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# Improved energy performance of a refrigerating machine using water spray upstream of the condenser

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ABSTRACT

An experimental and numerical study has been carried out on the improvement of the energy performance of a refrigerating machine using a water spray upstream of the condenser. The experimental setup is based on a reversible heat pump used in cooling mode. The spray has been simply added upstream from the heat pump in order to investigate the possible performance improvements on a real machine, leaving its own control system free to adapt itself. Condensation temperature and pressure data have been measured on the refrigerating fluid side, while temperature and humidity have been measured on the air upstream and downstream the condenser. A complete model has been developed, combining a thermodynamic model for the system and heat transfer models on the air and refrigerating fluid sides. Comparisons have been carried out. Results show that water spraying upstream of the condenser may increase the global COP of the system (refrigerating machine plus spraying system) up to 28.9% for relatively hot and dry air conditions (relative humidity 19,7% and temperature 308 K).



# Performance énergétique améliorée d'un système frigorifique utilisant une aspersion d'eau en amont du condenseur

*Mots clés :* Pompe à chaleur ; Condenseur ; Aspersion ; Evaporation ; Energie

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**Nomenclature**

| | |
|---|---|
| C | droplet concentration (kg kg$^{-1}$ of air) |
| Cp | heat capacity (J kg$^{-1}$ K$^{-1}$) |
| eff | cooling efficiency(–) |
| H | enthalpy (J kg$^{-1}$) |
| K | global exchange coef. (W m$^{-2}$ K$^{-1}$) |
| $\dot{m}$ | mass flow rate(kg s$^{-1}$) |
| Q | heat flux (W) |
| $R_{cond}$ | conductive resistance (K W$^{-1}$) |
| $R_{ext}$ | external thermal resistance (K W$^{-1}$) |
| $R_{int}$ | internal thermal resistance (K W$^{-1}$) |
| RH | relative humidity (%) |
| T | temperature (K) |
| $X_v$ | vapor quality (kg kg$^{-1}$) |
| $W_{eff}$ | effective power (W) |

*Greek letters*

| | |
|---|---|
| $\varepsilon$ | uncertainty (–) |
| $\sigma$ | exchange surface (m$^2$) |
| $\Omega$ | absolute humidity (kg kg$^{-1}$ of air) |
| $\eta_{eff}$ | effective efficiency (–) |
| $\tau_{col}$ | collected water rate (–) |

*Subscripts*

| | |
|---|---|
| 0 | initial |
| a | air |
| av | average |
| col | collected |
| Cp | refers to sensible heat |
| down | downstream |
| dis | discharge |
| evap | evaporation |
| elec | electrical |
| fan | refer to the fan |
| in | inlet |
| inj | injected |
| k | condensation |
| is | isentropic |
| Lv | refers to latent heat |
| *n* | number of pass |
| out | outlet |
| pump | refers to the pump |
| r | refrigerating |
| spray | spray |
| sub | subcooling |
| sup | superheat |
| tot | total |
| up | upstream |
| w | water or wall |

## 1. Introduction

There has been an increasing interest studying the improvement of heat exchanges by using water evaporation in the cold production domain these last years, either by means of water spraying or using cooling pads. Indeed, several works have shown that water evaporation upstream of a heat exchanger increases the heat transfer due to air temperature decrease and droplet impact on the exchanger walls for systems based on water spraying (Sarntichartsak and Thepa, 2013; Hajidavalloo and Eghtedari, 2010; Yu and Chan, 2011; Yang et al., 2012). Both methods have their own advantages and drawbacks.

For systems using water spraying (or mist flows), pulverization of water by the high pressure pump requires a higher energy than a pump used for the water circulation on the media pad. The water used for the spray must be demineralized and undergoes bacterial treatment in order to prevent from condenser fouling and from risks of spreading bacteria into the air, respectively. However, its advantages are to avoid any stagnant water and any environment where bacteria and microbial organisms can develop. Moreover, it requires no maintenance and does not create a pressure drop upstream of the condenser, as the pad does. Two studies (Sarntichartsak and Thepa, 2013; Hajidavalloo and Eghtedari, 2010) using water evaporation through a cooling pad have shown that the only air temperature decrease can improve the COP by around 50% in (Sarntichartsak and Thepa, 2013) and 18% in (Hajidavalloo and Eghtedari, 2010). Several works have also shown that mist flow allows to increase the COP (Yu and Chan, 2011; Yang et al., 2012). In particular, a numerical study conducted by Yu and Chan (2011) based on experimental data obtained on a chiller has shown that the electric cost per year can be reduced by around 18% depending on a condensing temperature control (CTC). The study realized by Yang et al. (2012) has also shown a COP increase using water spraying, up to 18.6% in conditions where the inlet air temperature was close to 30 °C for relative humidity between 40 and 70%.

Irstea has been working for several years on water mist application on the air flow upstream from condensers. This choice has been motivated by the fact that the optimization of the spray injection and evaporation upstream of the condenser allows to avoid the unwanted effects of fouling and bacteria transport risks. Pioneering numerical works (Youbi-Idrissi et al., 2007; Tissot et al., 2011) showed the possible air temperature decrease depending on air flow rate, temperature, humidity, but also on water flow rate and size of injected droplets. In (Tissot et al., 2011), the model developed by Collin et al. (2007), based on a Lagrangian tracking for the droplets combined with a solution by the Finite Volume Method of an Eulerian model for the air flow, has shown that the spray should be injected in a counter-flow situation, involving droplets with mean diameter below 25 μm. Numerical results have been confirmed and validated by the experimental study carried out by Tissot et al. (2012) on the loading of air with droplets. Boulet et al. (2013) have then studied the effect of a spray injection upstream from a condenser, using the same experimental setup. It has been observed that around 30% of the droplets may impact the tubes and the fins of the exchanger, the whole spray being evaporated either during its trajectory in the carrying air or due to this contact on the exchanger. This work has also shown that the water nozzles can be located very close from the exchanger (5 cm) for a counter current injection and that the heat