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Dynamic behavior of a direct expansion evaporator under frosting condition. Part II. Field investigation on a shipping container

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Abstract

A field investigation is performed on the frost formation at an evaporator of a commercial full-scale refrigerated container that uses R-12 as the working refrigerant. Results when compared with those from a numerical model presented earlier show that the model is capable of predicting the dynamic behavior of a direct expansion evaporator under both non-frosting and frosting conditions. The air outlet and energy transferred compare well between experiment and model, and within 20% for the air pressure drop. The frost occurrence and propagation agree well generally, with the frost formation first occurring at the first row where the refrigerant enters the evaporator.

Keywords: Marine transport; Refrigerated container; Experiment; Evaporator; Finned tube; Performance; Frost formation

Comportement dynamique d'un évaporateur à détente directe sous des conditions de givrage. Partie II. Etude sur le terrain portant sur un conteneur maritime

Motsclés: : Transport maritime ; Conteneur frigorifique ; Expérimentation ; Évaporateur ; Tube alieté ; Performance ; Givrage

1. Introduction

Refrigerated shipping containers are widely used in transporting and preserving perishable food and biological material. It is an important part of the global cold food chain which accounts for up to 31% of the world's food supply and has been estimated to grow at an annual rate of about 10% with the present volume of about half a million 20-foot containers [1]. The container temperature can vary from −30 to +20 °C depending on the type of goods. Operating carriage temperature at below freezing temperature is subjected to frost deposition and progressive build-up on the evaporator coil. The presence of the frost affects the system performance and hence the cargo being cooled. Temperature sensitive products require precise temperature

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control in the chilled cargo range [2] and temperature variation caused by frost deposition and build-up is a parameter to be concerned. However, there is scarcity in the literature about research on containers, especially in modeling and validation of container refrigeration systems under frosting condition.

Experimental studies on frost are mainly focused on a simple geometry such as cylinders, flat and parallel plates, annuli and tubular surfaces [3–5]. For more complex geometry of finned-tube evaporator little frost data are available, probably due to the large number of variables affecting the frost growth, including the complex geometry of the coil, the thermodynamic properties of refrigerant inside the coil and the coupling of the humid air with the varying frost properties. Most studies on finned-tube evaporator to-date use a single phase fluid, such as glycol/water mixture, as the working fluid [6–9]. Ameen [10], Deng et al. [11] and Seker et al. [12] conducted experiments on finned-tube heat exchanger using a volatile refrigerant, but they did not report on the dynamic variation of air temperature and frost formation and propagation inside the evaporator. Jia et al. [13] and Jia et al. [14] conducted experiments on a refrigerated container but their results only limited to conditions without frost. This paper presents experimental results conducted on a full-scale refrigerated container including the frost effect. Comparisons are also made between field measurements and theoretical results based on a numerical model presented in the previous paper [15].

2. Refrigerated container description and measurement procedure

A commercial 12.2 m (40 ft) container box consisting of a cargo section and a compactly designed refrigeration system at the front is used in the present study (Fig. 1). The evaporator is a finned-tube type heat exchanger consisting of nine circuits, six rows of copper tubing and a total of 514 aluminum fins. The outer diameter of the copper tube is 12.7 mm with a thickness of 0.432 mm. The working refrigerant is R-12, and the flow rate is controlled by a thermal expansion valve based on the superheat temperature picked up by the sensing bulb located at the evaporator outlet. Four electric heaters each rated at 750 W and 230 V are located at the bottom air-off coil side of the evaporator

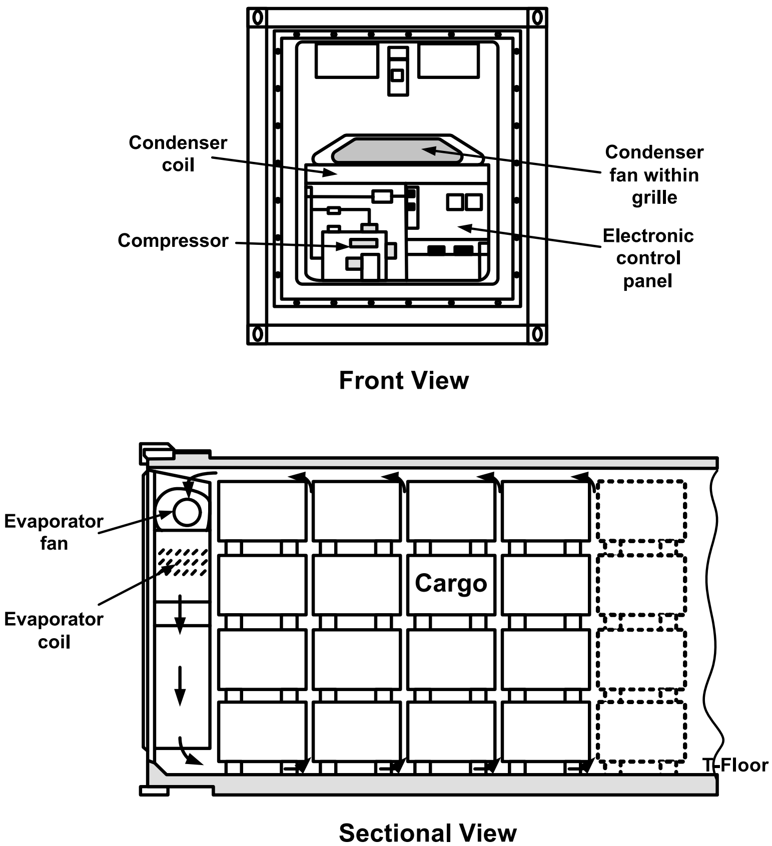

Fig. 1. Views of refrigeration container.