สัญญาเลขที่ RTA4980004

รายงานวิจัยฉบับสมบูรณ์

โครงการ

งานวิจัยขั้นสูงทางวิศวกรรมการปรับอากาศและการทำความเย็น

Advanced Research on Refrigeration and Air-Conditioning Engineering

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สนับสนุนโดยสำนักงานกองทุนสนับสนุนการวิจัย

(ความเห็นในรายงานนี้เป็นของผู้วิจัยสกว.ไม่จำเป็นต้องเห็นด้วยเสมอไป)

ผลงานโดยสรุป

งานที่ผ่านมาของกลุ่มวิจัยคือเน้นการศึกษาคุณลักษณะทางการไหล (เช่น รูปแบบการไหล ความดันที่ลดลง) และการถ่ายเทความร้อนและมวลของการไหลสองสถานะของสารทำความเย็น ในขณะเปลี่ยนสถานะที่เกิดขึ้นในระบบท่อ ทั้งในเชิงการทดลองและเชิงทฤษฎี ได้สร้างองค์ความรู้ใหม่ โดยมีผลงานทางวิชาการที่ก้าวหน้าทันสมัย ผลงานได้ถูกนำไปอ้างอิงโดยนักวิทยาศาสตร์ในต่างประเทศ สามารถพัฒนาจากงานวิจัยพื้นฐาน สู่งานวิจัยประยุกต์ซึ่งใช้กับอุตสาหกรรมในประเทศได้ ได้สร้างเครือข่ายงานวิจัยทั้งในประเทศและต่างประเทศอันจะมีประโยชน์ต่อคนรุ่นหลังในการแลกเปลี่ยนวิทยาการที่ก้าวหน้า กลุ่มวิจัย ได้นำศาสตร์ของ การถ่ายเทความร้อนและมวล กลศาสตร์ของไหล การไหลสองสถานะ และเธอร์โมไดนามิกส์ มาประยุกต์ เพื่อการเพิ่มประสิทธิภาพและลดการใช้พลังงานของระบบปรับอากาศและระบบทำความเย็น ความรู้ใหม่ต่างๆที่ได้จากงานวิจัยพื้นฐานเหล่านี้ สามารถนำไปประยุกต์ใช้ในการออกแบบอุปกรณ์แลกเปลี่ยนความร้อนต่างๆให้มีสมรรถนะสูงขึ้นได้ ซึ่งเป็นประโยชน์ต่ออุตสาหกรรมโดยตรง

โดยปกติกระบวนการแลกเปลี่ยนความร้อนระหว่างของไหลสองชนิดที่มีอุณหภูมิแตกต่างกัน สามารถทำได้โดยใช้อุปกรณ์ที่เรียกว่า อุปกรณ์แลกเปลี่ยนความร้อน ถ้าอุปกรณ์แลกเปลี่ยนความร้อนถูกออกแบบมาอย่างเหมาะสม การถ่ายเทความร้อนก็จะเป็นไปอย่างมีประสิทธิภาพ การเพิ่มความสามารถในการถ่ายเทความร้อน ถือเป็นสิ่งหนึ่งที่จะช่วยเพิ่มสมรรถนะของอุปกรณ์แลกเปลี่ยนความร้อน ซึ่งก็เท่ากับเป็นการประหยัดพลังงานหรือเป็นการใช้พลังงานอย่างคุ้มค่า กลุ่มวิจัยได้ศึกษาวิธีพัฒนา คอนเดนเซอร์ และ อีวาโปเรเตอร์ ซึ่งถือเป็นอุปกรณ์แลกเปลี่ยนความร้อนที่อยู่ในวงจรการปรับอากาศและการทำความเย็น ให้สามารถแลกเปลี่ยนความร้อนระหว่าง สารทำความเย็นกับอากาศได้ดียิ่งขึ้น การศึกษาสามารถทำทั้งจากการทดลองและจากการสร้างแบบจำลองทางคณิตศาสตร์ ตัวอย่างของงานวิจัยได้แก่ การออกแบบอุปกรณ์แลกเปลี่ยนความร้อนแบบใหม่ๆซึ่งอาจเป็นแนวทางในการนำไปประยุกต์ใช้ต่อไปในอนาคต การศึกษาถึงผลของ รูปร่างของครีบที่ใช้ในการถ่ายเทความร้อน ความหนาของครีบ ระยะห่างระหว่างครีบ วัสดุที่ใช้ ลักษณะการวางท่อ ต่อสมรรถนะทางการถ่ายเทความร้อน และการลดลงของความดันของอากาศขณะไหลผ่านอุปกรณ์แลกเปลี่ยนความร้อน ทั้งที่ภาวะที่ผิวท่อด้านนอกของคอนเดนเซอร์มีสภาพแห้ง และที่ภาวะที่ผิวท่ออีวาโปเรเตอร์เปียกด้วยน้ำที่เกิดจากการควบแน่น

กลุ่มวิจัยยังสนใจศึกษาในส่วนอุปกรณ์ระเหยซึ่งถือเป็นอุปกรณ์ที่สำคัญอีกตัวหนึ่งในวงจรการปรับอากาศและทำความเย็น อาทิ การนำอีเจ็กเตอร์ และ การนำท่อคาปิลลารีทั้งแบบแอเดียแบติก และ แบบ นอนแอเดียแบติก มาใช้เป็นอุปกรณ์ระเหย โดยสามารถพัฒนาแบบจำลองทางคณิตศาสตร์เพื่อจำลองการไหลของสารทำความเย็นในท่อคาปิลลารี ซึ่งมีการการไหลสองสถานะเป็นกลไกสำคัญ แบบจำลองดังกล่าวสามารถนำไปใช้ในการออกแบบหาขนาดท่อคาปิลลารีที่เหมาะสมที่ใช้กับสารทำความเย็นประเภทต่างๆ ที่ทำงานที่ภาวะต่างๆตามแต่กำหนด และเพื่อให้สะดวกต่อการใช้งานใน

ภาคสนาม คณะวิจัยสามารถพัฒนา แผนภูมิ เพื่อใช้เลือกขนาดท่อคาปิลลารี ที่เหมาะสมกับสารทำความเย็นและภาวะการใช้งานจริง ในส่วนของสารทำงานในวงจรการปรับอากาศและการทำความเย็นซึ่งเราเรียกว่าสารทำความเย็นกลุ่มวิจัยได้ศึกษาคุณลักษณะเฉพาะในการไหลของสารทำความเย็นทางเลือกใหม่ทั้งจากการทดลองและจากการพัฒนาแบบจำลองทางคณิตศาสตร์ ทั้งในด้านการถ่ายเทความร้อนและด้านกลศาสตร์ของไหล ในขณะที่สารทำความเย็นระเหย และควบแน่นภายในท่อเรียบและท่อที่ผิวภายในไม่เรียบ โดยศึกษาทั้งกับสารทำความเย็นบริสุทธิ์และกับสารทำความเย็นที่มีน้ำมันหล่อลื่นผสมซึ่งตรงกับสภาพการใช้งานจริง ผลลัพธ์จากการศึกษาทางด้านการถ่ายเทความร้อนจะอยู่ในรูปของสัมประสิทธิ์การถ่ายเทความร้อน สำหรับในเชิงกลศาสตร์ของไหลจะเสนอผลในรูปของ รูปแบบการไหลสองสถานะซึ่งเป็นไปได้หลากหลายรูปแบบการไหล แฟกเตอร์ความเสียดทาน และ ความดันลด สหสัมพันธ์ที่พัฒนาได้ทั้งสัมประสิทธิ์การถ่ายเทความร้อนและแฟกเตอร์ความเสียดทาน สามารถนำไปใช้ในการออกแบบอีวาโปเรเตอร์ และ คอนเดนเซอร์ ได้โดยตรง นอกจากนั้นแบบจำลองทางคณิตศาสตร์ที่พัฒนาขึ้นมาสามารถนำไปเป็นแนวทางและใช้ดัดแปลงเพื่อการออกแบบอุปกรณ์แลกเปลี่ยนความร้อนที่มีลักษณะแตกต่างออกไปได้

Research summary

The research work of our research group includes two-phase flow, heat transfer enhancement and thermal system design. Generally, the process of heat exchange between two kinds of fluid of different temperatures can be accomplished with equipment called a heat exchanger. A well-designed heat exchanger can transfer heat effectively. Heat transfer enhancement can increase the performance of a heat exchanger through the saving or cost-effective use of energy. Since Thailand is situated in a tropical zone, air conditioners and refrigerators are considered necessary appliances in Thai daily life. Additionally, Thailand has become an important production base for air conditioner and refrigerator manufactoring, as well as a top exporter of these products to the world market. Therefore, research and development, as well as the preparation of specialists - in this field is necessary.

Our research group has applied the sciences of heat and mass transfer, fluid mechanics, and thermodynamics in developing higher-performance heat exchangers, the main focus being on increasing the efficiency and reducing the power consumption of air conditioners and refrigerators. The new body of knowledge gained from this basic research can be applied in designing high-performance equipment that is directly useful in the industry. The research team has tried to study and develop condensers and evaporators, which are heat exchangers used in the cycle of refrigeration and air conditioning, to enable better heat exchange between the refrigerant and surrounding air. These studies covered both real experiments and simulation with mathematical models. One example of these studies is the design of new heat exchangers that can later be applied in the industry. Another important example is the study of the effects that various fin shapes, fin thickness, fin spacing, used materials and tube arrangement, used in heat exchangers, have on the efficiency of the heat transfer and pressure drop of air while flowing through heat the exchangers - both in the condition of the outer surface of the condenser being dry and in the condition of the surface of the evaporator being wet due to condensation.

Moreover, the research team studied the expansion device, which is another important part functioning in the refrigeration and air conditioning cycles. The research used ejectors and both adiabatic and non adiabatic capillary tubes as expansion devices. Mathematical models were developed to simulate the flow of refrigerant in capillary tubes in which the two-phase flow was the key mechanism. These models have been proved reliable as results

obtained from these models were similar to those presented in many published research articles. These models could be utilized in designing the appropriate sizes of capillary tubes used with various kinds of refrigerant in different working conditions. To facilitate field use, the research team also developed a selection chart enabling easy selection of capillary tube size suitable for chosen kinds of refrigerant and working conditions.

It is already known that even though the use of refrigerant is suitable for engineering aspects, it has some drawbacks in environmental aspects. In the near future, some refrigerants used nowadays will be banned. Thus, the research team has also studied the flow characteristics of alternative refrigerants both in terms of heat transfer and in terms of fluid mechanics. The flow characteristics were studied both while the refrigerants were flowing and evaporating, and while the refrigerants were flowing and condensing inside smooth pipes and non-smooth pipes. The studied refrigerants included both pure refrigerant and a mixture of refrigerant and lubricant oil. These studies covered both real experiments and developments of mathematical models. Results of heat transfer studies were presented in the form of a heat transfer coefficient, whereas results of fluid mechanics studies were presented in the form of a pressure drop plus the flow pattern occurring during phase changes. The developed correlations - both in terms of heat transfer coefficient and pressure drop - could be directly applied to the design of evaporator and condenser. The developed mathematical models could also be directly utilized or modified in the design of different heat exchangers.

ทุนเมธีวิจัยอาวุโส สัญญาเลขที่ RTA4980004

งานวิจัยขั้นสูงทางวิศวกรรมการปรับอากาศและการทำความเย็น

สรุปรายงาน

หัวหน้าโครงการ : ศาสตราจารย์ ดร. สมชาย วงศ์วิเศษ

รายงานในช่วงวันที่ 20 ก.ค. 2549 ถึง 24 มิ.ย. 2553

1. <u>การดำเนินงาน</u>

ได้ดำเนินการตามแผนที่วางไว้ทุกประการ โดยทำการวิจัยในหัวข้อต่อไปนี้

1.1 Micro-Channel Heat Exchanger used for Refrigeration and Air Conditioning

1.2 Heat and Mass Transfer Characteristics of Fin-and-Tube Evaporators used in Air Conditioning system

1.3 Saturated Pool Boiling Characteristics of New Alternative Fluorine-Based Refrigerants

1.4 Pool Boiling Characteristics of New Alternative Refrigerants "Nano-Fluids"

1.5 Hydrocarbon Mixtures to Replace Refrigerants used in an Automotive Air Conditioning System

1.6 Heat Transfer, Pressure Drop and Effect of Flow Direction of Working Fluids flowing Through a Plate Heat Exchanger Simulated as Evaporator and Condenser

1.7 Characteristics of Refrigerant HFC-134a Flowing Through Micro-Scale Short Tube Orifices

1.8 Vertical Upward Gas-Liquid Flow in Sinusoidal Wavy Channels

1.9 Heat Transfer and Pressure Drop Characteristics of Refrigerant HFC-134a During Evaporation and Condensation in Annulus Coil Evaporator and Condenser

1.10 Two-Phase Flow Patterns, Void Fraction and Pressure Drop in a Narrow Concentric Annuli

1.11 Performance of a Vapor Compression Refrigeration Cycle Using a Two-Phase Ejector as an Expansion Device

1.12 Experimental and Theoretical Investigations of Two-Phase Flow in Micro-Channels

1.13 Effects of Electrohydrodynamics on the In-Tube Condensation and Boiling Heat Transfer Enhancement of a New Alternative Refrigerant in Smooth and Micro-Fin Tubes

1.14 Two-Phase Flow Patterns and Pressure Drop in a Small Circular Tube Vertical Bend used in Refrigeration and Air conditioning

1.15 Forced Convective Heat Transfer Characteristic of New Alternative Refrigerants "Nano-fluid"

1.16 Selection Charts for Fluorine-Based Capillary Tubes Used in Refrigerator and Air-Conditioner

1.17 Effect of Geometric Parameters on the Air-Side Performance of Crimped Finned Tube Condenser used in the Air-Conditioning System

1.18 Heat Transfer Performance of a Helically Coiled Heat Exchanger

1.19 Performance of New Alternative Refrigerants Flowing Through Non-Adiabatic Capillary Tubes Used as An Expansion Device in Refrigeration and Air Conditioning System

1.20 Combined Refrigeration and Solar Energy Systems

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3. <u>บทความทางวิชาการลักษณะอื่น ๆ</u>

<u>สิทธิบัตรที่ยื่นจดกับกรมทรัพย์สินทางปัญญา</u>

1. วิธีการหาความยาวของท่อคาปิลลารีที่ใช้ในระบบปรับอากาศและระบบทำความเย็น
   (Patent no. 21195)
2. เครื่องยนต์สเตอร์ลิงแบบสองลูกสูบ
   (คำขอรับสิทธิบัตรเลขที่ 0601003084)
3. เครื่องยนต์สเตอร์ลิงแบบลูกสูบกำลังคู่
   (คำขอรับสิทธิบัตรเลขที่ 0601003085)

4. เครื่องยนต์สเตอร์ลิงแบบลูกสูบกำลังสี่ลูกสูบ
(คำขอรับสิทธิบัตรเลขที่ 0601003086)

5. ระบบการผลิตกำลังด้วยเครื่องยนต์สเตอร์ลิงพลังแสงอาทิตย์
(คำขอรับสิทธิบัตรเลขที่ 0601003087)

6. อุปกรณ์แลกเปลี่ยนความร้อนแบบท่อขดแบบสปริงติดครีบ
(คำขอรับสิทธิบัตรเลขที่ 0601003088)

7. แคลอริมิเตอร์สำหรับวัดความเข้มรังสีอาทิตย์จากตัวรวมรังสีอาทิตย์
(คำขอรับสิทธิบัตรเลขที่ 0601003089)

4. กิจกรรมอย่างอื่นที่เกี่ยวข้องกับงานวิจัย

- เป็น Reviewer พิจารณาโครงการให้ ฝ่ายวิจัยเชิงวิชาการ สกว
- เป็น Chair person การประชุมประจำปีนักวิจัยรุ่นใหม่พบเมธีวิจัยอาวุโส
- เป็นกรรมการบัญญัติคำศัพท์ทางวิศวกรรมเครื่องกลของราชบัณฑิตยสถาน
- เป็นกรรมการพิจารณาผลงานเพื่อเข้าสู่ตำแหน่งทางวิชาการให้มหาวิทยาลัยต่างๆ
- เป็น reviewer พิจารณาบทความให้กับวารสารระดับชาติและระดับนานาชาติ
- เป็นวิทยากรให้องค์กร และ มหาวิทยาลัยต่างๆในเรื่องที่เกี่ยวกับงานวิจัย
- เป็นบรรณาธิการหนังสือเฉลิมพระเกียรติจัดทำโดย สกว.
- ได้รับการเชิดชูเกียรติให้เป็นอาจารย์ดีเด่นด้านวิชาการและการวิจัยในโอกาสครบรอบ 48 ปี แห่งการสถาปนามหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี

5. ท่านได้พบอุปสรรคในการดำเนินงานหรือไม่ ถ้าพบกรุณาระบุว่ามีอะไรบ้างและได้แก้ไขอย่างไรบ้าง.....(ไม่มี).....

6. ความเห็นและข้อเสนอแนะ.....(ไม่มี).....

(ศ. ดร. สมชาย วงศ์วิเศษ)
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Technical note

Thermodynamic analysis of a Stirling engine including dead volumes of hot space, cold space and regenerator

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Abstract

This paper provides a theoretical investigation on the thermodynamic analysis of a Stirling engine. An isothermal model is developed for an imperfect regeneration Stirling engine with dead volumes of hot space, cold space and regenerator that the regenerator effective temperature is an arithmetic mean of the heater and cooler temperature. Numerical simulation is performed and the effects of the regenerator effectiveness and dead volumes are studied. Results from this study indicate that the engine net work is affected by only the dead volumes while the heat input and engine efficiency are affected by both the regenerator effectiveness and dead volumes. The engine net work decreases with increasing dead volume. The heat input increases with increasing dead volume and decreasing regenerator effectiveness. The engine efficiency decreases with increasing dead volume and decreasing regenerator effectiveness.
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Keywords: Stirling engine; Hot-air engine; Regenerative heat engine

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Effect of fin thickness on the air-side performance of wavy fin-and-tube heat exchangers under dehumidifying conditions

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Abstract

This study investigated the effect of fin thickness on the air-side performance of wavy fin-and-tube heat exchangers under dehumidifying conditions. A total of 10 samples were tested with associated fin thickness (δ_f) of 0.115 mm and 0.25 mm, respectively. For a heat exchanger with two rows ($N = 2$) and fin pitch F_p of 1.41 mm, the effect of fin thickness on the heat transfer coefficient is more pronounced. The heat transfer coefficients for $\delta_f = 0.25$ mm is about 5–50% higher than those for $\delta_f = 0.115$ mm whereas the pressure drop for $\delta_f = 0.25$ mm is about 5–20% higher. The unexpected difference in heat transfer coefficient subject to fin thickness is attributable to better interactions between the directed main flow and the swirled flow caused by the condensate droplet for $\delta_f = 0.25$ mm. The maximum difference in heat transfer coefficients for $N = 2$ and $F_p = 2.54$ mm subject to the influence of fin thickness is reduced to about 20%, and there is no difference in heat transfer coefficient when the frontal velocity is above 3 m/s. For $N \geqslant 4$ and $F_p = 2.54$ mm, the influence of fin thickness on the heat transfer coefficients diminishes considerably. This is because of the presence of tube row, and the unsteady/vortex shedding feature at the down stream of wavy channel. Based on the present test results, a correlation is proposed to describe the air-side performance for wavy fin configurations, the mean deviations of the proposed heat transfer and friction correlations are 7.9% and 7.7%, respectively.
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Keywords: Air-side performance; Wavy fin-and-tube heat exchangers; Colburn factor; Friction factor; Dehumidifying conditions

1. Introduction

Plate fin-and-tube heat exchangers are a basic type of heat exchanger employed in many industrial applications such as air conditioning, refrigeration and other thermal processes. In application, the dominated thermal resistance on the air-side of the heat exchanger normally limits the heat transfer rate. One way to enhance the heat transfer on the air-side of the heat exchanger is to modify the fin geometry. Among the enhanced fin configurations, herringbone wavy fin-and-tube heat exchangers are currently widely used because the corrugated fins can provide additional surface area and lengthen the mixing length of the airflow. In their application as evaporators, the surface temperature of the fins is generally below the dew point temperature. As a result, the moist air is condensed on the fins, giving rise to a significant change of the air-side performance of the heat exchanger. Development of the numerical simulation of fin-and-tube heat exchangers is generally difficult due to the complexity of the moist airflow pattern across the heat exchangers, so experimental study is needed.

The air-side performance of wavy fin-and-tube heat exchangers have been studied by a number of researches, see [1–5]. However, the effect of fin thickness on the air-side performance has received little attention in literature [6–8].

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Effects of EHD on heat transfer enhancement and pressure drop during two-phase condensation of pure R-134a at high mass flux in a horizontal micro-fin tube

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Abstract

Effects of electrohydrodynamic (EHD) on the two-phase heat transfer enhancement and pressure drop of pure R-134a condensing inside a horizontal micro-fin tube are experimentally investigated. The test section is a 2.5 m long counter flow tube-in-tube heat exchanger with refrigerant flowing in the inner tube and cooling water flowing in the annulus. The inner tube is made from micro-fin horizontal copper tubing of 9.52 mm outer diameter. The electrode is made from cylindrical stainless steel of 1.47 mm diameter. Positive high voltage is supplied to the electrode wire, with the micro-fin tube grounded. In the presence of the electrode, a maximum heat transfer enhancement of 1.15 is obtained at a heat flux of 10 kW/m^2, mass flux of 200 kg/m^2 s and saturation temperature of 40 °C, while the application of an EHD voltage of 2.5 kV only slightly increases the pressure drop. New correlations of the experimental data based on the data gathered during this work for predicting the condensation heat transfer coefficients are proposed for practical application.
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Keywords: Electrohydrodynamic; Condensation heat transfer; Heat transfer enhancement; Micro-fin tube

1. Introduction

Micro-fin tubes have been successfully implemented in the air-conditioning and refrigeration industries for effectively improving tube-side performance. This success is because of their ability to significantly improve the heat transfer coefficient with only a moderate increase of the friction penalty. A heat transfer enhancement technique utilizing electrohydrodynamic (EHD) can be achieved by utilizing the interaction between the electric field and fluid flow in a dielectric fluid medium. This interaction can result in the increase of fluid motion, which leads to a higher heat transfer coefficient.

The physical basis of the electrically enhanced condensation and boiling are due to the EHD force, (f_e), generated by an electric field and is given by the following Eq. (1) [1]:

$$f_e = qE - \frac{1}{2}E^2\nabla\varepsilon + \frac{1}{2}\nabla\left\langle E^2\left(\frac{\partial\varepsilon}{\partial\rho}\right)_T\rho\right\rangle \quad (1)$$

Eq. (1) can be further written in a more detailed form for non-polar fluids as follows in Eqs. (2) and (3):

$$f_e = f_1 + f_2 + f_3 + f_4 \quad (2)$$

$$f_e = qE - \frac{1}{2}E^2\nabla\varepsilon + \frac{1}{6}\varepsilon_o(\kappa-1)(\kappa-2)\nabla E^2 + \frac{1}{6}\varepsilon_o E^2\nabla\langle(\kappa-1)(\kappa-2)\rangle \quad (3)$$

The first term on the right of Eq. (3), known as the electrophoretic force, is the Coulomb force acting on the free

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A review of flow and heat transfer characteristics in curved tubes

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Abstract

The performance of heat exchangers can be improved to perform a certain heat-transfer duty by heat transfer enhancement techniques. In general, these techniques can be divided into two groups: active and passive techniques. The active techniques require external forces, e.g. electric field, acoustic or surface vibration, etc. The passive techniques require fluid additives or special surface geometries. Curved tubes have been used as one of the passive heat transfer enhancement techniques and are the most widely used tubes in several heat transfer applications. This article provides a literature review on heat transfer and flow characteristics of single-phase and two-phase flow in curved tubes. Three main categories of curved tubes; helically coiled tubes, spirally coiled tubes, and other coiled tubes, are described. A review of published relevant correlations of single-phase heat transfer coefficients and single-phase, two-phase friction factors are presented.
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Keywords: Curved tube; Heat transfer characteristics; Flow characteristics; Helically coiled tube; Spirally coiled tube; Pressure drop; Heat transfer coefficient; Friction factor

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Flow pattern and pressure drop of vertical upward gas–liquid flow in sinusoidal wavy channels

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Abstract

Flow patterns and pressure drop of upward liquid single-phase flow and air–water two-phase flow in sinusoidal wavy channels are experimentally studied. The test section is formed by a sinusoidal wavy wall of 1.00 m length with a wave length of 67.20 mm, an amplitude of 5.76 mm. Different phase shifts between the side walls of the wavy channel of 0°, 90° and 180° are investigated. The flow phenomena, which are bubbly flow, slug flow, churn flow, and dispersed bubbly flow are observed and recorded by high-speed camera. When the phase shifts are increased, the onset of the transition from the bubbly flow to the churn flow shifts to a higher value of superficial air velocity, and the regions of the slug flow and the churn flow are smaller. In other words, the regions of the bubbly flow and the dispersed bubbly flow are larger as the phase shift increases. The slug flow pattern is only found in the test sections with phase shifts of 0° and 90°. Recirculating gas bubbles are always found in the troughs of the corrugations. The recirculating is higher when the phase shifts are larger. The relationship between the two-phase multipliers calculated from the measured pressure drops, and the Martinelli parameter is compared with the Lockhart–Martinelli correlation. The correlation in the case of turbulent–turbulent condition is shown to fit the data very well for the phase shift of 0° but shows greater deviation when the phase shifts are higher.
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Keywords: Two-phase flow; Flow pattern; Pressure drop; Sinusoidal wavy channels

1. Introduction

Two-phase gas–liquid flow through a confined gap is encountered in several engineering applications including boiling behavior in mini-channels, cooling systems of various types of equipment such as high performance microelectronics, supercomputers, high-powered lasers, medical devices, and high heat-flux compact heat exchangers in spacecraft and satellites, etc. It can be expected that the restriction of the bubble space in the mini-channel is the cause of the differences in the two-phase flow characteristics from those in conventional channel geometries. This may also affect heat-mass transfer characteristics during the change of phase.

It is not possible to understand the two-phase flow phenomena without a clear understanding of the flow patterns encountered. It is expected that the flow patterns will influence the two-phase pressure drop, holdup, system stability, exchange rates of momentum, and the heat and mass during the phase-change heat transfer processes. The ability to accurately predict the type of flow is necessary before relevant calculation techniques can be developed.

Two-phase flow characteristics in small circular tubes have been studied by a number of researchers while those in mini-non-circular channels have received comparatively little attention in literature.

Zhao and Rezkallah [1] proposed a system parameter to elucidate the effects of inertia and surface tension in

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Corrigendum

Corrigendum to "Simultaneous heat and mass transfer characteristics for wavy fin-and-tube heat exchangers under dehumidifying conditions" [Int. J. Heat Mass Transfer 49 (2006) 132–143]

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Available online 14 June 2006

Unfortunately several printing errors slipped the authors attention during proof reading.

Corrections are as follows:

Page 133: The unit of $h_{d,o}$ should read kg m^{-2} s^{-1}.

Page 133: The unit of all enthalpies should read J kg^{-1}.

Page 135: Left column, Line 15–17 should read: (namely, the energy balance condition, $|\dot{Q}_w - \dot{Q}_a|/\dot{Q}_{avg}$, is less than 0.05, where $\dot{Q}_a$, $\dot{Q}_w$ and $\dot{Q}_{avg}$ are the air-side heat transfer rate, water-side heat transfer rate and average heat transfer rate, respectively).

Page 135: Table 1, The unit of fin thickness, S_p, D_c, P_t and P_l should read m.

Page 141: Eq. (27) should read:

$$j_h = 0.171e^{0.377N} Re_{D_c}^{(-0.0142N-0.478)} \left(\frac{S_p}{D_c}\right)^{(0.00412N-0.0217)} \times \left(\frac{A_o}{A_{p,o}}\right)^{(-0.114N+0.440)} \quad (27)$$

Page 141: Eq. (28) should read:

$$j_m = 0.315e^{-0.441N} Re_{D_c}^{(0.0580N-0.475)} \left(\frac{S_p}{D_c}\right)^{(-0.00471N+0.0216)} \times \left(\frac{A_o}{A_{p,o}}\right)^{(0.00223N+0.223)} \quad (28)$$

Page 141: Eq. (29) should read:

$$\frac{h_{c,o}}{h_{d,o}C_{p,a}} = 0.490e^{0.792N} Re_{D_c}^{(-0.0714N+0.00361)} \left(\frac{S_p}{D_c}\right)^{(0.00867N-0.0425)} \times \left(\frac{A_o}{A_{p,o}}\right)^{(-0.107N+0.203)} \quad (29)$$

Page 142: Conclusions, in topic 2 the sentence should read "Both the heat and mass transfer performances are increased when the fin spacing is reduced."

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Heat transfer characteristics of a spirally coiled, finned-tube heat exchanger under dry-surface conditions

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Author(s): Wongwises S, Naphon P

Source: HEAT TRANSFER ENGINEERING **Volume:** 27 **Issue:** 1 **Pages:** 25-34 **Published:** JAN-FEB 2006

Times Cited: 0 **References:** 19 **Citation Map**

Abstract: In the present study, the experimental and theoretical results of the heat transfer characteristics and performance of a spirally f coiled, finned-tube heat exchanger under sensible cooling conditions are investigated. The test section is a spiral-coil heat exchanger, which consists of a steel shell and a spirally coiled finned-tube unit. The spiral-coil unit consists of six layers of concentric, spirally coiled, finned tubes. Each tube is fabricated by bending a 9.6 mm-diameter straight copper tube into a spiral-coil of four turns. The innermost and outermost diameters of each spiral-coil are 145.0 and 350.4 mm, respectively. Aluminium annular fins with a thickness of 0.6 mm and outer diameter of 28.4 mm are placed helically around the tube. The edge of each fin at its inner diameter is corrugated. Air and water are used as working fluids in the shell side and tube side, respectively. A mathematical model based on mass and energy conservation is developed to simulate the heat transfer characteristics and performance of the heat exchanger. The results obtained from the present model show reasonable agreement with the experimental data.

Document Type: Article

Language: English

KeyWords Plus: TRANSFER COEFFICIENTS; PRESSURE-DROP; LAMINAR-FLOW; COMPACT; PIPES; CONVECTION

Reprint Address: Wongwises, S (reprint author), King Mongkuts Univ Technol, Dept Mech Engn, Thermal Engn & Multiphase Flow Res Lab, FUTURE, Bangkok 10140, Thailand

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Subject Category: Thermodynamics; Engineering, Mechanical; Mechanics

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Author(s): Wongwises S (Wongwises, Somchai), Kamsanam W (Kamsanam, Wason), Wang CC (Wang, Chi-Chuan)

Source: JOURNAL OF THERMOPHYSICS AND HEAT TRANSFER **Volume:** 20 **Issue:** 3 **Pages:** 624-627 **Published:** JUL-SEP 2006

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Document Type: Article

Language: English

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Comparison of drying kinetics of paddy using a pneumatic conveying dryer with and without a cyclone

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Author(s): Kaensup W (Kaensup, Weerachai), Kulwong S (Kulwong, Sittidej), Wongwises S (Wongwises, Somchai)

Source: DRYING TECHNOLOGY **Volume:** 24 **Issue:** 8 **Pages:** 1039-1045 **Published:** 2006

Times Cited: 1 **References:** 11 Citation Map

Abstract: The objective of the present work is to find the possibility of reducing the high initial moisture content of wet paddy using a small-scale, low-cost pneumatic conveying dryer that can be provided for each farming household. The dryer without a cyclone equipped at the exit of the dryer is studied and the data obtained from this system is compared with those obtained previously from the dryer with a cyclone. Parametric effects of the following variables are examined: velocity of drying air from 20 to 30 m/s, feed rate of rough rice from 150 to 350 kg/h, and drying air temperature from 35 to 70 degrees C. From the experimental results it is found that the drying process with and without a cyclone are able to lead to very rapid drying without any grain quality problems such as cracks in the rice kernel. For the same experimental conditions, the cyclone-equipped dryer gives around 1% higher decrease of moisture content, 2 degrees C higher average surface temperature of paddy, 3-4% higher average percentage of head rice yield, and 2 kg/h higher average evaporation rate. However, the energy consumption per evaporated mass of water is 20-30% lower than the non-cyclone-equipped dryer.

Document Type: Article

Language: English

Author Keywords: drying; hot air; moisture content; paddy; pneumatic conveying dryer

KeyWords Plus: MOISTURE-CONTENT; TEMPERATURE; QUALITY; RICE

Reprint Address: Wongwises, S (reprint author), King Mongkuts Univ Technol Thonburi, Dept Mech Engn, Bangkok 10140, Thailand

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Thermal performance of a spirally coiled finned tube heat exchanger under wet-surface conditions

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Author(s): Wongwises S, Naphon P

Source: JOURNAL OF MECHANICAL SCIENCE AND TECHNOLOGY **Volume:** 20 **Issue:** 2 **Pages:** 212-226 **Published:** FEB 2006

Times Cited: 0 **References:** 21 Citation Map

Abstract: This paper is a continuation of the authors' previous work on spiral coil heat exchangers. In the present study, the heat transfer characteristics and the performance of a spirally coiled finned tube heat exchanger under wet-surface conditions are theoretically and experimentally investigated. The test section is a spiral-coil heat exchanger which consists of a steel shell and a spirally coiled tube unit. The spiral-coil unit consists of six layers of concentric spirally coiled finned tubes. Each tube is fabricated by bending a 9.6 mm diameter straight copper tube into a spiral-coil of four turns. The innermost and outermost diameters of each spiral-coil are 145.0 and 350.4 mm, respectively. Aluminium crimped spiral fins with thickness of 0.6 mm and outer diameter of 28.4 mm are placed around the tube. The edge of fin at the inner diameter is corrugated. Air and water are used as working fluids in shell side and tube side, respectively. The experiments are done under dehumidifying conditions. A mathematical model based on the conservation of mass and energy is developed to simulate the flow and heat transfer characteristics of working fluids flowing through the heat exchanger. The results obtained from the present model show reasonable agreement with the experimental data.

Document Type: Article

Language: English

KeyWords Plus: TRANSFER COEFFICIENTS; PRESSURE-DROP; LAMINAR-FLOW; COMPACT; PIPES; CONVECTION

Reprint Address: Wongwises, S (reprint author), King Mongkuts Univ Technol Thonburi, Dept Mech Engn, Fluid Mech Thermal Engn & Multiphase Flow Res Lab, FUTURE, Bangkok 10140, Thailand

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A small-scale pneumatic conveying dryer of rough rice

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Author(s): Kaensup W, Kulwong S, Wongwises S

Source: DRYING TECHNOLOGY **Volume:** 24 **Issue:** 1 **Pages:** 105-113 **Published:** 2006

Times Cited: 2 **References:** 10 **Citation Map**

Abstract: This article studies the possibility of reducing the high initial moisture content of wet rough rice using a small-scale low-cost pneumatic conveying dryer as a first stage dryer. The parameters investigated are final moisture content, surface temperature of rough rice, head rice yield, drying rate, power consumption per unit mass of evaporated water, and physical characteristics of rice. Parametric effects of the following variables are examined: velocity of drying air from 20 to 30 m/s, feed rate of rough rice from 150 to 350 kg/h, initial moisture content from 22 to 26% (wet basis), and drying air temperature from 35 to 70 degrees C. From the experimental results, it is found that this drying method can be used for fresh rough rice with an initial moisture content of over 24% (wet basis). The drying process is able to lead to very rapid drying without any grain quality problems such as cracks in the rice kernel. The moisture content can be reduced to approximately 18% (wet basis) or about 5-6% of the initial moisture content within 3-4 s. The optimal drying air temperature is in the range of 50 to 60 degrees C. A comparison of pneumatic conveying drying data obtained from the present study with fluidized bed drying data reported in the open literature is also discussed.

Document Type: Article

Language: English

Author Keywords: drying; paddy; rough rice; pneumatic conveying dryer

KeyWords Plus: MOISTURE-CONTENT; PADDY; TEMPERATURE; QUALITY

Reprint Address: Wongwises, S (reprint author), King Mongkuts Univ Technol Thonburi, Dept Mech Engn, 91 Pracha Uthit Rd, Bangkok 10140, Thailand

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Simultaneous heat and mass transfer characteristics for wavy fin-and-tube heat exchangers under dehumidifying conditions

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Abstract

The present study proposes a new reduction method to calculate the heat and mass transfer characteristics of the wavy fin-and-tube heat exchangers under dehumidifying conditions. For fully wet conditions, the sensible heat transfer and mass transfer characteristics are relatively insensitive to the inlet relative humidity. The heat and mass transfer performances show appreciable influence of fin spacing at 1-row configuration. Both the heat and mass transfer performances increase when the fin spacing is reduced. However, the difference becomes less noticeable when $Re_{Dc} > 3000$. For 1-row configuration, larger wave height shows much larger difference with the fin spacing. However, the effect of inlet conditions and geometrical parameters on the heat and mass performance becomes less significant with the rise of number of tube rows. Test results show that the heat and mass transfer analogy is roughly applicable (the ratios of $h_{c,o}/h_{d,o}C_{p,a}$ are in the range 0.6–1.1, and is insensitive to change of fin spacing). The correlations are proposed to describe the heat and mass transfer characteristics. These correlations can describe 94.19% of the j_h factors within 15% and 83.72% of the j_m factors within 15%. Correspondingly, 93.02% of the ratios of $h_{c,o}/h_{d,o}C_{p,a}$ are predicted by the proposed correlation within 15%.
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Keywords: Wavy fin-and-tube heat exchangers; Dehumidifying; Heat transfer; Mass transfer

1. Introduction

The plate fin-and-tube heat exchangers are the most widely used heat exchangers in association with the application of air-conditioning and refrigeration systems. The heat exchangers can be used for condensers where surface is dry and evaporators in which surface may be wet provided the fin temperature is below the dew point temperature. In regard to the wet surface, simultaneous heat and mass transfer occurs along the fin surfaces. In general, the complexity of the moist air flow pattern across the fin-and-tube heat exchangers under dehumidifying conditions makes the theoretical

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Carbon Monoxide Emission and Concentration Models for Chiang Mai Urban Area

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ABSTRACT

An emission inventory containing emissions from traffic and other sources was complied. Based on the analysis, Carbon Monoxide (CO) emissions from traffic play a very important role in CO levels in Chiang Mai area. Analysis showed that CO emissions from traffic during rush hours contributed approximately 90% of total CO emissions. Regional Atmospheric Modeling System (RAMS) was applied to simulate wind fields and temperatures in the Chiang Mai area, and eight cases were selected to study annual variations in wind fields and temperatures. Model results can reflect major features of wind fields and diurnal variations in temperatures. For evaluating the model performance, model results were compared with observed wind speed, wind direction and temperature, which were monitored at a meteorological tower. Comparison showed that model results are in good agreement with observations, and the model captured many of the observed features. HYbrid Particle And Concentration Transport model (HYPACT) was used to simulate CO concentration in the Chiang Mai area. Model results generally agree well with observed CO concentrations at the air quality monitoring stations, and can explain observed CO diurnal variations.

Key words: carbon monoxide, emission, concentration, Chiang Mai, RAMS, HYPACT

doi: 10.1007/s00376-006-0901-9

1. Introduction

Carbon Monoxide (CO) is a highly toxic gas, which is considered a dangerous asphyxiant. Combined with haemoglobin of the blood it reduces the blood's ability to carry oxygen to cell tissues; high CO mixing ratio can directly affect human health. The oxidation of CO initiates photochemical reactions, which result in Ozone (O_3) production on a regional scale (Novelli et al., 1998). In cities, almost all of the CO is anthropogenic due to vehicle emission and fossil fuel combustion. Natural sources, such as forest fire and biomass burning, also produce huge quantities of CO. Pochanart (2003) studied surface CO variations from measurements during 1997–2000 in rural Thailand. The CO mixing ratios in Thailand show a strong seasonal variation with a maximum in the late dry season (February–March) and a minimum in the mid-wet season (July–August). In this study CO emission and dispersion on a local scale in Chiang Mai (18°78′N, 98°98′E, 312 meters above sea level) are studied. Chiang Mai is an important city for the regional administration, business, education, medical and is well known as a tourist and cultural city. Due to economic growth, Chiang Mai is facing environmental problems, especially the air pollution problem. Because of traffic congestion most vehicles emit many types of toxic gasses. Pollutants from the internal combustion process consist of Carbon Monoxide, Sulfur Dioxide, Nitrogen Dioxide, Hydrocarbons, and Lead etc. This study concentrated on CO which was emitted from traffic, industrial processes, airport, railway station, forest fire, fuel consumption and open burning. There are only 2 ambient air pollution monitoring stations, one in an urban area and the other in a suburban area, which do not cover the whole study area.

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Evaporation heat transfer and pressure drop of HFC-134a in a helically coiled concentric tube-in-tube heat exchanger

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Abstract

The two-phase heat transfer coefficient and pressure drop of HFC-134a during evaporation inside a smooth helically coiled concentric tube-in-tube heat exchanger are experimentally investigated. The test section is a 5.786-m long helically coiled tube with refrigerant flowing in the inner tube and heating water flowing in the annulus. The inner tube is made from copper tubing of 9.52 mm outer diameter and 7.2 mm inner diameter. The heat exchanger is fabricated by bending a straight copper tube into a spiral coil. The diameter of coil is 305 mm. The test run are done at average saturated evaporating temperatures ranging between 10 and 20 °C. The mass fluxes are between 400 and 800 kg m^{-2} s^{-1} and the heat fluxes are between 5 and 10 kW m^{-2}. The inlet quality of the refrigerant in the test section is calculated using the temperature and pressure obtained from the experiment. The pressure drop across the test section is directly measured by a differential pressure transducer. The effects of heat flux, mass flux and, evaporation temperature on the heat transfer coefficients and pressure drop are also discussed. The results from the present experiment are compared with those obtained from the straight tube reported in the literature. New correlations for the convection heat transfer coefficient and pressure drop are proposed for practical applications.
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Keywords: Two-phase; Evaporation; Heat transfer coefficient; Pressure drop; Refrigerant; Helically coiled tube

1. Introduction

Results from many researches show that the ozone layer is being depleted. The general consensus for the cause of this event is that the free chlorine radicals removes ozone from the atmosphere and later the chlorine atom is continued to convert more ozone to oxygen. The presence of chlorine in the stratosphere is the result of migration of chlorine-containing chemicals. The chlorofluorocarbons (CFCs) is a large class of chemicals which behaves in this manner. These chemicals have many unusual properties for example, nonflammability, low toxicity, and material compatibility that have led to their common widespread use, both consumers and industries around the world as refrigerants, solvent, and blowing agents for foams. Since the depletion of the earth's ozone layer has been discovered, many corporations have been forced to find alternative chemicals to CFCs. Because the thermophysical properties of HFC-134a are very similar to those of CFC-12. Refrigerant HFC-134a is receiving the supporting from the refrigerant and air-conditioning industry as a potential replacement for CFC-12. However, even the difference in properties between both refrigerants is small but it may result in significant differences in the overall system performance. Therefore, the properties of HFC-134a should be studied in detail before it is applied.

Heat transfer and pressure drop characteristics of refrigerants have been studied by a large number of researchers, both experimentally and analytically, mostly in a horizontal straight tube. The study of the heat transfer and pressure drop inside helicoidal tube has received comparatively little attention in the literature.

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Experimental investigation of hydrocarbon mixtures to replace HFC-134a in an automotive air conditioning system

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Abstract

This paper presents an experimental study on the application of hydrocarbon mixtures to replace HFC-134a in automotive air conditioners. The hydrocarbons investigated are propane (R290), butane (R600) and isobutane (R600a). The measured data are obtained from an automotive air conditioning test facility utilizing HFC-134a as the refrigerant. The air conditioner, with a capacity of 3.5 kW driven by a Diesel engine, is charged and tested with four different ratios of hydrocarbon mixtures. The experiments are conducted at the same surrounding conditions. The temperature and pressure of the refrigerant at every major position in the refrigerant loop, the temperature, flow rate and humidity of air, torque and engine speed are recorded and analyzed. The parameters investigated are the refrigeration capacity, the compressor power and the coefficient of performance (COP). The results show that propane/butane/isobutane: 50%/40%/10% is the most appropriate alternative refrigerant to replace HFC-134a, having the best performance of all the hydrocarbon mixtures investigated.
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Keywords: Automotive air conditioner; HFC-134a; Propane; Butane; Isobutane; Hydrocarbon mixture

1. Introduction

Stratospheric ozone absorbs the sun's high energy ultraviolet rays and protects both humans and other living things from exposure to ultraviolet radiation. Results from many researches show that this ozone layer is being depleted. The general consensus for the cause of this event is that free chlorine radicals remove ozone from the atmosphere, and later, chlorine atoms continue to convert more ozone to oxygen. The presence of chlorine in the stratosphere is the result of the migration of chlorine containing chemicals. The chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are a large class of chemicals that behave in this

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Flow pattern, pressure drop and void fraction of two-phase gas–liquid flow in an inclined narrow annular channel

Somchai Wongwises *, Manop Pipathattakul

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Abstract

Two-phase flow pattern, pressure drop and void fraction in horizontal and inclined upward air–water two-phase flow in a mini-gap annular channel are experimentally studied. A concentric annular test section at the length of 880 mm with an outer diameter of 12.5 mm and inner diameter of 8 mm is used in the experiments. The flow phenomena, which are plug flow, slug flow, annular flow, annular/slug flow, bubbly/plug flow, bubbly/slug–plug flow, churn flow, dispersed bubbly flow and slug/bubbly flow, are observed and recorded by high-speed camera. A slug flow pattern is found only in the horizontal channel while slug/bubbly flow patterns are observed only in inclined channels. When the inclination angle is increased, the onset of transition from the plug flow region to the slug flow region (for the horizontal channel) and from the plug flow region to slug/bubbly flow region (for inclined channels) shift to a lower value of superficial air velocity. Small shifts are found for the transition line between the dispersed bubbly flow and the bubbly/plug flow, the bubbly/plug flow and the bubbly/slug–plug flow, and the bubbly/plug flow and the plug flow. The rest of the transition lines shift to a higher value of superficial air velocity. Considering the effect of flow pattern on the pressure drop in the horizontal tube at low liquid velocity, the occurrence of slug flow stops the rise of pressure drop for a short while, before rising again after the air velocity has increased. However, the pressure does not rise abruptly in the tubes with $\theta = 30°$ and 60° when the slug/bubbly flow occurs. At low gas and liquid velocity, the pressure drop increases, when the inclination angles changes from horizontal to 30° and 60°. Void fraction increases with increasing gas velocity and decreases with increasing liquid velocity. After increasing the inclination angle from horizontal to $\theta = 30°$ and 60°, the void fraction appears to be similar, with a decreasing trend when the inclination angle increases.
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Keywords: Two-phase flow; Mini-channel; Narrow annular channel; Flow pattern; Pressure drop; Void fraction

1. Introduction

Two-phase gas–liquid flow through a confined gap is encountered in several engineering applications including boiling behavior in minichannels, cooling systems of various types of equipment such as high performance microelectronics, supercomputers, high-powered lasers, medical devices, high heat-flux compact heat exchangers in spacecraft and satellites etc. It can be expected that the restriction of the bubble space in the minichannel is the cause of the differences in the two-phase flow characteristics from those in conventional channel geometries. This may also affect heat-mass transfer characteristics during the change of phase.

It is not possible to understand the two-phase flow phenomena without a clear understanding of the flow patterns encountered. It is expected that the flow patterns will influence the two-phase pressure drop, holdup, system stability, exchange rates of momentum, heat and mass during the phase-change heat transfer processes. The ability to accurately predict the type of flow is necessary before relevant calculation techniques can be developed.

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Thermal Performance of a Spirally Coiled Finned Tube Heat Exchanger Under Wet-Surface Conditions

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This paper is a continuation of the authors' previous work on spiral coil heat exchangers. In the present study, the heat transfer characteristics and the performance of a spirally coiled finned tube heat exchanger under wet-surface conditions are theoretically and experimentally investigated. The test section is a spiral-coil heat exchanger which consists of a steel shell and a spirally coiled tube unit. The spiral-coil unit consists of six layers of concentric spirally coiled finned tubes. Each tube is fabricated by bending a 9.6 mm diameter straight copper tube into a spiral-coil of four turns. The innermost and outermost diameters of each spiral-coil are 145.0 and 350.4 mm, respectively. Aluminium crimped spiral fins with thickness of 0.6 mm and outer diameter of 28.4 mm are placed around the tube. The edge of fin at the inner diameter is corrugated. Air and water are used as working fluids in shell side and tube side, respectively. The experiments are done under dehumidifying conditions. A mathematical model based on the conservation of mass and energy is developed to simulate the flow and heat transfer characteristics of working fluids flowing through the heat exchanger. The results obtained from the present model show reasonable agreement with the experimental data.

Nomenclature

A : Area
C_p : Specific heat, kJ/(kg ℃)
D : Tube diameter, m
De : Dean number
E_h : Enthalpy effectiveness
E_w : Umidity effectiveness
G : Mass flux, kg/(m^2 s)
h : Heat transfer coefficient, W/(m^2 ℃)
h_T : Combined conductance through tube surface and water inside tube, W/(m^2 ℃)
h_D : Mass transfer coefficient, kg/(m^2 s)
i : Enthalpy, kJ/kg
i_{fg} : Enthalpy of condensation, kJ/kg
J : Colburn j factor
j : Number of segments
k : Thermal conductivity, W/(m ℃)
Le : Lewis number
M : Mass flow rate per coil, kg/s
m : Total mass flow rate, kg/s
n : Number of coil turns
Nu : Nusselt number
Pr : Prandtl number
Q : Heat transfer rate, W
r : Tube radius, m
R_{min} : Minimum coil radius, m
Re : Reynolds number
R_n : Average radius of curvature, m
T : Temperature, ℃
U : Overall heat transfer coefficient, W/(m^2 ℃)
δ : Thickness, m
α : Rate of radius change per radian, m/radian
ω : Humidity ratio

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Condensation heat transfer and pressure drop of HFC-134a in a helically coiled concentric tube-in-tube heat exchanger

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Abstract

The two-phase heat transfer coefficient and pressure drop of pure HFC-134a condensing inside a smooth helically coiled concentric tube-in-tube heat exchanger are experimentally investigated. The test section is a 5.786 m long helically coiled double tube with refrigerant flowing in the inner tube and cooling water flowing in the annulus. The inner tube is made from smooth copper tubing of 9.52 mm outer diameter and 8.3 mm inner diameter. The outer tube is made from smooth copper tubing of 23.2 mm outer diameter and 21.2 mm inner diameter. The heat exchanger is fabricated by bending a straight copper double-concentric tube into a helical coil of six turns. The diameter of coil is 305 mm. The pitch of coil is 35 mm. The test runs are done at average saturation condensing temperatures ranging between 40 and 50 °C. The mass fluxes are between 400 and 800 kg m^{-2} s^{-1} and the heat fluxes are between 5 and 10 kW m^{-2}. The pressure drop across the test section is directly measured by a differential pressure transducer. The quality of the refrigerant in the test section is calculated using the temperature and pressure obtained from the experiment. The average heat transfer coefficient of the refrigerant is determined by applying an energy balance based on the energy rejected from the test section. The effects of heat flux, mass flux and, condensation temperature on the heat transfer coefficients and pressure drop are also discussed. It is found that the percentage increase of the average heat transfer coefficient and the pressure drop of the helically coiled concentric tube-in-tube heat exchanger, compared with that of the straight tube-in-tube heat exchanger, are in the range of 33–53% and 29–46%, respectively. New correlations for the condensation heat transfer coefficient and pressure drop are proposed for practical applications.
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Keywords: Two-phase flow; Condensation; Heat transfer coefficient; Pressure drop; Refrigerant; Helically coiled tube

1. Introduction

The presence of chlorine in the stratosphere is the result of migration of chlorine-containing chemicals. The chlorofluorocarbons (CFCs) are a large class of chemicals which behaves in this manner. These chemicals have many unusual properties for example, nonflammability, low toxicity, and material compatibility that have led to their common widespread use, both consumers and industries around the world as refrigerants, solvent, and blowing agents for foams. Since the depletion of the earth's ozone layer has been discovered, many corporations have been forced to find alternative chemicals to CFCs. Because the thermophysical properties of HFC-134a are very similar to those of CFC-12. Refrigerant HFC-134a is receiving the supporting from the refrigerant and air-conditioning industry as a potential replacement for CFC-12. However, even the difference in properties between both refrigerants is small but it may result in significant differences in the overall system performance. Therefore, the properties of HFC-134a should be studied in detail before it is applied.

Heat transfer and pressure drop characteristics of refrigerants have been studied by a large number of researchers, both experimentally and analytically, mostly in a horizontal straight tube. The study of the heat transfer and pressure drop inside helicoidal tube has received comparatively little attention in the literature.

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Effect of throat diameters of the ejector on the performance of the refrigeration cycle using a two-phase ejector as an expansion device

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Abstract

This paper is a part in a series that reports on the experimental study of the performance of the two-phase ejector expansion refrigeration cycle. In the present study, three two-phase ejectors are used as an expansion device in the refrigeration cycle. The effects of throat diameter of the motive nozzle, on the coefficient of performance, primary mass flow rate of the refrigerant, secondary mass flow rate of the refrigerant, recirculation ratio, average evaporator pressure, compressor pressure ratio, discharge temperature and cooling capacity, which have never before appeared in open literature, are presented. The effects of the heat sink and heat source temperatures on the system performance are also discussed.
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Keywords: Refrigeration; Ejector system; Experiment; Performance; Parameter; Geometry; Nozzle

Effets des diamètres des tuyères des éjecteurs sur la performance du cycle frigorifique à l'aide d'un éjecteur diphasique utilisé comme dispositif de détente

Mots clés : Froid ; Système à éjecteur ; Expérimentation ; Performance ; Paramètre ; Géométrie ; Tuyère

1. Introduction

Throttling loss is one of the thermodynamic losses in a conventional vapor compression refrigeration cycle. In order to reduce this loss, various devices and techniques have been attempted to use instead of the conventional devices. Ejector is a device that uses a high-pressure fluid

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Performance of a twin power piston low temperature differential Stirling engine powered by a solar simulator

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Abstract

This paper provides an experimental investigation on the performance of a low-temperature differential Stirling engine. In this study, a twin power piston, gamma-configuration, low-temperature differential Stirling engine is tested with non-pressurized air by using a solar simulator as a heat source. The engine testing is performed with four different simulated solar intensities. Variations of engine torque, shaft power and brake thermal efficiency with engine speed and engine performance at various heat inputs are presented. The Beale number, obtained from the testing of the engine, is also investigated. The results indicate that at the maximum simulated solar intensity of 7145 W/m^2, or heat input of 261.9 J/s, with a heater temperature of 436 K, the engine produces a maximum torque of 0.352 N m at 23.8 rpm, a maximum shaft power of 1.69 W at 52.1 rpm, and a maximum brake thermal efficiency of 0.645% at 52.1 rpm, approximately.
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Keywords: Stirling engine; Hot-air engine; Solar-powered heat engine; Solar simulator

1. Introduction

The low temperature differential (LTD) Stirling engine is a type of Stirling engine that can operate with a low temperature heat source. There are many low temperature heat sources available including solar energy. The LTD Stirling engine then provides the possibility of direct conversion of solar energy to mechanical work.

A LTD Stirling engine can be run with small temperature difference between the hot and cold ends of the displacer cylinder (Rizzo, 1997). LTD Stirling engines provide value as demonstration units, but they immediately become of interest when considering the possibility of power generation from many low-temperature waste heat sources in which the temperature is less than 100 °C (Van Arsdell, 2001). Some characteristics of the LTD Stirling engine are as follow (Rizzo, 1997):

(1) Displacer to power piston swept volumes ratio is large.
(2) Diameters of displacer cylinder and displacer are large.
(3) Displacer length is short.
(4) Effective heat transfer surfaces on both end plates of the displacer cylinder are large.
(5) Displacer stroke is small.
(6) Dwell period at the end of the displacer stroke is rather longer than the normal Stirling engine.
(7) Operating speed is low.

The LTD Stirling engine has been studied by many researchers. Many studies in the field of LTD Stirling

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Performance of low-temperature differential Stirling engines

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Abstract

In this paper, two single-acting, twin power piston and four power pistons, gamma-configuration, low-temperature differential Stirling engine are designed and constructed. The engine performance is tested with air at atmospheric pressure by using a gas burner as a heat source. The engine is tested with various heat inputs. Variations of engine torque, shaft power and brake thermal efficiency at various heat inputs with engine speed and engine performance are presented. The Beale number obtained from testing of the engines is also investigated. The results indicate that, for twin power piston engine, at a maximum actual heat input of 2355 J/s with a heater temperature of 589 K, the engine produces a maximum torque of 1.222 N m at 67.7 rpm, a maximum shaft power of 11.8 W at 133 rpm, and a maximum brake thermal efficiency of 0.494% at 133 rpm, approximately. For the four power pistons engine, the results indicate that at the maximum actual heat input of 4041 J/s with the heater temperature of 771 K, the engine produces a maximum torque of 10.55 N m at 28.5 rpm, a maximum shaft power of 32.7 W at 42.1 rpm, and a maximum brake thermal efficiency of 0.809% at 42.1 rpm, approximately.
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Keywords: Stirling engine; Hot-air engine; Regenerative heat engine

1. Introduction

The Stirling engine is a simple type of external-combustion engine. The Stirling engine was the first invented regenerative cycle heat engine. Robert Stirling patented the Stirling

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A critical review of convective heat transfer of nanofluids

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Abstract

A nanofluid is a suspension of ultrafine particles in a conventional base fluid which tremendously enhances the heat transfer characteristics of the original fluid. Furthermore, nanofluids are expected to be ideally suited in practical applications as their use incurs little or no penalty in pressure drop because the nanoparticles are ultrafine, therefore, appearing to behave more like a single-phase fluid than a solid–liquid mixture. About a decade ago, several published articles focused on measuring and determining the effective thermal conductivity of nanofluids, some also evaluated the effective viscosity. There are only a few published articles on deriving the forced convective heat transfer of nanofluids. The purpose of this article is to summarize the published subjects respect to the forced convective heat transfer of the nanofluids both of experimental and numerical investigation.
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Keywords: Nanofluids; Ultrafine; Effective thermal conductivity; Effective viscosity; Forced convective heat transfer

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