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Research paper

Modeling and experimental validation of a tube-in-tube refrigerant cooled absorber

Tommaso Toppi*, Marcello Aprile, Marco Guerra, Mario Motta

Department of Energy, Politecnico di Milano, 20156 Milano, Italy

HIGHLIGHTS

- Tube-in-tube refrigerant cooled absorber for absorption chiller is modelled.
- The model is validated by comparison with experimental data.
- Both heat transfer rate and pressure drops are predicted with sufficient accuracy.
- The model accuracy decreases for low transfer rate conditions.
- Sensitivity analysis on the inputs confirms the validation reliability.

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ABSTRACT

A model for predicting heat and mass transfer and pressure drops occurring inside a tube-in-tube refrigerant cooled absorber (RCA) is developed. This heat exchanger is used as a low pressure absorber in a half-effect water-ammonia absorption chiller. The two-phase stream, resulting from the mixing at low pressure of the weak solution coming from the generator and the refrigerant leaving the evaporator, flows in the tube-in-tube annulus, while the stream of condensed refrigerant, throttled to a pressure level intermediate between condenser and evaporator pressures, flows counter-current in the internal tube. The RCA model is validated by comparing overall heat transfer duty, pressure drops on each stream and temperature axial profile in the annulus with experimental data. Results are in reasonable agreement with experiments in most of the analyzed cases, although some deviations exist in off-design operations. A sensitivity analysis of the model has shown that the measurement uncertainty of the inputs to the model does not affect the validity of the results.

1. Introduction

A refrigerant cooled absorber (RCA) is a heat exchanger where the cooling effect for absorbing some refrigerant vapor within a solution mixture is provided by the evaporation of a fraction of liquid refrigerant. Such device can be effectively employed in absorption cycles, although its use is not common. One example is represented by the prototype of half-effect absorption chiller that has been recently realized [1], experimentally demonstrated [2] and characterized [3]. The key operating principle of the cycle (see Fig. 1) consists in utilizing part of the liquid refrigerant leaving the condenser (CON) to cool, at an intermediate pressure, the solution in which the remaining part of the refrigerant is absorbed after leaving the evaporator (EVA). Such operation takes place inside a tube-in-tube counter current refrigerant cooled absorber (RCA). A two-phase water-ammonia solution (with ammonia mass fraction about 0.55) at low pressure (4.5–5 bar) flows in the RCA annulus, counter-current with respect to the refrigerant (ammonia mass fraction above 0.99 at about 8–10 bar) flowing in the internal tube. In the annulus, the vapor is absorbed in the liquid solution, while in the internal tube, part of the refrigerant evaporates.

A properly sized RCA is crucial for the cycle operation. At parity of other conditions, an effective RCA allows increasing the pressure in the air cooled absorber (ABS), which in turn allows keeping a high ammonia mass fraction at the inlet of the generator (GEN). Thus, the concentration gradient in the GEN increases, providing a positive effect on cycle performance and capacity.

In the literature, many experimental and numerical studies can be found about tube-in-tube heat exchangers.

* Corresponding author. Tel.: +39 02 2399 3922; fax: +39 02 2399 3868.
E-mail address: tommaso.toppi@polimi.it (T. Toppi).

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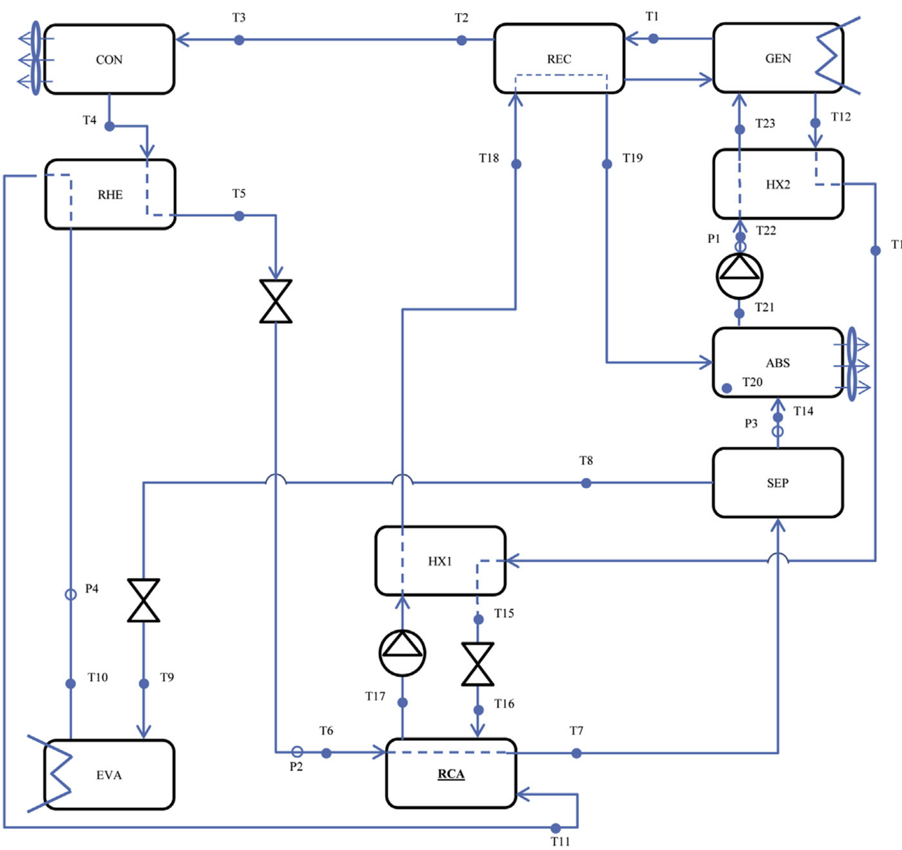

Fig. 1. Scheme of the half-effect cycle.

Garimella et al. [4] investigated single-phase heat transfer within coiled annular ducts, finding higher heat transfer coefficients for the coiled annular ducts compared to the ones for straight annulus. The augmentation of the Nusselt number is higher in the laminar region than in the transition region, while the turbulent region is not investigated.

Wongwises and Polsongkram addressed two-phase flow in the internal tube [5,6], investigating both evaporation and condensation heat transfer and pressure drop of HFC-134a in a helically coiled concentric tube-in-tube heat exchanger, with two-phase refrigerant flowing in the inner tube and water in the annulus. Focusing on the effects of coiling on the heat transfer coefficient and pressure drops, they found an increase of both when compared with a straight heat exchanger.

A finite volume numerical model for a tube-in-tube heat exchanger with both smooth and fluted tube is proposed by Huang et al. [7], with refrigerant flowing in the annulus and cooling or heating water flowing in the inner pipe. A discussion over the precise and reliable methods for tracking the phase change location is also proposed, with the purpose of reducing the number of finite volumes and the computational time.

Concerning the pressure drop, Ekberg et al. [8] experimentally investigated two-phase flow regimes, void fraction and pressure drop in horizontal concentric annuli, comparing the experimental results with existing correlations. They verified that the same correlation might either overestimate or underestimate the experimental data, depending on the flow type.

Several works focused on the effect of coiling, comparing heat transfer coefficients and pressure drops in coiled and straight pipes. The impact of coiling resulted to be dependent on several parameters, such as the hydraulic diameter, the Dean number, the presence of spacers, the relative position of the two pipes (concentric, eccentric, with contact) and the flow type (single-phase or two-phase flow).

Kumar at al [9] carried out an experimental and numerical investigation on a single-phase flow in a tube-in-tube helical heat exchanger, with semicircular plates to support the inner tube and to provide high turbulence in the annulus region. They pointed out that the heat transfer coefficient and the friction factor increase for coiled tube compared with straight tube, both in the inner pipe and in the annulus.

These achievements are confirmed by Aria et al. [10], who investigated heat transfer and pressure drops on a boiling flow of HFC-134a inside a vertical helically coiled concentric tube-in-tube heat exchanger.

However, the extension of these results from single-phase to two-phase flow is not straightforward. In fact, as pointed out by Xin et al. [11], the Lockart-Martinelli parameter appears to be lower for coiled than for straight annular pipes. This implies that, even if the single-phase pressure drops increase from straight to coiled annulus, the same may not apply to two-phase flow.

Louw and Meyer [12] investigated the effects on heat transfer and pressure drops of the contact between internal and external tube, when no spacers are placed between the internal and external pipe. According to their findings, with respect to the case of concentric pipes, the Nusselt number decreases in the internal pipe and increases in annulus, while pressure drops in the annulus increase because of the tube contact.

To the best knowledge of the authors, a study on a tube-in-tube heat exchanger like the RCA, with two-phase flow in both the inner tube and the annulus, has not been presented previously.