conditions:
  - $T_{w,ei}$: From 10°C to 35°C
  - $T_{w,ci}$: From 10°C to 50°C
  - $T_{w,co}$: From 60°C to 90°C
- Total number of measured points = 42
• There is a subcooling that maximizes $\text{COP}_h$

• The heating capacity always increases with subcooling
Results

Subcooling in subcooler:

**a)**
- Refrigerant
- Water Line
- Condenser
- Liquid Receiver
- Subcooler
- Water Cond
- 3 WAY VALVE

**b)**

Heating COP [\(T_{w,ei} \leq 10^\circ\text{C} \text{(SMC)}\), \(T_{w,ei} \leq 20^\circ\text{C} \text{(SMC)}\), \(T_{w,ei} \leq 30^\circ\text{C} \text{(SMC)}\)]

Heating Capacity [\(T_{w,ei} \leq 10^\circ\text{C} \text{(SMC)}\), \(T_{w,ei} \leq 20^\circ\text{C} \text{(SMC)}\), \(T_{w,ei} \leq 30^\circ\text{C} \text{(SMC)}\)]
Comparison Model

- The software IMST-ART estimates the heat pump performance with a detailed model of each of its components.
- The model has been validated with the experimental results (errors lower than 2% in terms of COP)
- Condenser was enlarged 25% in order to have the same heat transfer area than the SMS design (Condenser + Subcooler)

**SMC design + 25% of condenser length vs. SMS design**
Model validation

- The model of the SMC design is validated with the experimental results
- Heating COP and condensing temperature are well predicted by the model
Comparison SMC vs. SMS

• The heating COP increases with the enlarged condenser
• At high water temperature at the condenser the heating COP for the enlarged SMC design could be higher than the SMS design
Comparison

Condenser size effect

• The optimal subcooling has a low dependency with the condenser size

• Heating COP increases with condenser size, but it is more significant at small sizes.
Conclusions

- Optimization of subcooling improves the performance of heat pumps more than 30% for high temperature lift of the secondary fluid.

- Two water to water heat pump prototypes for the application of domestic hot water production has been built with COPs of 5.5 for the nominal conditions (Twcond=10°C-60°C, Twev=20°C).

- It has been demonstrated that both systems has been reliable with some advantages and disadvantages but not related with the COP of the system.

- The optimal subcooling does not show a high dependency on the condenser size.
Thanks for your attention

Emilio Navarro
emilio.navarro@iie.upv.es