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Review

Current and future prospects of enhanced heat transfer in ammonia systems

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ABSTRACT

In the last decade a moderate headway has been made in the application of enhanced surface heat exchangers in ammonia refrigeration systems. This has been a result of the persistent issue of ozone and global warming which has resulted in keen interest in natural refrigerants such as ammonia that has played a prominent role in the refrigeration industry for years, particularly in the field of food, beverage and marine. The only drawback with ammonia is the toxicity; hence, if smaller heat exchangers could be introduced in order to reduce ammonia charge, this negative aspect about ammonia can be addressed to a great extent. In order to achieve this goal, novel and compact heat exchangers with enhanced surfaces have to be introduced. This paper presents an over view of the status of ammonia as a refrigerant and discusses the present and the future trends in the development of compact heat exchangers for use in ammonia refrigeration.

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Systèmes à ammoniac : perspectives d'amélioration du transfert de chaleur aujourd'hui et demain

Mots clés : Système frigorifique ; Ammoniac ; Enquête ; Technologie ; Échangeur de chaleur ; Échangeur multitubulaire ; Échangeur à plaque

1. Introduction

The depletion of ozone layer and the global warming have left a marking impression on the business of air conditioning and refrigeration. Various international treaties and protocols have left the industry with few choices. Firstly, chlorofluorocarbons (CFCs) were put on the hit list. The genuine belief was that the hydrochlorofluorocarbons (HCFCs) such as R-22

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would stay with us for a while, but that is not the case. Europeans are aggressively moving toward imposing serious restrictions on not only HCFCs but also HFCs; case in point, the 2006 F-Gas regulation.

These fundamental issues and concerns bring us to the discussion of alternatives, especially the most well known natural refrigerant, ammonia which has been successfully used in industrial refrigeration. It is apparent that with the advent of mechanical refrigeration in the late 1800s, human civilization changed forever. Without refrigeration, we would have not accomplished major advances in the last century. This technological advance has directly contributed to food preservation, indoor air quality and comfort control, gas liquefaction, food and beverage production and electronic cooling. In order to maintain this improved standard of living, it is imperative to keep the refrigeration equipment in running condition.

Presently, two different approaches are being used, i.e., direct or indirect cooling. With indirect cooling the use of ammonia does not become a serious issue since toxicity does not become a limiting factor. However, in direct applications the use of ammonia becomes a major point of discussion. In United States all major food, meat and beverage processing and storage facilities use ammonia exclusively as a refrigerant of choice. In recent years the local jurisdiction has imposed new regulations on inventory control. Consequently, it introduced strict PSM (Process Safety Management) procedures in place at the facilities. In view of these developments, contractors and end users are more receptive to systems that would result in drastic reduction in the refrigerant inventories.

Historically, ammonia has proved to be an excellent refrigerant with the following characteristics:

- Excellent thermodynamic and transport properties.
- Environmentally friendly with ODP and GWP of zero.
- Pungent odor; therefore, self-alarming refrigerant.

The only drawback of ammonia is its toxicity. This issue can be addressed by introducing innovative heat exchanger designs that would result in limited charge systems; hence, reducing the potential for serious damage in case of an accidental release.

2. Heat transfer enhancement

According to Bergles et al. (1983) there are several types of enhancement techniques. The two basic categories are (1) passive and (2) active. In a passive technique heat transfer enhancement is achieved by changing the surface structure. In an active technique external influence such as momentum, electric or magnetic force is applied. The concept of heat transfer enhancement has been applied to heat exchangers for several decades; however, it has been limited to halocarbon refrigerant applications. Since ammonia did not play any role in the air conditioning business, there was practically no development in this field. Moreover, halocarbons are compatible with copper and copper alloys; hence, it is easy to work with copper than materials that are compatible with ammonia, such as carbon steel, stainless steel and titanium.

The subject of ammonia heat transfer enhancement has shown some momentum since the early 1990s. But the progress has not been monumental for reasons mentioned above. Very few companies in this business have taken the initiative to probe into the potential use of high efficiency tubes. Ammonia related enhanced heat transfer research has also been limited. In the past 10 years, less than five research projects have been undertaken by ASHRAE. Similarly, limited research activity has been reported in Europe and Asia. Literature search on the subject indicates less than 60 publications which is extremely low as compared to enhancement work related to halocarbons.

3. Recent developments in shell-and-tube technology

Enhanced surface tubes have been used successfully in various applications on a limited scale. It is important to select enhancement according to the need of a particular application, e.g., it is not wise to apply enhancement on ammonia side while the controlling side is the process side. Hence, preliminary screening of individual thermal resistances is very critical.

3.1. *Enhancement variation in a flooded tube bundle*

In a United States patent Ayub (2006) has disclosed a flooded evaporator with various types of enhanced tubes along the bundle height. It has been observed that enhanced surface tubes cause high vapor generation which could become so intense that it causes high vapor-rich zone in the upper section of a tube bundle. Higher void fraction is not desirable since it starves the tubes of liquid refrigerant and in turn affects the performance of the evaporator.

Ayub proposed to utilize various types of tubes appropriately selected along the height of the tube bundle, with high efficiency tubes having strong nucleate-boiling characteristics in the lower section, i.e., Section I as shown in Fig. 1, followed by tubes with moderate nucleate-boiling characteristics in Section II, still another suitable kind of tubes in Section III and even plain tubes (if required) in Section IV. Depending on the size of the tube bundle, these tubes could then be

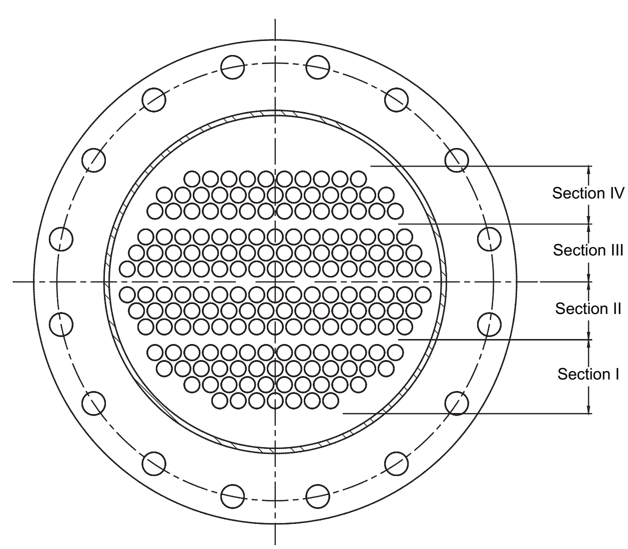

Fig. 1 – Different types of tubes in different sections of a flooded tube bundle.

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