狹窄水平雙套管中 R-134a 冷媒流動沸騰熱傳和氣泡特性研究

研究生: 賴祐民　　　　　　　　　　指導教授: 林清發

國立交通大學機械工程學系

摘要

本研究以實驗方式探討管道尺寸對流動沸騰熱傳(含次冷及飽和流動沸騰)及相關氣泡特徵之影響。以環保冷媒 R-134a 為工作流體流入一水平狹窄雙套管之測試段，並流道之間隙由 0.2 至 2.0mm。測試段則由玻璃外管及加熱內銅管組成來量測熱傳係數及流場觀測。一電橋式加熱棒置於銅管內部提供熱通量加熱狹窄流道內流動之冷媒。

首先，提出冷媒 R-134a 在飽和流動沸騰之測試結果。從所量測之沸騰曲線發現，沸騰初始之溫度突降現象在飽和流動沸騰中並不明顯。飽和流動沸騰熱傳係數隨尺寸減少而增加。此外，熱通量增加亦會使得熱傳係數明顯增加。然而，冷媒之質通量及飽和溫度對熱傳係數影響甚小。從流場觀測之結果顯示氣泡脫離尺寸隨著質通量增加而稍微減小。並且在高熱通量下，許多氣泡從加熱表面之成核孔產生並趨向合併成大氣泡。在較小間隙如 0.2 及 0.5mm，流譜將由氣泡流轉變為彈狀流。在管道中之彈狀流的特徵則是由液狀彈狀消長伴隨大、小氣泡。

接著，冷媒 R-134a 在次冷流動沸騰之熱傳結果以沸騰曲線及熱傳係數型式表示。在沸騰曲線中可發現沸騰初始之溫度突降現象在次冷流動沸騰中非常明顯。次冷流動沸騰熱傳係數隨間隙尺寸減少而增加但隨次冷度增加而減少。此外，熱通量增加亦會使得熱傳係數明顯增加。然而，冷媒之質通量及飽和溫度對熱傳係數影響不大。次冷流動沸騰之流場觀測顯示氣泡隨冷媒之質通量及次冷度增加而被抑制，然而增加熱通量對氣泡數目、合併及脫離頻率則有正面影響。再者，飽和溫度降低造成氣泡脫離頻率及成核密度減小。在較小間隙如 0.2 及 0.5mm，伴隨著高熱通量將使流譜由氣泡流轉變為彈狀

流。隨著尺寸變小將使得氣泡脫離頻率及彈狀流中大氣泡平均速度增加。

最後，我們把這個實驗中流動沸騰氣泡脫離直徑、產生頻率及成核密度的資料作分析，求出氣泡特徵之 3 個經驗式，並利用此經驗公式推得氣泡流區之熱傳係數。至於彈狀流區之熱傳係數則則是修正 Cornwell and Kew 經驗式所得。

關鍵字: 狹窄雙套管，次冷及飽和流動沸騰，冷媒 R-134a，熱傳及氣泡特徵，沸騰曲線

Heat Transfer and Bubble Characteristics Associated with Flow Boiling of Refrigerant R-134a in a Horizontal Narrow Annular Duct

Student: Yow-Min Lie **Advisor: Prof. Tsing-Fa Lin**

Institute of Mechanical Engineering

National Chiao Tung University

ABSTRACT

Experiments have been conducted here to investigate how the channel size affects the flow boiling heat transfer (including subcooled and saturated flow boiling) and associated bubble characteristics of the ozone friendly refrigerant R-134a in the horizontal annular duct with the gap between the inner and outer pipes of the duct being relatively small. Both the subcooled and saturated flow boiling characteristics are considered. The gap of the duct is varied from 0.2 to 2.0 mm in this study. The test section for the horizontal annular duct consists of an outer pipe made of Pyrex glass and an inner heated copper pipe, intending to measure the boiling heat transfer coefficient and to facilitate the visualization of boiling processes. A cartridge heater is installed inside the inner pipe to provide the required heat flux to the refrigerant flow in the narrow annular duct.

First, the experimental heat transfer data for the saturated flow boiling of R-134a in the horizontal narrow annular duct are examined. From the measured boiling curves, the temperature undershoot at ONB are insignificant for the saturated flow boiling of R-134a in the duct. The saturated flow boiling heat transfer coefficient increases with a decrease in the gap size of the duct. Besides, raising the imposed heat flux can also cause a significant increase in the boiling heat transfer coefficients. However, the effects of the refrigerant mass flux and saturated temperature on the boiling heat transfer coefficient are small. The results from the flow visualization show that the mean diameter of the bubbles departing from the heating surface decreases slightly at increasing mass flux. Besides, at a high imposed heat flux many bubbles generated from the cavities in the heating surface tend to merge together to form a big bubbles and in the smaller ducts with the gap at 0.2 and 0.5 mm the bubbly flow changes to a

slug flow. The slug flow in the ducts is characterized by a number of liquid slugs interdispersed with big bubbles along with small bubbles in the liquid slugs.

Then, the experimental heat transfer data for the subcooled flow boiling of R-134a in the narrow duct have been expressed in terms of boiling curve and boiling heat transfer coefficient. From the boiling curves, the temperature undershoot at ONB are significant for the subcooled flow boiling of R-134a in the duct. The subcooled boiling heat transfer coefficient increases with a reduction in the gap size, but decreases with an increase in the inlet liquid subcooling. Besides, raising the imposed heat flux can cause a significant increase in the boiling heat transfer coefficient. However, the effects of the refrigerant mass flux and saturated temperature on the boiling heat transfer coefficient are milder. Visualization of the subcooled flow boiling processes reveals that the bubbles are suppressed by raising the refrigerant mass flux and inlet subcooling. Moreover, raising the imposed heat flux produces positive effects on the bubble population, coalescence, departure frequency. Furthermore, a decrease in the saturated temperature results in a reduction in the bubble departure frequency and active nucleation site density. In the smaller ducts with δ = 0.2 & 0.5 mm subject to a high heat flux a change from the bubbly flow to the slug flow also occurs. The bubble departure frequency and the mean speed of the big bubbles in the slug flow increase at reducing duct size.

Correlations for the subcooled and saturated flow boiling heat transfer coefficients of R-134a in the narrow annular duct are proposed. Besides, data for some quantitative bubble characteristics such as the mean bubble departure diameter, departure frequency and the mean active nucleation site density have been correlated.

Keywords: narrow annular duct, subcooled and saturated flow boiling, R-134a, heat transfer and bubble characteristics, boiling curve