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The Influences of the Fluid Initial Temperature and Fluid Flow Rate to the Boiling Heat Transfer: A Short Review

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Abstract. Recently, Low Temperature Vacuum Drying with induced Nucleation Boiling (LTVD-NB) has been studied for water reduction methods. However, low dewatering temperature led to longer drying process. Hence, to improve the LTVD-NB dewatering performance, the study on Boiling Heat Transfer (BHT) such as parameters, conditions and phenomena that may affect the heat transfer in boiling process should be understood further. Currently, some of parameters such as dewatering temperature, surface roughness, and initial water content effects in LTVD-NB have been discovered. However, the effect of the fluid initial temperature and hot water flow rate to the BHT in LTVD-NB is still unclarified. Hence, the objective of this paper is to review and examine the influences of fluid initial temperature and the effect of fluid flow rate to the BHT. In general, the result shows that the higher fluid initial temperature and flow rate significantly enhanced the BHT. As a result, the BHT in LTVD-NB system can be improved which will significantly improve the dewatering process of honey in the future.

1. Introduction

Boiling is a process of which liquid turn into vapor phase when it is heated above of its boiling point. Nucleation Boiling (NB) is one of the boiling phase which bubbles nucleate, grow and depart from the heated surface [1]. NB is characterized by a very high rate of heat extraction at the heater surface due to formation of hundreds of tiny bubbles that grow and detach from the surfaces [2]. As the surface temperature is higher than the liquid saturation temperature, small bubbles of vapor started to form on the heater surface, growing, rising and released from the liquid. NB phase usually depends on the configuration of the part such as the heater surface, the initial temperature, velocity of the quenchant, and its thermal properties [2].

Currently, the study of NB under the vacuum conditions is still limited since LTVD-NB is one of the recent studies that has been developed for water reduction method of the Stingless Bee Honey (SBH). However, the low dewatering temperature resulting to long dewatering process which further study on the maximizing the BHT in LTVD-NB is needed. Abdul Halim et al., (2022) studied the effect of dewatering temperature and Surface Roughness (SR) on pool boiling of SBH in LTVD-NB system at the temperature of 40, 45 and 50 °C and 0.80, 3.39, 8.82 and 11.33 μm SR. The findings shows that as the dewatering temperature increased from 40 to 50 °C, the increments in Heat Transfer Coefficient (*h*) were 122, 67, 52 and 90% for SR of 0.80, 3.32, 8.82 and 11.33 µm [3]. These are due to the increase in temperature that can provide higher Heat Flux (*q*") which increase the rate of heat transfer from the heater to the SBH. Besides, *h* also tends to increase with the increase of the heater SR due to the higher nucleation cavity site that present on the rougher heater surface that can exhibit more bubble formation. This will lead to higher *h* which significantly increase the dewatering process.

Syazwan Ramli et al., (2024) studied the effect of Initial Water Content (IWC) of SBH to the dewatering performance of LTVD-NB. The experiments were done at three different IWC of SBH which are 22.5, 24.5 and 27.5 %. The findings suggest that the decreased in IWC lead to lower *h* which ranging from approximately 4 to 8 kW/m^{2}K for the same SR of 11.33 µm and heat flux at 60 kW/m^2 [4]. The author suggests the IWC greatly influences the SBH honey concentration which affects the viscosity. In viscous environment, the mobility of water molecules is restricted which contributes to the lower *h* and evaporation rate.

In previous studies of LTVD-NB for dewatering of SBH, the detailed methodologies provided are missing some of the parameters that may affect the BHT. The initial temperature of the liquid and the hot water flow rate that flow inside the cylindrical heater is not provided by the authors. These parameters generally affect the NB which was discussed by some of the previous researchers. Liscic & Singer (2014) mentioned that the initial temperature of the fluids is one of the parameters that NB depended on while Azmi et al., (2014) explained that the flow rate generally influence the heat transfer due to the fluid flow properties that depend on the Reynold (*Re*) and Nusselt (*Nu*) number which affecting the *h* [2][5].

Figure 1.1 shows the boiling phase of water at atmospheric pressure. In the NB region (B'-D), it is known that the temperature difference between surface temperature, T_w and saturation temperature T_{sat} that leads to the occurrence of NB provided that the heat flux is below the CHF [6]. Hence, saturation temperature of the fluid is able to reach faster when the initial temperature is higher and vice versa. Besides, initial temperature also affects the viscosity of the fluid which influenced the NB bubble parameter such as bubble frequency, departure time and buoyancy which impact the *h* [4].

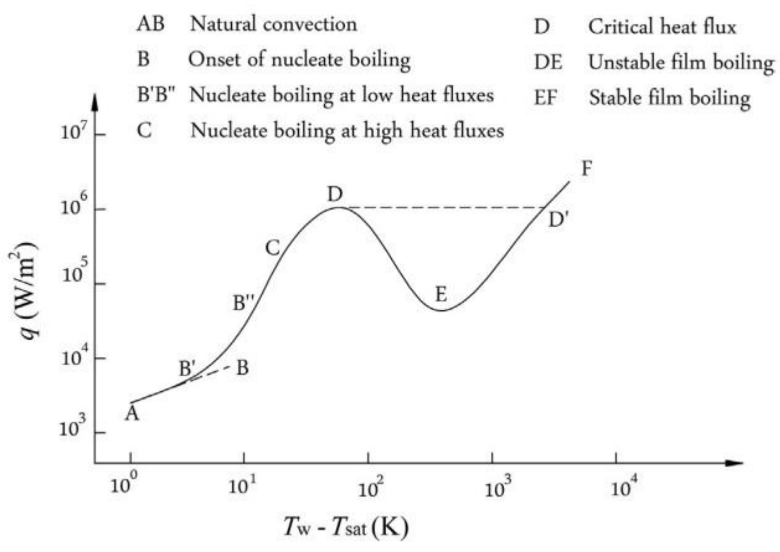

Figure 1.1 Pool boiling curve of water at atmospheric pressure [7].

While physical factors may affect NB, natural phenomenon that occurred during NB is also one of the indicators that represents the NB mechanism. Bubble dynamics is one of the important sub-phenomena in NB, which basically influences the Nucleate Boiling Heat Transfer (NBHT) coefficient. It is known that bubble formation rate, bubble transition frequency, bubble size and bubble speed may affect bubble dynamic mechanism which contribute to NB performance [3]. It is also known that bubble size may increase during the bubble elevation time before released from the liquid surface [2]. The graphical mechanism of NB bubble formation is as shown in Figure 1.2 [7].

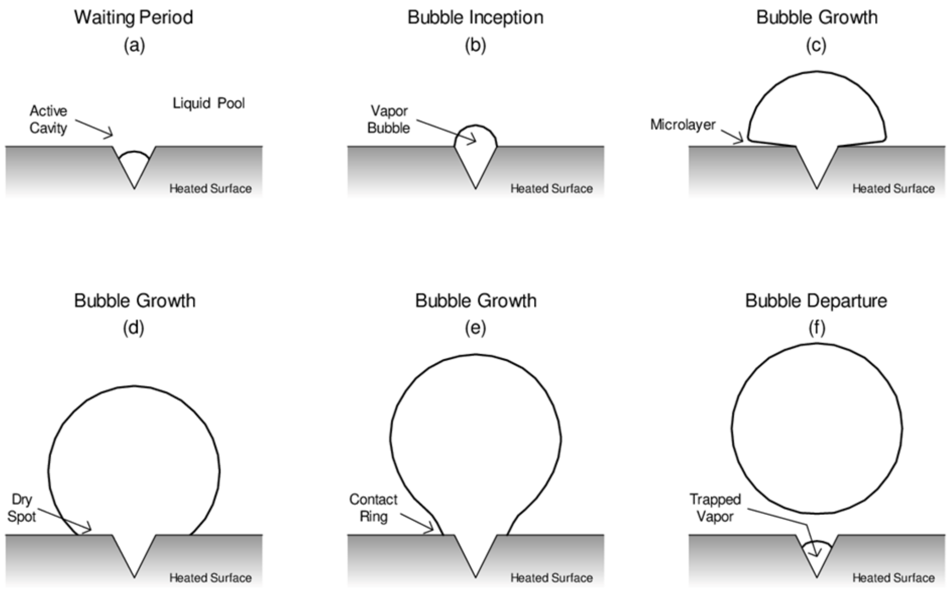

Figure 1.2 Pool boiling curve of water at atmospheric pressure [7].

When the heater surface temperature (T_{sur}) is higher than liquid saturation temperature (T_{sat}), the bubble started to form on the heater surface due to vapor formation at hot surface temperature. As the process continue, bubble size started to increase due to the bubble temperature that higher than the liquid temperature [3]. The bubble continues to detach from the heater surface while moving upward and released from the liquid surface [2].

Nucleate bubble characteristic is one of the important studies in NB which explains the NB phenomena that usually determine the boiling performance along with other parameters that affect NB. Due to the nature of boiling process that is complex, it is crucial to study the influences of initial temperature which may affects the bubble dynamics in NB that can influence the BHT since the effect of this parameters in LTVD-NB is still unidentified. Hence, by varying the initial temperature of medium, their effects on the NB bubble dynamics and BHT can be understood further since higher initial fluid temperature significantly affect h and q" in NB [8]. Hence, the study of the fluid initial temperature effects is one of the potential research gaps that are recommended to be studied in future specifically in LTVD-NB system.

Besides, the fluid flow rate is generally known to affect heat transfer. This can be verified through the heat transfer equation that gain or lost to a system as in Equation 1.1. Equation 1.1 shows that where heat transfer (q) is directly proportional to the mass flow rate (m).

$$q = mC_p\Delta T \qquad 1.1$$

where q is the heat transfer from or to a substance [kW], m is the mass flow rate [kg/s], C_p is the specific heat capacity of substance [kJ/kg.K] and ΔT is the temperature differences [K].

Some of the dimensionless numbers such as Re and Nu number are greatly influenced by the fluid flow rate which explains how heat transfer is dependent on the flow rate. Theoretically, higher flow rate enhanced the h due to the increase in the Re and Nu that affect h [5]. Based on the previous research, the effect of the hot water flow rate in LTVD-NB is still unknown. The general idea of how the hot water flow rate affects the dewatering rate, bubble dynamics and BHT in LTVD-NB system is still unrevealed. Thus, the study of the fluid flow rate effects in LTVD-NB is also one of the potential gaps that are recommended to be investigated in future studies.

2. The influences of fluid initial temperature to the Boiling Heat Transfer

Initial liquid temperature is one of the parameters that affect NB [2]. The initial temperature of a liquid significantly impacts nucleate boiling, influencing the heat transfer efficiency and the dynamics of bubble formation. Higher initial temperature of liquid may reduce the superheat requirement in which boiling process can initiate faster due to their higher temperature that are closer to the saturation temperature. The viscosity of the liquid is also dependent on the liquid temperature.

Thus, higher initial temperature may reduce the liquid viscosity and increase the h in the nucleate pool boiling. This will influences the bubble dynamics due to higher liquid initial temperature that increasing the nucleation rate of bubbles [9]. This is because at higher liquid initial temperature enhances the thermal energy available to the liquid, reducing the liquid viscosity thus promoting bubble formation at nucleation sites on the heated surface [9].

Markal et al., (2023) investigated the relationship between the differences in inlet temperature on flow boiling behaviour of expanding micro-pin-fin type heat sinks. The experiments were carried out on the initial temperature of deionized water at 25, 45 and 65 °C and the findings shows that when the initial temperature of working fluid decreased, the trend shows the enhancement in the h [10]. They suggest the increase in initial temperature increase the vapor quality inside the heat sink which increase the pressure drop thus reducing the h.

Cheng & Wu, (2023) examined the influences of different inlet subcooling degrees to the heat transfer on flow boiling using deionized water at the temperatures of 20, 40 and 60 °C. Their finding provided that higher inlet subcooling degree of deionized water provided higher q'' and CHF [11]. The main reason for such result is due to the higher inlet subcooling temperature that needs higher heat flux to set off the bubble nucleation.

Surtaev et al., (2021) studied the effects of initial water temperature to the convection time and bubble radius in a pulse heating microheater. The experiment was carried out using deionized water at the temperatures of 27, 38 and 51 °C with the pulse duration of 100 -2000ms. The outcome of the experiments showed that the higher initial temperature providing lesser power and convection time required to achieve the equivalent bubble radius [12]. This is due to higher liquid temperature that required lesser energy for the water to increase their temperature until reached to the saturation state.

Dalkilic et al., (2020) studied the effects of inlet temperature of R134a in microchannel with the different saturation inlet temperature of 20, 24 and 28 °C. The findings of their experiments show the enhancement of h when the saturation inlet temperature is higher. The increased in saturation inlet temperature increased the h of the system due to the decreased in temperature differences that increased heat transfer coefficient accordingly. However, CHF trend decreased as the inlet temperature increased. They suggest this is caused by the physical properties of the R134a fluids that changed as the inlet temperature is varied due to the two-phase boiling system which the vapour and liquid fraction impact the CHF [13].

Chen et al., (2018) investigated the effects of the different inlet temperature on the convective heat transfer in subcooled flow boiling. Using distilled water at the inlet temperature of 90, 100 and 110 °C, their findings shows that the increased in liquid bulk inlet temperature increasing the trend of h [14]. The authors states that the increase in h is due to the lower subcooling degree that intensified the boiling process which increase the bubble nucleation rate.

Lu et al., (2017) observing the effects of subcooled temperatures on the confined bubble growth nucleate boiling inside small the evaporator film. The experiments was carried out using water at different initial temperatures of 27 to 87 °C and the findings showed that as the liquid initial temperature decreased, the growth rate of the bubble height decreases [15]. The decrease initial temperature reduced the sensible heat of the water. For the same heat supply to the system, lower initial temperature needs more energy to produce the same bubble growth rate as the higher initial temperature. Thus, lower initial temperature significantly reduced the nucleate bubble growth rate.

Choi et al., (2017) studied the effects of nanofluid initial temperature on the heat transfer. The experiment was carried out with subcooled inlet temperatures ranging from 40 to 80 °C with Fe_3O_4 nanofluids as the sample [16]. Their results demonstrated that the higher inlet temperature of deionized water and nanofluids increased the CHF while the nanofluids provided better heat transfer compared to deionized water [16]. The higher initial temperature increases the heat flux due to the decrease of the liquid flow resistance such as viscosity that increase the surface wettability of the liquid with the heater causing the CHF to increase.

Sarafraz et al., (2015) studied the effect of different inlet temperature range on flow boiling using the deionized water and CuO-water nanofluids at the temperatures of 70 80 and 90 °C. The findings shows that the higher inlet temperature of liquid provides higher h [17]. The authors suggest the phenomena is due to the increase of the onset nucleate boiling. At higher initial temperature, onset nucleate boiling is reached faster from the forced convection region which significantly increase the h. The summarized of the previous literatures done in relating the effect of initial temperature to the boiling heat transfer are as in Table 1.

Table 1. Summarized of the previous literature done on the effect of fluid initial temperature in boiling process

Author & Year	Parameter Studied	Fluid	Temperature/Pressure Condition	Findings
J. Zhang et al., 2024 [18]	Effect of hot water inlet temperature to the pool boiling	R245fa	84 – 111 °C (1 atm)	As the inlet temperature increases, the external h increases along with the heat flux.
Al-Waaly, 2024 [19]	Effect of subcooling inlet temperature on flow boiling heat transfer through a microchannel	Water	Subcooling degree of 5 - 25 °C (1 atm)	The average h enhances with the rise in the degree of inlet subcooling.
Markal et al., 2023 [10]	Effect of inlet temperature on flow boiling behaviour of	Deionized water	25, 45 and 65 °C (1 atm)	The findings show that as the initial temperature of working fluid

	expanding micro-pin-fin type heat sinks			decreased, the trend shows the enhancement in the *h*.
Cheng & Wu, 2023 [11]	Effects of different inlet subcooling degrees to the heat transfer on flow boiling	Deionized water	Subcooling degree of 20, 40 and 70 °C (1 atm)	Higher inlet subcooling degree of deionized water trends provide higher *q"* and CHF.
Chernov et al., 2022 [20]	The influence of the radiation power on the vapor bubble nucleation and growth for different inlet liquid temperature	Water	25, 35 and 45 °C (1 atm)	Inlet temperature have no dependency on the induction time. However, higher liquid initial temperature increases the energy provided at the same radiation power level.
Ma et al., 2022 [21]	Effect of inlet temperature on flow boiling in micro pin finned surface heatsink	Deionized water	30 – 50 °C (1 atm)	Lower inlet temperature increased the CHF and pressure drop due to larger dynamic viscosity obtained.
Surtaev et al., 2022 [12]	Effect of initial water temperature to the convection time and bubble radius	Deionized water	27, 38 and 51 °C (1 atm)	The higher the initial temperature, less power and convection time required to achieve the equivalent bubble radius.
Dalkılıç et al., 2020 [13]	Effect of inlet temperature of two-phase flow to heat transfer coefficient and CHF in microflow channel	R134a	20, 24 and 28 °C (1 atm)	Higher inlet temperature enhanced the *h* trend. CHF trend is decreasing as the inlet temperature increased.
Chen et al., 2018 [14]	Effect of different inlet temperature on convective heat transfer in subcooled flow boiling	Distilled water	90, 100 and 110 °C (1 atm)	The increased in bulk inlet temperature provides increasing the trend of *h*.
Q. Zhang et al., 2018 [22]	Effect of different inlet temperature during rapid depressurization process on transient heat transfer	R113	40, 50, 70 °C (1 atm)	Evaporation rate is faster as the inlet temperature of the refrigerant is increased.
Lu et al., 2017 [15]	Effects of subcooled temperatures on the confined bubble growth nucleate boiling inside small the evaporator film	Water	26 - 90 °C (1 atm)	As the liquid initial temperature decreased, the growth rate of the bubble height decreases.
Choi et al., 2017 [16]	Effect of different inlet temperature range	Fe_3O_4 - water	40, 60 and 80 °C (1 atm)	Higher inlet temperature resulting CHF enhancement. With the increase of mass flux, the CHF also trendily enhanced.
Sarafraz et al., 2015 [17]	Effect of different inlet temperature on flow boiling	DI water and CuO-water	70, 80 and 90 °C (1 atm)	Higher inlet temperature of fluid provides higher *h*.

Hasan et al., 2014 [23]	Effect of liquid initial temperature on boiling explosion	Water	20, 60 and 100 °C (1 atm)	Higher initial temperature of water reduced the time taken for boiling explosion due to higher cumulative energy content.

The current literature study on BHT based on the initial fluid temperature is still limited to common fluid such as water, refrigerant and nanoparticle liquids. The study on the nucleate boiling of the organic liquid such as honey is limited and only a few parameters that have been discussed by previous authors. Besides, the current experiments were all done under normal atmospheric pressure while the effect of fluid initial temperature to the NB, bubble dynamics and h under vacuum conditions for SBH liquid is still undiscovered.

3. The effects of fluid flow rate to the Boiling Heat Transfer

In boiling heat transfer, fluid flow rate also has a significant impact on the h. This is due to the flow characteristics that influence the heat transfer. Theoretically, heat transfer can be increased when the fluid flow rate is higher owing to the higher Reynold Number (Re) achieved in high flow rate. Re is a dimensionless parameter that predicts the fluid flows characteristics. Azmi et al., (2014) suggest that the h of nanofluids can be improved by 81.1% when the Re of the flowing nanofluid increased. This is due to the increased in the Nusselt Number (Nu) when the Re is increased which affecting the h [5]. The relationship between Nu and h is briefly shown in Equation 3.1 [5]

$$Nu = \frac{hD}{k} \qquad 3.1$$

where Nu is the Nusselt Number, h is the heat transfer coefficient [W/m^{2}K], D is diameter inside a pipe [m], k is the thermal conductivity of the fluids [W/mK].

Yang et al., (2023) studied the effects of different water flow rates on heat transfer characteristics of evaporator. The experiment was done using water as the medium with flow rate ranging from 1 - 2 L/min. Their finding shows that the h trend is increased as the evaporator water flow rate increased. They suggest this is due to the higher water flow rate inside the evaporator resulting in higher outlet water temperatures that accelerated the water vaporization process which gave higher h in general [24].

Zajec et al., (2023) investigated the effect of mass flow rate on bubble size distribution in flow boiling in annular test section. The test was done using R245fa as the working fluid with different mass flux of 150 – 750 kg/m^{2}s. It was seen as the as the mass flux of refrigerant increased, the generated bubble size decreased due to higher mass flux that limit the large bubbles formation. The heat flux trend also increased as the mass flow rate of refrigerant increased as more heat can be transfer at higher flow rate [25].

Hu et al., (2023) investigate the effects of hot water flow rate to the flow boiling of R22. The experiment was carried out with different hot water mass flow rates of 8 – 24 L/min. The significant enhancement of h was found due to the ability of R22 to absorb the heat provided by the hot water. Authors explain this is due to the R22 refrigerant that undergoes the phase change inside the tube which significantly enhanced the h based on the energy conversion principle provided from the hot water to the R22 which the specific heat and flow rate of both hot water and R22 play the important role that improved the h [26].

Wang et al., (2023) studied the effect of different mass flux of the hot water ranging from 0.85 to 1.69 kg/m^{2}s with the temperature of 60 to 85 °C. They suggest the increase of *h* trend is in the temperature range of 60 to 70 °C for almost all the mass flux values. As the temperature is increased further until reached at 85 °C, *h* trends are started to decrease. They suggest that the main reason is due to the presence of phase change at higher temperature which started to reduce the trend of *h* [27].

Vosough et al., (2020) research the influence of fluid flow rate in subcooled flow boiling condition. The research was conducted using Calcium Sulphate as the working at the flow rates of 2.5, 5.5 and 11.5 L/min. The result shows that the higher flow rate of the calcium sulphate provides increasing in the trend of the *h*. This is because increasing the flow rate enhances the *h* due to increase in flow turbulence and shear stress which causes the surface temperature to be reduced that leads to increase the heat transfer coefficient [28].

Cho (2020) studied the effect of hot water flow rate to heating process of water in bathhouse. The experiment flow rates were set on 1.5, 3.5 and 6.5 L/min using water as the working fluid. The findings of the experiment shows that the heating process improves as the water flow rate improved. Time taken to reach target temperature is shorter when the hot water flow rate increased due to higher heat is transferred from the hot water to the cold water [29].

Sinha et al., (2019) investigated the effect of flow rates on bubble dynamics and temperature gradients in nucleate flow boiling regime. The experiments were carried out using water at the *Re* 2400 to 7200 *Re*. Their results demonstrated that as the *Re* increased, time taken for bubble growth was increased. Bubble diameter was found to decrease as the *Re* increased. However, time taken for bubble lift-off is shorter when *Re* is increased [30]. Authors suggest this may be due to the decreasing strength of the thermal gradients at high *Re* that affect the bubble interface that cause rapid changes in bubble shape.

Ranjbarzadeh et al., (2017) performed an experiment regarding the effects of different *Re* to the convective heat transfer coefficient in an isothermal pipe. The experiments were done using water-graphene oxide nanofluid as the working fluids with *Re* range of 5250 – 36500 *Re*. The findings suggest that at Re of 36500, the *h* was improved up to 40.3 %. This is due to the higher *Re* that improved the fluid turbulency that increase the Nu number which significantly improved the *h* and overall heat transfer [31].

Sarafraz & Hormozi (2014) study the effects of different mass flux and heat flux of nanofluids to the heat transfer mechanism inside the vertical annulus. The experiment was run using water-CuO nanofluids as the working fluids with the mass flux of 353 – 1059 kg/m^{2}s. They suggest a significant increase in their findings with *h* increased when the mass flux and heat flux were increased [32]. Thus, higher mass flux of nanofluid can transfer more energy to the nanofluids which affecting the *h*. Table 2 summarized the related findings on the influence of fluid flow rate to the boiling heat transfer.

Table 2. The summarized the findings of fluid flow rate effect on the boiling process.

Author & Year	Parameter Studied	Fluid	Flow condition	Findings
ARIMA et al., 2024 [33]	Effect of different hot water flow rate to BHT in a plate heat exchanger	Ammonia	1 – 7 L/min	The overall *h* trend increases as the flow velocity of the hot increases.

Ye et al., 2024[34]	Effect of different R134a mass flow rate to the flow boiling	R134a	0.24 – 0.48 L/min	The increase in mass flow rate reduced the *h* .
Al-Waaly, 2024 [19]	Impact of inlet mass flux on flow boiling heat transfer through a microchannel	Water	400 and 800 kg/m^{2}s	*h* is enhanced as the mass flux of the water increases.
Yang et al., 2023 [24]	Effects of different water flow rates on heat transfer characteristics of evaporator	Water	1 – 2 L/min	*h* trended upward as the water flow of the evaporator increased.
Zajec et al., 2023 [25]	Effect of mass flow rate on bubble size distribution in flow boiling in annular test section	R245fa	150 – 750 kg/m^{2}s	As the mass flux of refrigerant increased, the generated bubble size decreased due to higher mass flux limit the formation of larger bubbles. The heat flux increased as the mass flow rate of refrigerant increased.
Wang et al., 2023 [27]	Effect of hot water mass flux on the heat transfer coefficient in forced flow annular tube under negative pressure	Water	0.85 – 1.69 kg/m^{2}s	The increase in the mass flux of the hot water significantly increases the trend of *h*.
Hu et al., 2023 [26]	Effect of hot water flow rate to the boiling of R22 flow boiling	Water	8 – 24 L/min	The boiling heat transfer coefficient of R22 increases significantly with the increase of hot water flow rate.
Hernaiz et al., 2023 [35]	Effect of hot water flow rate to the flow boiling of n-pentane with nanomaterials	Water	0.8 – 2 L/min	*h* increases as the hot water flow rate increases for 0.01 wt% Al_2O_3. Other nanomaterials solution has no significant impact on *h* trend.
Vosough et al., 2020 [28]	The influence of fluid flow rate in subcooled flow boiling condition	Calcium Sulphate solution	2.5, 5.5 and 11.5 L/min	Higher flow rate of the calcium sulphate provides increasing in the trend of the *h*.
Cho, 2020 [29]	Effect of hot water flow rate to heating process of water in bathhouse	Water	1.5, 3.5 and 6.5 L/min	Heating process improves as the flow rate improved. Time taken to reach target temperature is shorter as the flow rate of hot water increased.
Youssef Sakr et al., 2019 [36]	Effect of different hot water flow rate to the flow boiling of R134a	Water	1 – 3 L/min	*h* increases as the hot water flow rate increase due to higher *q*" is provided to the heating medium.
Sinha et al., 2019 [30]	Effect of flow rates and on bubble dynamics and temperature gradients in nucleate flow boiling regime	Water	2400 – 7200 *Re*	As the *Re* increased, time taken for bubble growth was increased. Bubble diameter decreased as the *Re* increased. However, time taken

				for bubble lift-off is shorter when *Re* increased.
Ranjbarzadeh et al., 2017 [31]	Effects of different *Re* to the convective heat transfer coefficient	Water – graphene oxide nanofluids	5250 – 36500 *Re*	Higher *Re* improved *h* significantly with up to 40.3% increase in *h*.
Azmi et al., 2014 [5]	Effects of *Re* to the convective heat transfer coefficient in nanofluids	Water – TiO_2 nanofluids	8000 – 30000 *Re*	*h* significantly improved by 81.1% at *Re* of 23,558.
Sarafraz & Hormozi, 2014 [32]	Effects of different mass flux and heat flux of nanofluids to the heat transfer mechanism	Water – CuO nanofluids	353 – 1059 kg/m^{2}s	A significant increase in the *h* with the increase in mass flux and heat flux.

The current literature study on BHT based on the fluid flow rate is still bounded to common fluid such as water, refrigerant and nanoparticle liquids. The study of the nucleate boiling on the organic liquid such as honey is limited and only a few parameters that have been discussed by previous authors. The effects of fluid flow rate to the NB, bubble dynamics and *h* under vacuum conditions for SBH organic liquid is still unexplored.

4. Conclusion

As conclusion, both the initial temperature of the fluid and its flow rate significantly impact the boiling heat transfer process. The initial temperature of the fluid affects the key parameters in boiling process such as heat transfer coefficient, critical heat flux, bubble dynamics, and fluid properties. These factors contribute to the efficiency of heat transfer during the boiling process. A higher fluid initial temperature generally accelerates the boiling process by enhancing these parameters. Similarly, the fluid flow rate also plays a crucial role in improving BHT. Increasing the flow rate tends to enhance heat transfer due to its effects on the flow parameters such as Reynolds number (*Re*) and Nusselt number (*Nu*), which influence the heat transfer coefficient. Understanding the combined effects of fluid flow rate and initial temperature in BHT can assist future research in optimizing the BHT under various conditions.

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