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Effect of Microchannels Dimensions on Flow Boiling Using R134a

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ABSTRACT

In this study, we look at the effects of microchannel dimensions of tooling such as channel width and depth on the flow boiling aspects of refrigerant R134a, an issue that has received growing academic interest in the context of small scale, high-performance thermal management of electronics, aerospace and automotive system. Due to their increased surface-area-volume ratios, microchannels provide better performance in terms of heat-dissipation and thus, a large amount of experimental data has been undertaken correspondingly; by using an engineered experimental system our research endeavors in constructing better heat-extraction coolant data sets including the heat-transfer coefficient (HTC), critical heat flux (CHF), pressure drop, and flow-regime dynamics in the boiling cycle. The experimental evidence shows that channels of reduced diameter improve nucleate boiling, due to the large interfacial surface and stable and enhanced nucleation of bubbles, but it increases the pressure losses through vapor barrier and flow disturbances. Conversely, deeper channels enhance CHF by increasing wetted area and flow state stabilization, but at the cost of the possibility of unreasonable addendum to hydraulic resistance with excessive ones. It has been observed by flow-regime transition relating to bubbly flow to annular flow based on geometry and mass-flux conditions. This fact literally demonstrates that balancing the width and depth in microchannel design is an important issue when designing such a microchannel to perform very well in boiling. Ultimately, the research will provide us with good experimental results and theoretical information, which we can utilize to develop good R134a microchannel heat sinks that will assist in sweating away overheating of high-performance systems.

1. Introduction

1.1. Importance of Flow Boiling in Microchannels

Microchannel flow boiling is also a rather neat technology in regards to science experiments on heat transfer; it can make small systems so much more efficient. It has shorter heating times compared to the past techniques hence it can be used effectively to cool out various appliances such as electronics, vehicles and airplanes. At a required level of high thermal management, microchannel heat sinks are capable of absorbing heat in the range of 10 MW/mm^3.

Flow boiling maintains the temperature of the wall rather evenly distributed in each cell and increases the heat transfer coefficient of the same geometry. This is because the behavior of flow interacts Black at the phase changes at the microscale. The research has proved that flow boiling enables higher transfer of latent heat during phase change than single-phase flow therefore making the entire process of heat exchange more effective in the system.

However, a number of issues still remain, especially in terms of the rate of mass flow; under mass flow rates may contribute to super heating, and early dry out can occur along with supporting walls. The current interest in the

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modification of channel geometries and surface characteristics to resolve these problems has led to the successful stabilization of bubble pockets and boiling waves.

Selecting the refrigerants, e.g. R134a is important in order to customize microchannel configurations to applications and achieve maximum thermal efficiency. Other scientists are investigating geometric refinement, pinning approaches and new surface treatment to enhance the performance of heat transfer in microchannels in a variety of operating regimes. Nevertheless, the fluid dynamics of such small channels is not successfully characterized, and the behavior of flowing is highly influenced by the size of the channels and the characteristics of the material. The emergence of new microchannel flow-boiling technology will be a potentially major alteration to electronics, affordable cooling and refrigeration. Therefore, to make most of the microchannel tech you really want a combination of both fluid dynamics, material science, and thermodynamics, [1], [2] and [3].

1.2. Role of Refrigerant R134a in Heat Transfer Applications

The popularity in our HVAC course is because R134a is a good thermal material and is environmentally friendly. It has a high level of conductivity and specific heat thus enhances better heat transfer processes during phase changes, particularly with microchannel set up. It essentially possesses almost zero global warming attributes, thus is good as a replacement to the aged coolants. With that said, it does vary in response to mass and heat flux, whereby constriction of the channels increases the ratio of surface to volume enhancing the nucleation and the bubble expansion, becoming solid convective heat transfer processes.

The trick is in more of the higher the mass flux, the better R134a can change into slug and/or annular flow exposing more surface area and potentially pull a better part the heat off hot surfaces. To calculate pressure drop in microchannels, you must have a real understanding of the behavior of R134a under such circumstances. When you opposite it to R600a, you will realize that R600a can surpass R134a with respect to the heat transfer coefficient of the local temperature in some conditions, however, both coolants basically have similar characteristics in most of the HVAC applications.

It becomes very cumbersome to boil R134a in small microchannels--then it starts to nucleate boil, then transitions to convective, and the effect of this goes with the size of the channel. It is still attempting to optimize the microchannel designs in order to eliminate such dead spots and dry-outs, and new surface optimizations and channel geometries are being tested to improve thermodynamic performance using refrigerants such as R134a as well as considering the environmental impact in its entire life cycle, [4] and [5].

2. Literature Review

2.1. Overview of Previous Studies on Flow Boiling

Boiling microchannels has gained significant interest due to their ability to draw high heat transfer rates and allow homogeneous cooling of walls. Researchers have been studying boiling processes, flow configurations, and channel geometry to improve nucleation processes and remove flow instability issues. A critical literature review in the flow boiling in microchannels depicts a series of gaps in extant literature most especially the effects of microchannel designation in relation to heat transfer indicates and heat flux curiosity. Other recent experimental studies by Peng and Wang have revealed specific non-coherence in the boiling behavior in microchannels over conventional tubes especially in respect of lack of partial nucleate boiling in subcooled conditions in microchannels. These observations bring to focus the idea that microscale boiling pattern deviate greatly to the unclassical macroscopic pattern.

The comparison of additional literature would reveal the existence of an extreme correlation between the fluid characteristics and flow regimes in microchannel boiling. Through a relevant submission by Kew and Cornwell, it was disclosed that predictive correlations optimized to refrigerant R141b become less faithful below a specified hydraulic diameter and hence the need to have tailored correlations based on the exquisite geometry of the geometry.

Surface topography and coating are also factors that have been considered as a way of augmenting boiling performance. The wettability and bubble dynamics can be changed through use of proper surface treatment leading to best thermal transport. However, the best selection of coating materials, their microstructural properties, the optimal thickness needed to obtain the maximum performance are a question of pure research, as well as a question, which should be discussed with respect to systematic research.

In addition, current research is aiming at the control of mini-channels flow involving progressively multiphase fluids. The study by Harirchian relates the consistency of the thermal and mass exchange in different forms of stratification whereby cryogenic fluids like FC-77 are used. It is believed that the evolution into the more sophisticated methods of measuring and visualization will enable us to indeed know better the processes of microscale convection, and to improve predictive models to use in the engineering practices, [1], [2], [3], [6] and [7].

2.2. Effects of Microchannel Geometry on Boiling Performance

Microchannel structure has a strong effect on the boiling effects; the change in channel sizes also alter the heat transfer, flow rates. It has been shown that the surface volume ratio that intensifies in tandem with the decrease in the channel width and depth outright improves the heat transfer activity and sustain a transformation in the basic system that dictates the liquid vapor interaction.

Of special interest in relation to the nucleate boiling is the aspect ratio of the channel. Higher height-width ratio encourages the creation of a greater amount of the vapor bubbles that is favorable in cooling use within miniature refrigeration systems. At the microscale, experimental results show that the greater the mass flux directed towards the channel is, the greater the heat transfer coefficient is. Moreover, an increase in the velocity of pumping the fluid and a decrease in the channel dimension causes the heat exchange to be taken to a greater level since more mixing at the liquid-vapour interface is induced.

However, narrow channels become wobbly. Varying forms would cause different instabilities disrupting the flow. With the addition of waves or other structures, the slug flow is smoother and there are improved heat exchanges with an added straight channel. On the other hand, large channels and large bubbles put the probability of dry-out high, whereas growing channels keep a liquid immobile even with a lot of heat flowing.

When the bubbles go out of a bubbly regime to a slug or annular regime, the overall efficiency changes of the entire system particularly within the evaporation cycles. Geometry also uses character tweaks to change the way the bubbles behave long vapor bubbles end up consuming more thermal energy than isolated bubbles.

The boiling parameters, which are crucial in the design of microchannels, such as heat flux critical (CHF) and the associated heat-transfer parameters are still under research. Thermal optimization of high-performance systems requires special experimental work and application of high precision materials, [8], [9], [10] and [11].

3. Theoretical Framework

3.1. Governing Equations for Flow Boiling

The flow boiling studies in microchannels are conditional upon broad insight in the basic equations of the related thermal and hydrodynamics. Major equations are the continuity equation, momentum equation (Navier-Stokes), and energy conservation equation and are a collective description of the behavior of fluids and heat transfer.

Continuity equation: The equation of mass conservation in a microchannel is the continuity equation:

$$\partial\rho/\partial t + \nabla\cdot(\rho u) = 0 \quad (1)$$

In this case, the symbols ρ denote fluid density, u stands as the velocity vector and t is the time. It states that change in any mass quantity of any control volume has to be counterbalanced by net flow across its limits.

Navier-Stokes equations define momentum conservation that may be simplified in the case of laminar flow under low Reynolds numbers. The balance of momentum and viscous effects as well as gradient of pressure:

$$\rho(\partial u/\partial t + u\cdot\nabla u) = -\nabla P + \mu\nabla^2 u \quad (2)$$

P here represents pressure and μ represents dynamic viscosity. Other terms can be used to include the effects of phase changes and surface tension at mini scales during flow boiling.

Energy conservation is concerned with heat transfer in passing stationary between a liquid and a vapor:

$$\rho Cp(\partial T/\partial t + u\cdot\nabla T) = k\nabla^2 T + \dot{q} \quad (3)$$

Cp in the given equation is the specific heat capacity, T stands for the temperature, k is the thermal conductivity and q years is the ratio of heat generated or absorbed internally. The current calculation explains changes in temperature that can be explained by the conduction, convection, and changes of phase.

The mathematical analysis of the two-phase flow dynamics in microchannels is an important task, due to the complexity of manipulation of canonical heat-transfer coefficients, characteristics of fluid properties, and flow regimes that are predominant when acoustic systems operate. Specifically, one of the studies describes microchannel boiling and generalizes the experimental correlations to surround the impacts of the variables including mass flux, heat flux, saturation temperature, and hydraulic diameter. Another such model is the superposition model of saturated boiling proposed by Liu and his colleagues that considers the microchannel flow characteristics. Then there are such practitioners as Thome et al., who divided the heat transfer into three regions: heat transfer of the heating surfaces, the film transport, and the vapor blankets, which assists in obtaining better predictions of the situation under varying circumstances. The use of pressure drops is also very critical in estimating the performance of a channel when boiling. A researcher using the Darcy Weisbach factor or variations thereof typically estimates viscous losses and losses due to a liquid liquid-vapor interaction. In the future, we will require models which combine the equation of control with experimental data to reduce the number of trials in real world applications, [1], [4], [12] and [13].

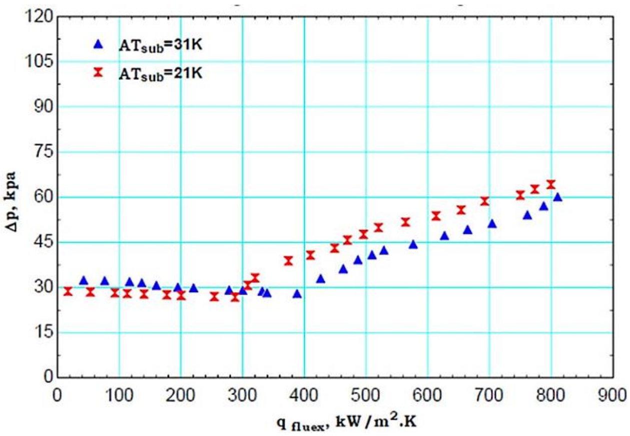

Figure 1. The variation with heat flux of experimental pressure drop versus three inlets of mass fluxes at 1700 kg/m^2.s in subcooled temperature, [1].

3.2. Boiling Heat Transfer Mechanisms

Transfers in the heating of the microchannel are to a certain extent complicated, and on small scale, they are completely affected by the fluid dynamics. When flow boiling takes place, there are three primary forms of heat transfer where each has distinct peculiarities, namely, nucleate, convectional and film boiling.

In microchannels, it can actually be the primary thing in nucleate boiling particularly when quality of the vapor is poor. Fundamentally, the vapor bubbles only burst and expand on the hot walls. Once large enough they released to the bulk fluid that assists in the heat exchange since the flesh of the bubbles is in contact with more of the hot liquid and the colder liquid. I discovered that at low, near zero levels of mass flux when the vapor quality becomes even below 0.4 plugs along with the mass flux, nucleate boiling provides the largest contribution to desirable heat transfer. In essence, the greater mass flow the higher the volume and strength of the bubbles, thus, increasing the heat transfer coefficient.

As the quality of the vapor increases, the conduction boiling prevails. The liquid and the vapor phases further proceed to internalize each other in the channel and produce a characteristic flow structure known as stratified or annular. These indicate in the case of a high mass flux and forced convection comes in, along with the action of the nucleate boiling bubble. Nucleate boiling is thought to increase the ratio of the local heat transfer with high quality, but depending on the convectional strength, it may cause an overturn at the high end.

The channel geometry, such as all of its aspect ratio, changes the interaction of the underlying mechanisms and, hence, the pressure drop across the channel and its thermal efficiency. Channels that are wider in diameter enhance chances of entrapment of a bubble in relation to the structure of bubbles and at the same time facilitates the process of nucleation; conversely, when a channel is narrower in diameter it develops high levels of frictional drag as a result of the reduction of liquid films that surround gas bubbles thereby leading to annular flow regimes. Film boiling is a rather significant phenomenon, but its effectiveness is rather insufficient. It is a mere thin slice of vapor between the water and the hot wall that keeps them away. It normally occurs during good flow regimes or at an elevated temperature, and it does not rewet under some noticeable volatile.

Critical heat flux (CHF) numbers are extremely essential in the tuning of cooling limits of 3D microchannels. Crossing the CHF leads to dry-out and overheating. The drop profiles of the flow need to be calculated so that they can be used to optimize the design of microchannel. Methods recent experiments have attempted to reinvent geometries or surface treatments to have greater control over the behavior of bubble nucleation and two-phase flow.

Observation of the way liquids behave in microchannels in these experiments can teach us a great deal about the way to manipulate these liquids. Nevertheless, it is difficult to achieve better performance using a work of change of geometry or working conditions as it is difficult to establish the correlations with all the big numbers of interactions in these mini-scale, multi-phase systems, [1], [6], [8], [14] and [15].

4. Methodology

4.1. Experimental Setup Description

We established an experimental system to research the experiment with flow boiling in microchannels to prevent the errors in data and wobbling of the conclusion. The system has got about a custom flow loop that makes the thermal conditions constant to ensure proper readings. Sergeant and Dash (2009) indicate that silicon or stainless steel microchannels allow us to explore the effect of various geometries on the performance of the flow boiling.

To increase the heat-transfer efficiency, an aluminium block heater was added to provide a similar thermal input to every microchannel. The attendant temperature changes were monitored continuously using thin-film nickel thermocouples thus, allowing one to locate the heat-transfer coefficients to a minute degree even at boiling temperatures.

Sonic cameras and strain gauges were used to record the microchannel fluid dynamics. The pressure and visual data were priceless in describing the character of phenomena like bubble nucleation, expansion as well as separation, irrelevant of which are in direct relationship to the general efficiency of heat-transfer. The choice of refrigerant R134a was determined due to their ease of use and ability in the experiment due to good thermophysical property of using refrigerant. At the mass flow rate, experimental trials of 250 $kg.m^{-2}s^{-1}$ and 500 $kg.m^{-2}s^{-1}$ were carried out. These variations in the inlet sub-cooling rate had the effect of varying the speed of the critical heat flux (CHF) as well as the boiling nature of the individual microchannels. Pressure gradient measurement was taken across every such experiment along the entire length of the hollow structure.

The experimental modelling is based on well-determined geometrical parameters that define the aspects of pressure-drop behaviour. As a result, the hypotheses are stated in the kind of relations among channel geometry, flow conditions, and heat -transfer performance. The uncertainty analyses have been performed and extensive enough to determine possible gaps in measurement tools and methods applied in the course of the tests. This systematic review makes our conclusions reliable and valid to compare the experimental results with the theoretical ones, and correlations with literature results, [8], [10], [15], [16] and [17].

4.2. Microchannel Dimensions and Specifications

Microchannels are completely revolutionizing the flow-boiling heat transfer. After altering their geometry, it is possible to increase the heat-flux index (HFI) with low-pressure drops. Recently, scientists focused on channels, starting with the sizes of 100 mm all the way to more than 5,000 mm, and discovered that the small-sized ones actually facilitate the boiling phenomenon in water as the water itself boils that fast it turns to a vapour. The depth is also influential to some extent - with it changing, the flow pattern and behaviour of a bubble becomes different.

The group is also testing triangular shape cavities, as they appear to be better than the traditional rectangular microchannels. Triangles are used to maintain uniform film of liquid, elevate density in transfer points of nucleation and maintain uniform temperature of walls during boiling. The impact of mass flux in comparison to the dimensions of the microchannels with regarding heat-transfer rates is a critical matter that needs to be taken into account.

Such studies of flow boiling often use refrigerants with thermodynamic properties, including e.g., that of R134a, that are beneficial to performance. Appropriate choice of the optimum refrigerant may as well influence the optimum channel size and geometrical optimization will be more influential in future stage of technological evolution.

Overall, the effect of the microchannel size on the heat- transfer operation of a flow boiling system is an enormous input; therefore, it is likely to emerge as a crucial provision in the development of efficient thermal management solutions to cooling of electronic systems, refrigeration and other industrial provision. The control obtained using geometric optimization will gain greater significance in an attempt to come up with incredibly efficient systems, [9], [12], [18], [19] and [20].

5. Results and Discussion

5.1. Influence of Channel Width on Heat Transfer Coefficient

The flow-boiling dynamics in the microchannels are, actually, dependent on the size of the conduit, with the width of the channels having one of the most significant effects. It is also found that narrowing the channel alters the pathways of the flow significantly and may alter the overall heat transfer efficiency. The tiny channels are in reality more suitable in nucleate boiling at low heat flux since they limit the size of the vapor bubbles that, at low heat flux, implies that the bubbles travel nearer to the heated surfaces and thus are brought away by the heated walls quicker. Below approximately 400 micrometres in the channel width, the general pattern you will observe will include the following ones; bubble, slug, churn, wispy-annular and annular flows.

It is rather complex on the relationship between channel width, the amount of fluid that is transporting, or the mass flux, and the amount of vapour there is. Heat-transfer coefficient in the local region also skyrockets when pumping more fluid through (higher mass flux) since convection is then increased. The microchannel dimensions also alter the tendency of pressure drops occurring in boiling, namely, this acceleration of the pressure change becomes magnified by the timely formation of vapour and its immediate concentration.

The rate of heat transfer can vary as well even when you are looking at the channels that are not far apart. In narrow channels, there is a great variation in wall temperature with respect to that in wide channels, chiefly due to localized boiling effects. The closer we run channels to each other (i.e., the lesser the distance between them), the higher the total heat exchange is, as the wider is the liquid surface area to contact the vapour.

In addition, microchannel cooling can work well only under conditions of subcooling inlet fluids differing from those with deionized water, R134a, etc. at different mass fluxes, so to handle the situation, it is necessary to get a feel of the behaviour of the various fluids. In the real world, it will require performing design to supply the appropriate thermal control, [1], [21] and [22].

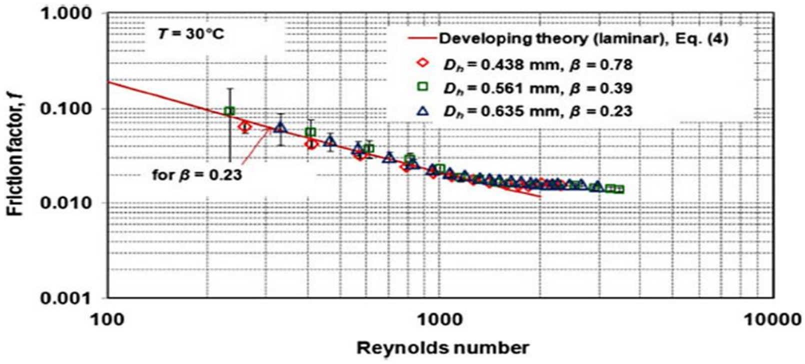

Figure 2. Experimental value of the factor of friction at an inlet temperature of 30 °C using 0.438, 0.561, and 0.635 mm channels, [1].

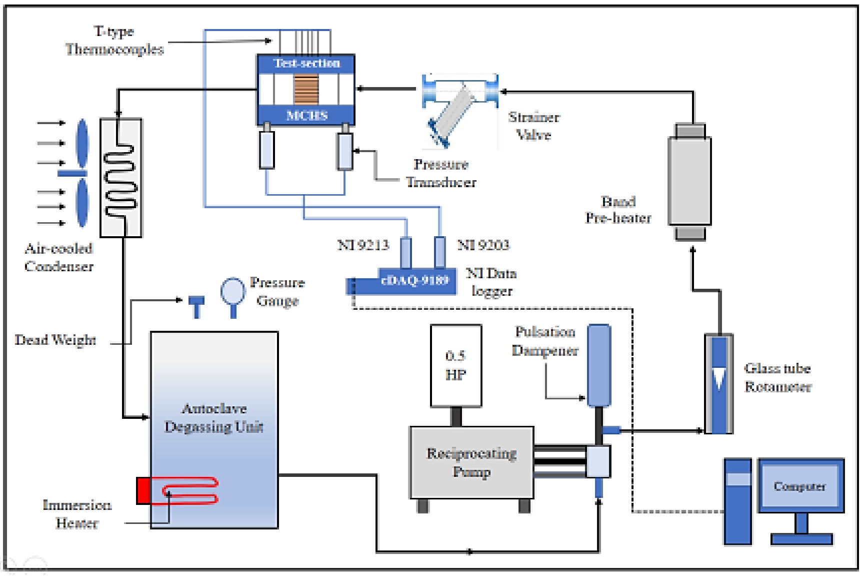

Figure 3. Experimental flow loop, [21].

5.2. Influence of Channel Depth on Critical Heat Flux

We have established that critical heat flux (CHF) constraint is generally determined by the depth of a microchannel that is very vital in enabling cooling systems within electronic circuits to operate effectively. The deeper channels provide additional space of heat exchange, larger boiling surface regions and improved boiling. That is, the more profound the channel, the greater the CHF since the liquid will interact with more contacts promoting an increase in vapour liquid contact and reducing dry-out possibilities.

More depths are however more challenging to sustain flow in the boiling due to the need of extra layers and deeper geometry to ensure that the flow maintained itself is not destabilized. It is also involved in bubble dynamics, in deeper channels bubbles flow more smoothly and create smoother heat transfers, with less concentrations of heat generated in locations adjacent to the wall.

Depth/width ratio or aspect ratio can be significant in the performance of CHF as well as the overall performance of general heat-transfer. As we have observed, the maximum CHF is found in the right aspect ratio since the liquid film around the bubble caps best behaves to enhance thermal conductance, and contact. Slippery microchannels tend to score high however when the channels become too wide then you are faced with redistribution issues.

During lab tests, CHF is usually linearly dependent on channel size when conditions are kept well controlled particularly when refrigerant is used such as R134a. It means that in designing the geometry of a given microchannel, we must ensure that we get rid of any undesired thermal gain, but pharmacologically we cannot afford to overstress the hydraulic performance. The bottom line is that you need to find that middle number between thermal advantages and downsides of the flow in order to have the best thermal-management system, [23], [24] and [25].

5.3. Flow Regimes Observed During Experiments

The flow boiling in microchannels has been examined varyingly by adjusting searches of channel designs, mass fluxes, and heat removal. Qu and Mudawar got a list of five types of channels when the diameter is less than 400 mm: bubble, slug, churn, wispy-annular, and annular. Convective boiling replaces this in these minute holes as well as vapour bubbles travel very swiftly. The larger ones (such as n-boils) are able to contain more vapour with higher temperatures and transition to new regimes earlier than the smaller ones. The aspect ratio is also relevant in microchannels with rectangular shape. The aspect ratio to tight channels at high-mass-flux rates should be made smaller by Mohammed and Fayyadh, and tends to result in the instability causing the system to come to a standstill.

The microchannels can be actually observed with high-speed cameras and the researcher can see the behaviour of bubbles as well as the location of two-phase flow instability. The implications of these findings as to microchannel cooling applications are so important that it is still rather uncertain how well these findings will work in the large and real world systems, [1] and [22].

5.4. Pressure Drop Behavior in Microchannels

The size of the channels is a major issue as it alters the resistance to the fluids and flow behaviour. Even changing the aspect ratio can cause a perturbation on the pressure drop. It happens that a pressure drop when R134a is the refrigerant increased to a further height when the channel in question was shallow or skinny-thin-in-width-thanks-to-added-friction and funny-flow-patterns. Besides, the formation and coalescence of bubbles complicates the dynamics of pressure as well.

The drop of pressure reacts differently in experiments when the mass flux in an experiment is varied but the heat flux is maintained constant. Locking the pressure the pressure spike is also caused by low mass fluxes, which for faster convection is countered by high mass flux. R134a and R1234yf are rather viscous such that they can operate the higher pressure in the same conditions.

In the fine scale of measuring stuff, it becomes apparent that local temperature variations indeed cause the pressure at the centre of each microchannel. The expansion and heating of the walls have the potential to alter the vapour pressure at the terminus and unless this is regulated the entire apparatus may prove unstable.

The greatest concern is in coming up with the complete system performance as the entire microchannel variations, roughness and geometry come in. Currently the exciting new stuff is the regime-based modelling, which has potential as fine as it is capable of computing the heat transfer coefficient and pressure gradients at the heat transfer tranquilities pinpointing the penetration in the phase-change cases within narrow entrances.

These observations play an important role in the enhancement of designs of rigid heat exchangers derived through microfluidic networks in high-performance thermal management in a group of industrial tasks, [10], [19], [24] and [26-30].

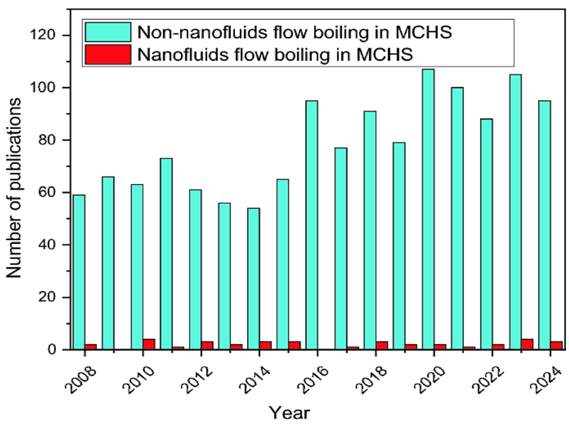

Figure 4. Publication Count on Flow boiling in Microchannel Heat sinks (MCHS) Per Year, [27].

6. Conclusions

We investigated the flow boiling through microchannels and established that the size of channels, the type of refrigerant, and the nature of the boiling behaviour were the direct determinants of the heat transfer coefficient and the critical heat flux (CHF). The width of the channel is crucial, channels with a narrow width are able to initiate nucleation at lower heated flux but usually become stuck at a large pressure drop due to the trapped vapour. Another thing is the depth of the channel: the deeper the channel the greater the wetted area and the steady flow, and when it comes to CHF more is better. The results can assist in the design of micro-channel systems to be used in the regeneration of heat on a large scale and with a minimum risk of dry out. The other important observation was that the resistivity varies across the different sizes of the channel in bubbling mixtures of R134 a. We also noticed that the smoother channel walls do increase turbulence and resistance in reality hence the need to balance between the heat transfer as well as pressure drop. This information is of relevance to body of knowledge on micro-channel cooling technology as it provides the experimentation to adjust geometry towards improved cooling efficiency. According to these considerations, the next step that scientists will have to consider is the choice of materials and surfaces and expose them to changes that may increase heat-transfer rates and, thus, make the systems more scalable and interactively flexible.

7. Future Work

The flow-boiling phenomenon in microchannels is studied and provides a sequence of research questions highlighting the highly vulnerable areas of the need to be improved with regard to the performance indicators and knowledge underpinnings. In particular, one must search after the high surface area materials, which inhibit high heat transfer ability of substrates. Additional studies in the future should seek to enhance the various moderations to be conducted over surfaces or engineered overcoats that inhibit the coalescence of bubbles and encourage an increase in nucleation rate in order to maximize the entire heat-transfer process. A Microchannel technology has a challenge on scalability and to level comparison of studies and create comprehensive models it is important to solely create standard experimental conditions. With experimental data, symmetric numerical models can be highly informative in the comprehension of highly intricate flow regimes in well-shared conditions, including mass flux and heat. It should also be studied how nanofluid formulations perform under different operating conditions even the non-persistent state to guarantee the long-term effectiveness. In addition, the general efficiency of the refrigerant in terms of its effects by temperature as well as its usage to the environment should be evaluated, besides the emerging refrigerants efficiency must be compared and be evaluated under the same conditions as any other fluid. A broader research agenda must be taken to probe the behaviour of two-phase flows and especially in its applications with regard to efficacy of the evaporative stage. An overreaching inquiry that challenges material science, model shortcomings, and basics of thermodynamics and empirical findings will play a critical part in offering substantial improvements, nurturing new evolutions and ability to perform in a consistent, uniform manner.

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