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Jurnal Asiimetrik: Jurnal Ilmiah Rekayasa dan Inovasi is published regularly every **two times a year**, in **January** and **July**. This journal publishes research-based scientific articles, case studies, review articles, engineering and innovations that cover both theoretical and practical as well as their development. The topics of scientific articles published cover the fields of Architecture, Civil Engineering, Industrial Engineering, Informatics Engineering, Mechanical Engineering and Electrical Engineering.

SUMMARY. Alfarisi et al, conducted a finite element analysis on the modification of the design of R22 car wheels made of aluminum to produce the best variant of the existing model. **Suhartono and Muin**, conducted research to determine the effects of seawater on reinforced concrete and the effects on reinforcement on corrosion rate and on concrete on compressive strength when inhibitors have been added. Meanwhile, **Ajiban et al.** analyzed the effect of air pressure and nozzle distance on the quality of water-based paint using a gravity feed spray gun. Research by **Hasan et al.** was conducted to determine the effect of heat flux on the frequency of bubble appearance in boiling pools. Pool boiling is a boiling process in which all fluid motion is caused by natural convection currents. **Abdulah et al.** in their research optimized the heat transfer performance using Response Surface Methodology-Central Composite Design (RSM-CCD) for nano-coolant (AL2O3+EG/W) in electric vehicle batteries. **Osman et al.** conducted a study to determine the performance of the machine and whether there was a significant difference from the grinding machining process. Control map analysis was used to determine the consistency of machine performance and comparison of feed rate to determine machine performance. **Syaka et al.** conducted a study to determine the effect of fuel pressure variations on the performance, especially torque and power, of a direct injection 2-stroke gasoline engine. **Nugraha et al.** conducted research on the design of a wind speed measurement system in a pitot tube-based wind tunnel. **Puspa et al**, conducted research on the characteristics of the Thermal Electric Generator (TEG) type SP1848 27145 SA with the aim of knowing the character of voltage output, power and Seebeck coefficient values in the SP1848 27145SA TEG system when temperature changes occur. **Waisal et al**, analyzed the mechanical properties and microstructure of aluminum and copper sheet welding results using the friction stir spot welding method. **Agustina et al**, analyzed the comparison of rectifier performance in power plant applications. Meanwhile, **Suharyanto and Kurniawan** conducted research related to the effect of heat treatment temperature on the hardness of jaw implants produced by the EDM process. **Lukiano et al**, conducted research on the numerical analysis of the effect of gurney flaps on the aerodynamic performance of NACA 4415 airfoil. Another case with **Billad et al**, who conducted research to prove that the erosion effect can reduce and increase the value of NACA 0015 airfoil. While **Ulhakim et al**, through their research, evaluated the performance of using TiO2 nanofluids made using ethylene glycol (EG) and distilled water as the base liquid, which was then called TiO2-EG/W. **Nabil et al**, conducted research on public street lighting monitoring systems using telegram-based wireless sensor network applications. **Rimantho**, developed a waste management model using the Soft System Methodology (SSM) approach to assess the challenges of wood pellet production as a renewable energy source from biomass waste and possible solutions. While **Purwanto et al**, conducted architectural planning with natural lighting systems that can affect occupant productivity and energy efficiency.

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The Effect of Heat Flux on the Frequency of Bubble Appearance in a Boiling Pool

Pengaruh Fluks Kalor Terhadap Frekuensi Munculnya Bubble Pada Didih Kolam

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Abstract

This research was conducted to determine the effect of heat flux on the frequency of bubbles appearing in boiling ponds. All fluid movement in pool boiling is caused by natural convection currents. The boiling pool consists of four areas of the pool boiling regime. The division of the four areas is based on the value of the heat flux and the difference between the surface temperature of the heater and the fluid. Using a two-phase heat transfer unit (H654 P.A. Hilton machine), The results showed that the power used greatly influences the boiling process, and besides that, the volume of water used also affects the duration of the boiling process. Based on tests using various power levels of 75 W, 110 W, 168 W, 237.5 W, and 290 W. The occurrence of bubbles will be faster and more numerous when using a lower volume of water and greater power. The heat transfer will be greater if a bubble appears, where latent heat plays a very important role. With mathematical analysis, an increase of 1 bubble per minute occurs for every increase in heat flux of 1.3 W/m^2.

Keywords: pool boiling, heat flux, two-phase flow, bubble.

***SDGs*:**

7 AFFORDABLE AND CLEAN ENERGY

Abstrak

Penelitian ini dilakukan untuk mengetahui pengaruh fluks kalor terhadap frekuensi munculnya *bubble* pada didih kolam. Didih kolam merupakan proses pendidihan dimana segala pergerakan fluidanya disebabkan oleh arus konveksi natural. Didih kolam terdiri dari empat daerah *pool boiling regime*. Pembagian keempat daerah tersebut berdasarkan nilai fluks kalor dan selisih dari suhu permukaan pemanas dan fluida. Metode penelitian menggunakan mesin *two phase heat transfer unit H654 P. A. Hilton*. Hasil penelitian menunjukkan bahwa daya yang digunakan sangat berpengaruh terhadap proses pendidihan, selain itu tingkat volume air yang digunakan juga mempengaruhi lamanya proses pendidihan. Berdasarkan pengujian menggunakan bervariasi daya 75 W, 110 W, 168 W, 237,5 W dan 290 W. Peristiwa munculnya *bubble* akan semakin cepat dan banyak ketika menggunakan volume air lebih rendah dan daya yang besar. Dengan analisis matematis dihasilkan kenaikan 1 *bubble* per menit terjadi pada setiap kenaikan fluks kalor 1,3 W/m^2.

Kata Kunci: didih kolam, fluks kalor, aliran dua fase, *bubble*.

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1. INTRODUCTION

Boiling heat transfer is a process of changing the form of a substance from the liquid phase to the gas phase. Boiling occurs when a liquid comes into contact with a heating surface such as a metal that has a temperature greater than the liquid's saturation temperature (Prasetya, 2011). Boiling is the most common type of convection heat transfer in industry and science. Boiling heat transfer is very efficient for transferring large amounts of heat because the heat transfer process involves the latent heat value of the fluid used. Much work has focused on improving the heat transfer efficiency of boiling by changing the physical and chemical properties of the surface using different technological processes in its fabrication (Kaniowski and Pastuszko, 2021). When the temperature of the heating surface exceeds the saturation temperature of the liquid, the liquid around the heater will vaporize and form bubbles around the heating surface. Due to the buoyancy force, the bubbles attached to the heating surface then move up to the top of the surface (Çengel, 2002).

Pool boiling is one of the heat transfer processes that is widely applied in cooling systems. Pool boiling was chosen because it has the ability to transfer heat twice as well as the single-phase heat transfer method in conventional cooling methods. Boiling is a phase change phenomenon from liquid to vapor that occurs at the solid-liquid interface that begins with the formation of air bubbles on the surface due to heat transfer from the surface of the solid.

The boiling process initially, the heated fluid will experience several stages. The first stage experienced by the fluid is convection boiling in this area has not formed bubbles. Then then in the second stage will experience the formation of bubbles in the nucleate boiling area. In nucleate boiling, 2 areas of bubble formation are known, namely the bubble area formed and then broken into the fluid liquid and the saturated boiling area where the bubble formed will rise to the surface of the fluid liquid. The subcooled boiling area which is a boiling process where the temperature of most of the heated fluid is still below the saturation temperature, in this area the researchers will study. Furthermore, in the third stage called transition boiling, the bubbles formed will envelop part of the heating surface. After the entire heating surface is covered by a bubble layer, the fourth stage is film boiling (Holman, 1990).

Conducted research on the boiling pool heat transfer and critical heat flux in saturated water which were studied experimentally under transient power conditions (Ayoobi *et al.*, 2019). A chrome-aluminum-iron alloy wire laid horizontally in a pool of water was used as the heating element. The heating rate in the test section was increased linearly depending on time by applying voltage control for 1 second to 5000 seconds. The results show that as the time period increases, the transient boiling heat transfer coefficient in nucleate boiling increases, decreases at the transition from nucleate boiling to film boiling, and increases again in film boiling. The transient boiling heat transfer coefficient decreases in the second part of film boiling as the heat flux and thickness of the vapor film around the wire increase.

Developed pool boiling curves and the corresponding bubble dynamics of these porous copper samples were experimentally investigated (Ma, Huang and Wang, 2021). To facilitate vapor release as well as liquid filling in the three-dimensional porous surface, a multi-layer gradient opening open-cell porous copper was developed. Results show that the Onset of Nucleate Boiling (ONB) of the gradient sample is only about 8.3% of the smooth surface and the maximum heat transfer coefficient (about 8.2 × 10 W/m-K) is about 8 times higher than the smooth surface.

A review of methods to improve boiling heat transfer was conducted in three main sections (Mehralizadeh, Shabanian and Bakeri, 2020): (1) surface texture, (2) surface characteristics and (3) surface structure. The effects of these methods on boiling process parameters, especially heat transfer coefficient and critical heat flux were elaborated. Also, other parameters such as the onset of nucleate boiling and bubble dynamics features (active nucleation site density, bubble departure diameter, and bubble departure frequency) were also reviewed.

Pool boiling experiments were conducted by (Chuang, Chang and Ferng, 2019) to investigate the effect of heating orientation on boiling heat transfer characteristics and bubble dynamics. Based on the measured data, the boiling heat transfer capability increases with increasing inclination angle of the heating surface. This enhanced effect is in the lower heat flux region and insignificant in the higher heat flux region. Conducted a study with high-speed visualization revealed that higher square micropillars have a faster bubble emergence frequency at low heat flux, because higher micropillars are conducive to inducing capillary flow and help separate the paths of emerging bubbles and filling liquid (Zhao *et al.*, 2020). However, the increase in bubble diameter at high heat flux restrains the bubble exit with higher square micropillars.

Conducted experiments on the main boiling mechanisms occurring in thermosyphon evaporators where only pool boiling occurs (Guichet, Almahmoud and Jouhara, 2019). The importance of bubbles in increasing the boiling point heat transfer coefficient was demonstrated and factors such as the nucleation process, bubble growth, microlayer evaporation, sensible and latent heat transfer coupled with the transient conduction that occurs at bubble emergence from the cavity, and the diameter of bubble emergence.

Conducted research that provided research progress in the modification of the heat transfer surface of boiling pools by passive reinforcement technology, including micro-scale and macro-scale (Chu *et al.*, 2023). It is explained that the macro structure leads to the improvement of the boiling heat transfer effect, mainly by using the macro structure to increase the heat transfer surface area. While the micro-scale structure mainly improves the heat transfer performance of boiling pool through increasing the nucleation density, while the critical heat flux is also improved to a certain extent.

The main parameters affecting heat transfer under nucleate pool boiling conditions are heat flux, saturation pressure, and thermophysical properties of the working fluid; therefore, the effects of these parameters on heat transfer under nucleate pool boiling conditions have been most widely investigated and are fairly well established. The effects of these parameters on the heat transfer coefficient are usually compound effects and vary with changes in boiling conditions. In many cases, an accurate quantitative description of the parameters affecting nucleate pool boiling is not possible. Based on the above, the appearance of nucleate pool boiling on a metal plate of uniform thickness and in a horizontal position without any special surface treatment would be an ideal case for evaluation (Pioro, Rohsenow and Doerffer, 2004).

Nucleic boiling correlations are widely used. Due to differences in surface roughness exponents no single correlation gives a completely satisfactory prediction (Jones, McHale and Garimella, 2009). One prediction of the nucleate boiling equation to be used uses the equation from (Rohsenow, 2022).

Investigated micro roughness and smooth surfaces and explained that smaller nucleation cavities lead to smaller bubbles whereas higher bubble frequencies lead to larger fluxes (Benjamin and Balakrishnan, 1996). Conducted a comprehensive analytical and numerical review on heat transfer of boiling pool nucleates (Stojanović *et al.*, 2022). From his study, it has been understood the characteristics of boiling phenomena such as bubble emergence, bubble emergence frequency, and bubble waiting time and growth. Generally, the frequency of bubble emergence is expressed as the sum of bubble waiting time and bubble growth by equation (1):

$$f = \frac{1}{(\tau_w + \tau_g)} \quad (1)$$

Where τ_w, τ_g are bubble dwell time and bubble growth time, respectively. As shown by many experiments, the frequency of bubble appearance depends not only on the wall superheat, thermophysical properties of the fluid, phase contact angle, cavity size, and interaction between bubbles, but also on the surface roughness.

Based on the previous explanation, the author will examine the effect of heat flux on the frequency of bubble appearance in boiling pools using a two phase heat transfer unit H654 P. A. Hilton machine.

2. METHODOLOGY

2.1. Research Flow Chart

The research began by studying the literature related to the research focus. Then proceed to check the condition of the two phase pool boiling research tool used. The research flow chart is presented as Figure 1.

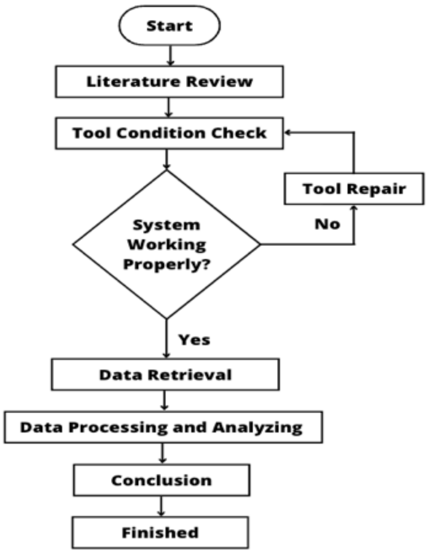


Figure 1. Research flow chart.

Initial testing of the tool is intended to test whether the system is working properly or not. The parameters of the system working properly include, the heater is functioning, the condensation process occurs and the temperature measurement system and flow meter work properly. If the test conditions do not work properly, improvements will be made.

Data collection was carried out based on the research parameters, namely power, and water volume in the pool. Data processing and analysis were carried out after data collection was completed. Analysis is used based on data and equations related to research. Finally make a conclusion on the results of the previous analysis.

2.2. Research Flow Chart

The two phase heat transfer boiling pool tool in Figure 2 below has the following component parts, the dimensions of the glass tube are 80 mm in diameter, 300 mm in length, and 0.0015 m in volume^3.

Figure 2. Two phase heat transfer unit P.A. Hilton Ltd. engineers.

Condenser surface area 0.032 m^2. The effective heater length is 42 mm, diameter is 12.7 mm, and has a heater surface area of 0.0019 m^2. The temperature gauge uses a K-type thermocouple sensor, while the water flow rate measurement uses a water flow meter.

The main part of the research test for bubble emergence observation is inside the research test tube presented in Figure 3.

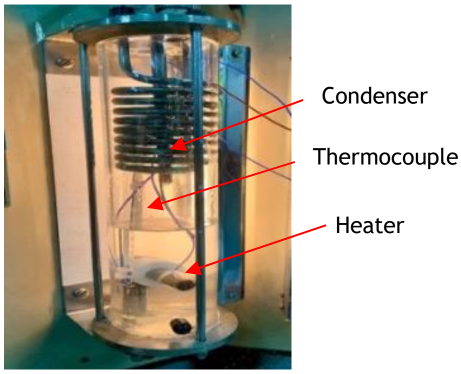


Figure 3. Research test tube.

Inside the test tube in Figure 3, there is a heater, where bubbles will appear on the surface of the heater. The temperature sensor is placed in the water fluid at the bottom and top of the heater, the temperature sensor is also placed on the surface of the heater.

2.3. Engine Testing Preparation

1) Installation of a two phase heat transfer unit:
   - Filling the fluid tube by inserting fluid in the form of water through a hose that has been connected to the machine.
   - Filling water in the tub with the water pump and connecting the hose from the water pump to the condenser.

2) Arduino installation:
   - Connect the usb cable to a laptop or computer that has the Arduino software installed.

The research measurements are supported by real time measurements using an Atmega 328 micro control that is integrated with a parallax DAQ.

2.4. Machine Running Procedure

1) Ensure that the voltmeter and ampere voltage regulator are in the zero position.
2) Switch to the on position to start the engine.
3) Connect the arduino usb cable to a laptop that has the arduino software installed.
4) Using a flow meter control valve to adjust the water flow rate to the condenser.
5) Increase the heat input using a voltage regulator and determine the desired voltage and current strength.
6) Observe until bubbles appear on the surface of the heater.

2.5. Nucleate Boiling

The calculation is done by referring to the equation (2), (3) and (4) (Bergman, 2011):

$$\dot{q}_{nc} = \mu_l h_{fg} \left[\frac{g(\rho_l-\rho_v)}{\sigma}\right]^{1/2} \left[\frac{C_p(T_s-T_{sat})}{C_{sf} h_{fg} Pr_l^n}\right]^3 \quad (2)$$

where:

$\dot{q}_{nc}$ = nucleate boiling heat flux (W/m^2)
μ_l = viscosity of liquid fluid (kg/m.s)
h_{fg} = enthalpy of vaporization (J/kg)
g = gravitational acceleration (m/s^2)
ρl = liquid density (kg/m^3)
ρv = vapor density (kg/m^3)
σ = surface tension (N/m)
C_p = specific heat (J/kg.K)
T_s = surface temperature (°C)
T_{sat} = fluid saturation temperature (°C)
C_{sf} = surface constant
Pr = Prandtl number
n = fluid experimental constant

Heat transfer rate of boiling:

$$\dot{Q}_{boiling} = A.\dot{q}_{nc} \quad (3)$$

where:

$\dot{Q}_{boiling}$ = heat transfer rate (W)
A = heating surface area (m^2)

Evaporation rate:

$$\dot{m}_{evaporation} = \frac{\dot{Q}_{boiling}}{h_{fg}} \quad (3)$$

where:

$\dot{m}_{evaporation}$ = water evaporation rate (kg/s)
h_{fg} = enthalpy of vaporization (J/kg)

3. RESULTS AND DISCUSSION

3.1. Experimental Results on Nucleic Boiling

In this test, variations in power and water volume were used as shown in Table 1. Based on Table 1, there are 5 powers used which are obtained by determining different voltage and current strengths. Various power parameters were used to determine the effect of heat flux on temperature and bubble appearance.

Table 1. Power variation in the test.

No.	Power (W)	Voltage (V)	Current A)
1	75	75	1
2	110	85	1,3
3	168	105	1,6
4	237,5	125	1,9
5	290	145	2

Temperature data collection in each test using arduino software where arduino will take temperature data every second (Prayudha, Fadhil and Novianto, 2022). There are 3 temperature sensors connected to the arduino consisting of the temperature on the surface of the heater, the temperature of the water above and below the heater. This is done to find out the temperature comparison in each different area.

Table 2. Tests at water volume = 557.6 mm^3.

No.	Power (W)	Heater (° C)	Top (° C)	Bottom (° C)
1	75	97,7	97,86	55,3
2	110	94,49	94,7	57,74
3	168	99,99	103,17	99,19
4	237,5	95,43	94,19	59,69
5	290	105,14	103,69	100,52

Table 3. Tests at water volume = 778.7 mm³.

No.	Power (W)	Heater (° C)	Top (° C)	Bottom (° C)
1	75	95,76	92,4	55,01
2	110	92,9	89,67	49,16
3	168	94,94	92,48	56,09
4	237,5	93,34	93,68	56,87
5	290	99,78	101,16	90,72

Table 4. Tests at water volume = 994.7 mm³.

No.	Power (W)	Heater (° C)	Top (° C)	Bottom (° C)
1	75	56,15	47,94	42,53
2	110	60,87	52,91	40,74
3	168	69,83	62,46	56,39
4	237,5	68,24	60,45	59,12
5	290	82,08	77,18	74,79

The resulting data is the average value taken by arduino and produces temperatures as listed in Table 2 for testing water volume 557.6 mm^3, Table 3 for testing water volume 778.7 mm^3 and Table 4 for testing water volume 994.7 mm^3.

3.2. Effect of Heat Flux on Temperature with Variation of Water Volume

This section discusses the effect of heat flux on temperature as a function of the volume of water consumed. Then the graph of the effect of heat flux on temperature can be obtained in Figure 4, Figure 5 and Figure 6 with various variations in water volume.

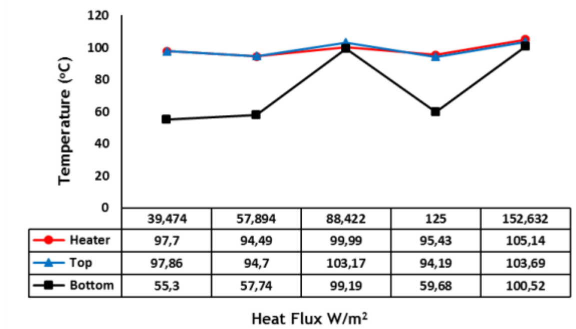


Figure 4. Graph of the effect of heat flux on temperature with water volume = 557.6 mm³

It can be seen from several experimental graphs that there are three temperatures used, namely: heater temperature in red, upper area water temperature in blue and lower water temperature in black. In some of the graphs above, the resulting temperature is strongly influenced by the heat flux given.

The water temperature will continue to increase according to the amount of heat flux input given. As well as water volume peramater also affects the length of the boiling process. In some variations of the volume of water tested, the resulting temperature produces the fact that the lower the volume of water used, the faster it reaches the boiling process, and the resulting temperature is higher. Vice versa, if the volume of water used is higher, the boiling process will take longer, and the resulting temperature is lower as illustrated in the graph.

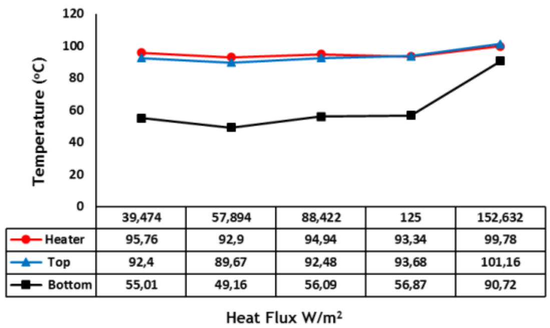


Figure 5. Graph of the effect of heat flux on temperature with water volume = 778.7 mm³

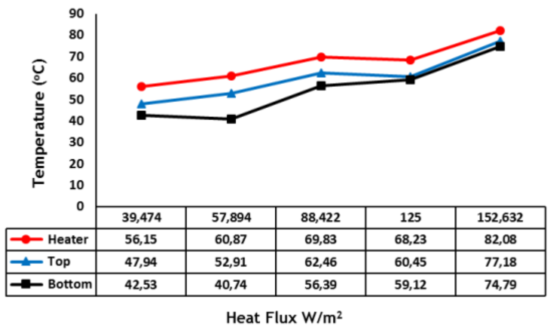


Figure 6. Graph of the effect of heat flux on temperature with water volume = 994.7 mm³

In Figure 5 and Figure 6, the bottom fluid temperature is higher and almost close to the heater surface temperature. This happens because the heater surface temperature has reached the water saturation temperature (~100° C). As a result, the boiling process (the appearance of bubbles) begins. The effect of this boiling causes very high heat transfer, causing the bottom fluid temperature to be very high.

The following is presented in Table 5 properties of water at a saturation temperature of 100° C.

Table 5. Properties of water at 100°C

Water properties	Value
Viscosity of liquid (μ_l)	0.282 x 10^{-3} kg.m/s
Enthalpy of vaporization (h_{fg})	2257 x 10^3 J/kg
Liquid density (ρ_l)	957.9 kg/m³
Liquid density (ρ_v)	0.6 kg/m³
Surface tension (σ)	0.0589 N/m
Specific heat (Cp)	4217 J/kg,K
Experimental constant (C_{sf})	0,0130
Prandtl number	1,75

From this data, it can be calculated:

- Nucleate boiling heat flux by equation (1):

$$\dot{q}_{nucleate} = (0{,}282 \times 10^{-3})(2257 \times 10^{3})\left[\frac{9{,}81 \times (957{,}9 - 0{,}6)}{0{,}0589}\right]^{\frac{1}{2}} \times \left(\frac{4217(102-100)}{0{,}0130(2257 \times 10^{3}) \times 1{,}75^{1}}\right)^{3} = 11{,}27 \times 10^{4}\,\frac{W}{m^2}$$

- Heat transfer rate of boiling by equation (2):

$$\dot{Q}_{boiling} = A.\dot{q}_{nucleate}$$
$$\dot{Q}_{boiling} = 1{,}9 \times 10^{-3} m^2 \times 1{,}1{,}27 \times 10^{4}\,\frac{W}{m^2}$$
$$\dot{Q}_{boiling} = 214{,}13\,W$$

- Water evaporation rate by equation (3):

$$\dot{m}_{evaporation} = \frac{\dot{Q}_{boiling}}{h_{fg}}$$
$$\dot{m}_{evaporation} = \frac{214{,}13\,W}{2257 \times 10^{3}\,J/kg}$$
$$\dot{m}_{evaporation} = 9{,}49 \times 10^{-5}\,kg/s$$

3.3. Variation of Water Volume and Power on Temperature

The variation of water volume at each power against temperature produced graphs in Figure 7 at 75 Watts, Figure 8 at 110 Watts, Figure 9 at 168 Watts, Figure 10 at 237.5 Watts and Figure 11 at 290 Watts. From some of the graphs produced above, the parameter volume of water used greatly affects the temperature of the water produced, the more volume of water used, the lower the temperature produced and the longer it takes to reach the boiling process. Conversely, the less volume of water used, the faster it reaches the boiling process, and the resulting temperature is high.

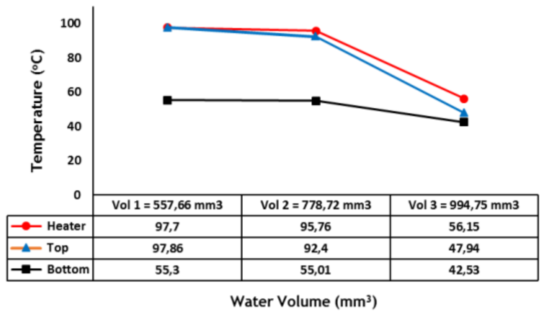


Figure 7. Graph of changes in water volume against temperature at 75 Watts of power.

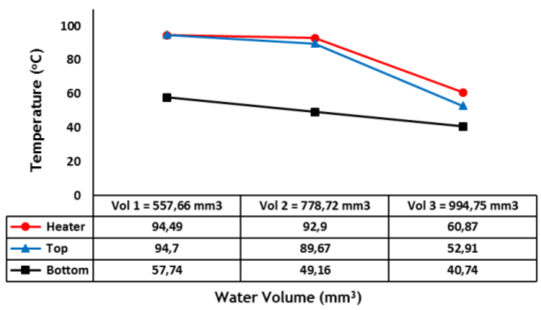


Figure 8. Graph of changes in water volume against temperature at 110 Watts of power.

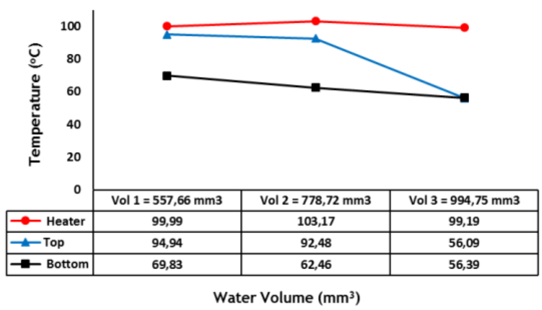


Figure 9. Graph of changes in water volume against temperature at 168 Watts of power.

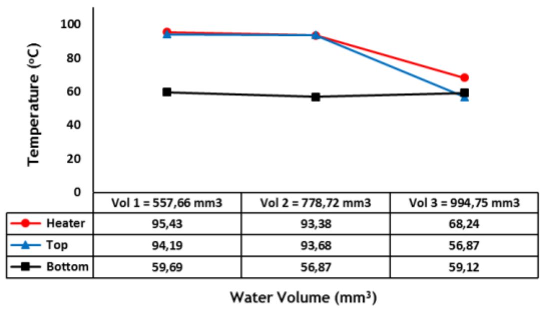
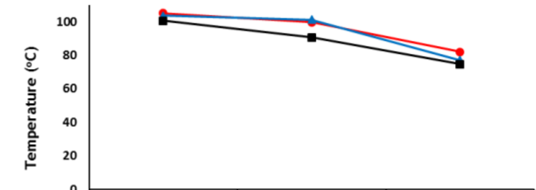


Figure 10. Graph of changes in water volume against temperature at 237.5 Watts of power.



	Vol 1 = 557,66 mm3	Vol 2 = 778,72 mm3	Vol 3 = 994,75 mm3
Heater	105,14	99,78	82,08
Top	103,69	101,16	77,18
Bottom	100,52	90,72	74,79

Figure 11. Graph of changes in water volume against temperature at 290 Watts of power.

In some variations, the power parameters used also affect the temperature and the appearance of bubbles. With the smallest power parameter of 75 Watts, the appearance of bubbles that float reaches the top of the surface and takes longer to reach its saturation temperature. Whereas at the highest power, 290 Watts, the bubbles that appear are more numerous and faster, so that the change in the phase of water from liquid to vapor will occur more quickly.

3.4. Effect of Calorific Flux on *Bubble* Emergence Frequency

Testing the effect of heat flux has been carried out with different power variations and different water volumes. The graph below shows the effect of heat flux on the frequency of bubble appearance/minute. The data collection process is carried out when the bubble appears and rises to the top of the surface.

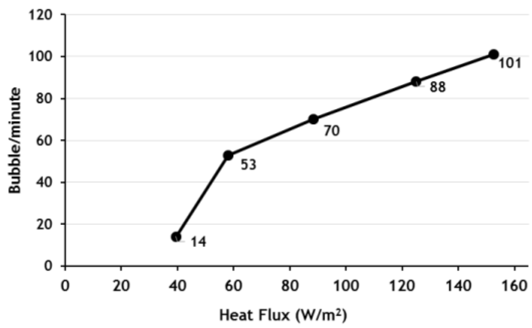


Figure 12. Graph of the effect of heat flux on bubble appearance/minute.

From Figure 12, it can be seen that at low heat flux, the frequency of bubble appearance is quite small, and the higher the heat flux given, the higher the frequency of bubble appearance, so that the event of bubble appearance is quite a lot and will continue to increase.

The above phenomenon has been investigated by Derewnicki where he reported that rapid heating produces bubbles spontaneously on the heating surface (Derewnicki, 1985).

The frequency of bubble appearance from a rate of 14 bubbles per minute at 39,474 W/m^2 increased linearly to 101 bubbles per minute at 152,632 W/m^2. By mathematical analysis, an increase of 1 bubble per minute occurs at every 1.3 W/m increase in heat flux^2.

This is in accordance with the theory that the rate of heat transfer in water will affect the rate of evaporation of water, where the higher the heat transfer rate will be directly proportional to the rate of evaporation of water. This water vaporization rate will cause the appearance of bubbles which indicates the boiling process in water and will evaporate.

4. CONCLUSION

The power used greatly affects the boiling process. The greater the power used, the faster the boiling process is achieved. This leads to a faster bubble appearance process. It was found that in addition to power affecting the frequency of bubble appearance, the volume of water also affects the frequency of bubble appearance and the length of the boiling process. The higher the volume of water used, the longer the boiling process occurs and the smaller the frequency of bubble appearance per minute.

In this test, using varying heater power 75 W, 110 W, 168 W, 237.5 W and 290 W. The frequency of bubble appearance from a rate of 14 bubbles per minute at 39,474 W/m^2 increased linearly to 101 bubbles per minute at 152,632 W/m^2. Thus, an increase of 1 bubble per minute occurs at every 1.3 W/m increase in heat flux^2. The heat transfer will be greater if there is the appearance of bubbles, where latent heat plays a major role.

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The Effect of Heat Flux on the Frequency of Bubble Appearance in a Boiling Pool

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The Effect of Heat Flux on the Frequency of Bubble Appearance in a Boiling Pool

Pengaruh Fluks Kalor Terhadap Frekuensi Munculnya Bubble Pada Didih Kolam

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Abstract

This research was conducted to determine the effect of heat flux on the frequency of bubbles appearing in boiling ponds. All fluid movement in pool boiling is caused by natural convection currents. The boiling pool consists of four areas of the pool boiling regime. The division of the four areas is based on the value of the heat flux and the difference between the surface temperature of the heater and the fluid. Using a two-phase heat transfer unit (H654 P.A. Hilton machine), The results showed that the power used greatly influences the boiling process, and besides that, the volume of water used also affects the duration of the boiling process. Based on tests using various power levels of 75 W, 110 W, 168 W, 237.5 W, and 290 W. The occurrence of bubbles will be faster and more numerous when using a lower volume of water and greater power. The heat transfer will be greater if a bubble appears, where latent heat plays a very important role. With mathematical analysis, an increase of 1 bubble per minute occurs for every increase in heat flux of 1.3 W/m^2.

Keywords: pool boiling, heat flux, two-phase flow, bubble.

SDGs:

7 AFFORDABLE AND CLEAN ENERGY

Abstrak

Penelitian ini dilakukan untuk mengetahui pengaruh fluks kalor terhadap frekuensi munculnya *bubble* pada didih kolam. Didih kolam merupakan proses pendidihan dimana segala pergerakan fluidanya disebabkan oleh arus konveksi natural. Didih kolam terdiri dari empat daerah *pool boiling regime*. Pembagian keempat daerah tersebut berdasarkan nilai fluks kalor dan selisih dari suhu permukaan pemanas dan fluida. Metode penelitian menggunakan mesin *two phase heat transfer unit H654 P. A. Hilton*. Hasil penelitian menunjukkan bahwa daya yang digunakan sangat berpengaruh terhadap proses pendidihan, selain itu tingkat volume air yang digunakan juga mempengaruhi lamanya proses pendidihan. Berdasarkan pengujian menggunakan bervariasi daya 75 W, 110 W, 168 W, 237,5 W dan 290 W. Peristiwa munculnya *bubble* akan semakin cepat dan banyak ketika menggunakan volume air lebih rendah dan daya yang besar. Dengan analisis matematis dihasilkan kenaikan 1 *bubble* per menit terjadi pada setiap kenaikan fluks kalor 1,3 W/m^2.

Kata Kunci: didih kolam, fluks kalor, aliran dua fase, *bubble*.

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1. INTRODUCTION

Boiling heat transfer is a process of changing the form of a substance from the liquid phase to the gas phase. Boiling occurs when a liquid comes into contact with a heating surface such as a metal that has a temperature greater than the liquid's saturation temperature (Prasetya, 2011). Boiling is the most common type of convection heat transfer in industry and science. Boiling heat transfer is very efficient for transferring large amounts of heat because the heat transfer process involves the latent heat value of the fluid used. Much work has focused on improving the heat transfer efficiency of boiling by changing the physical and chemical properties of the surface using different technological processes in its fabrication (Kaniowski and Pastuszko, 2021). When the temperature of the heating surface exceeds the saturation temperature of the liquid, the liquid around the heater will vaporize and form bubbles around the heating surface. Due to the buoyancy force, the bubbles attached to the heating surface then move up to the top of the surface (Çengel, 2002).

Pool boiling is one of the heat transfer processes that is widely applied in cooling systems. Pool boiling was chosen because it has the ability to transfer heat twice as well as the single-phase heat transfer method in conventional cooling methods. Boiling is a phase change phenomenon from liquid to vapor that occurs at the solid-liquid interface that begins with the formation of air bubbles on the surface due to heat transfer from the surface of the solid.

The boiling process initially, the heated fluid will experience several stages. The first stage experienced by the fluid is convection boiling in this area has not formed bubbles. Then then in the second stage will experience the formation of bubbles in the nucleate boiling area. In nucleate boiling, 2 areas of bubble formation are known, namely the bubble area formed and then broken into the fluid liquid and the saturated boiling area where the bubble formed will rise to the surface of the fluid liquid. The subcooled boiling area which is a boiling process where the temperature of most of the heated fluid is still below the saturation temperature, in this area the researchers will study. Furthermore, in the third stage called transition boiling, the bubbles formed will envelop part of the heating surface. After the entire heating surface is covered by a bubble layer, the fourth stage is film boiling (Holman, 1990).

Conducted research on the boiling pool heat transfer and critical heat flux in saturated water which were studied experimentally under transient power conditions (Ayoobi *et al.*, 2019). A chrome-aluminum-iron alloy wire laid horizontally in a pool of water was used as the heating element. The heating rate in the test section was increased linearly depending on time by applying voltage control for 1 second to 5000 seconds. The results show that as the time period increases, the transient boiling heat transfer coefficient in nucleate boiling increases, decreases at the transition from nucleate boiling to film boiling, and increases again in film boiling. The transient boiling heat transfer coefficient decreases in the second part of film boiling as the heat flux and thickness of the vapor film around the wire increases.

Developed pool boiling curves and the corresponding bubble dynamics of these porous copper samples were experimentally investigated (Ma, Huang and Wang, 2021). To facilitate vapor release as well as liquid filling in the three-dimensional porous surface, a multi-layer gradient opening open-cell porous copper was developed. Results show that the Onset of Nucleate Boiling (ONB) of the gradient sample is only about 8.3% of the smooth surface and the maximum heat transfer coefficient (about 8.2 × 10 W/m-K) is about 8 times higher than the smooth surface.

A review of methods to improve boiling heat transfer was conducted in three main sections (Mehralizadeh, Shabanian and Bakeri, 2020): (1) surface texture, (2) surface characteristics and (3) surface structure. The effects of these methods on boiling process parameters, especially heat transfer coefficient and critical heat flux were elaborated. Also, other parameters such as the onset of nucleate boiling and bubble dynamics features (active nucleation site density, bubble departure diameter, and bubble departure frequency) were also reviewed.

Pool boiling experiments were conducted by (Chuang, Chang and Ferng, 2019) to investigate the effect of heating orientation on boiling heat transfer characteristics and bubble dynamics. Based on the measured data, the boiling heat transfer capability increases with increasing inclination angle of the heating surface. This enhanced effect is in the lower heat flux region and insignificant in the higher heat flux region. Conducted a study with high-speed visualization revealed that higher square micropillars have a faster bubble emergence frequency at low heat flux, because higher micropillars are conducive to inducing capillary flow and help separate the paths of emerging bubbles and filling liquid (Zhao *et al.*, 2020). However, the increase in bubble diameter at high heat flux restrains the bubble exit with higher square micropillars.

Conducted experiments on the main boiling mechanisms occurring in thermosyphon evaporators where only pool boiling occurs (Guichet, Almahmoud and Jouhara, 2019). The importance of bubbles in increasing the boiling point heat transfer coefficient was demonstrated and factors such as the nucleation process, bubble growth, microlayer evaporation, sensible and latent heat transfer coupled with the transient conduction that occurs at bubble emergence from the cavity, and the diameter of bubble emergence.

Conducted research that provided research progress in the modification of the heat transfer surface of boiling pools by passive reinforcement technology, including micro-scale and macro-scale (Chu *et al.*, 2023). It is explained that the macro structure leads to the improvement of the boiling heat transfer effect, mainly by using the macro structure to increase the heat transfer surface area. While the micro-scale structure mainly improves the heat transfer performance of boiling pool through increasing the nucleation density, while the critical heat flux is also improved to a certain extent.

The main parameters affecting heat transfer under nucleate pool boiling conditions are heat flux, saturation pressure, and thermophysical properties of the working fluid; therefore, the effects of these parameters on heat transfer under nucleate pool boiling conditions have been most widely investigated and are fairly well established. The effects of these parameters on the heat transfer coefficient are equally compound effects and vary with changes in boiling conditions. In many cases, an accurate quantitative description of the parameters affecting nucleate pool boiling is not possible. Based on the above, the appearance of nucleate pool boiling on a metal plate of uniform thickness and in a horizontal position without any special surface treatment would be an ideal case for evaluation (Pioro, Rohsenow and Doerffer, 2004).

Nucleic boiling correlations are widely used. Due to differences in surface roughness exponents no single correlation gives a completely satisfactory prediction (Jones, McHale and Garimella, 2009). One prediction of the nucleate boiling equation to be used uses the equation from (Rohsenow, 2022).

Investigated micro roughness and smooth surfaces and explained that smaller nucleation cavities lead to smaller bubbles whereas higher bubble frequencies lead to larger fluxes (Benjamin and Balakrishnan, 1996). Conducted a comprehensive analytical and numerical review on heat transfer of boiling pool nucleates (Stojanović *et al.*, 2022). From his study, it has been understood the characteristics of boiling phenomena such as bubble emergence, bubble emergence frequency, and bubble waiting time and growth. Generally, the frequency of bubble emergence is expressed as the sum of bubble waiting time and bubble growth by equation (1):

$$f = \frac{1}{(\tau_w + \tau_g)} \qquad (1)$$

Where τ_w, τ_g are bubble dwell time and bubble growth time, respectively. As shown by many experiments, the frequency of bubble appearance depends not only on the wall superheat, thermophysical properties of the fluid, phase contact angle, cavity size, and interaction between bubbles, but also on the surface roughness.

Based on the previous explanation, the author will examine the effect of heat flux on the frequency of bubble appearance in boiling pools using a two phase heat transfer unit H654 P. A. Hilton machine.

2. METHODOLOGY

2.1. Research Flow Chart

The research began by studying the literature related to the research focus. Then proceed to check the condition of the two phase pool boiling research tool used. The research flow chart is presented as Figure 1.

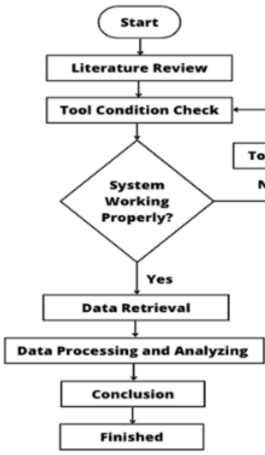

Figure 1. Research flow chart.

Initial testing of the tool is intended to test whether the system is working properly or not. The parameters of the system working properly include, the heater is functioning, the condensation process occurs and the temperature measurement system and flow meter work properly. If the test conditions do not work properly, improvements will be made.

Data collection was carried out based on the research parameters, namely power, and water volume in the pool. Data processing and analysis were carried out after data collection was completed. Analysis is used based on data and equations related to research. Finally make a conclusion on the results of the previous analysis.

2.2. Research Flow Chart

The two phase heat transfer boiling pool tool in Figure 2 below has the following component parts, the dimensions of the glass tube are 80 mm in diameter, 300 mm in length, and 0.0015 m in volume[3].

Figure 2. Two phase heat transfer unit P.A. Hilton Ltd. engineers.

Condenser surface area 0.032 m^2. The effective heater length is 42 mm, diameter is 12.7 mm, and has a heater surface area of 0.0019 m^2. The temperature gauge uses a K-type thermocouple sensor, while the water flow rate measurement uses a water flow meter.

The main part of the research test for bubble emergence observation is inside the research test tube presented in Figure 3.

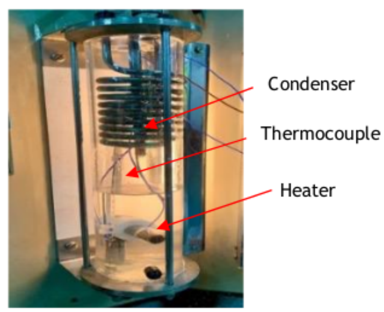

Figure 3. Research test tube.

Inside the test tube in Figure 3, there is a heater, where bubbles will appear on the surface of the heater. The temperature sensor is placed in the water fluid at the bottom and top of the heater, the temperature sensor is also placed on the surface of the heater.

2.3. Engine Testing Preparation

1) Installation of a two phase heat transfer unit:
    - Filling the fluid tube by inserting fluid in the form of water through a hose that has been connected to the machine.
    - Filling water in the tub with the water pump and connecting the hose from the water pump to the condenser.

2) Arduino installation:
    - Connect the usb cable to a laptop or computer that has the Arduino software installed.

The research measurements are supported by real time measurements using an Atmega 328 micro control that is integrated with a parallax DAQ.

2.4. Machine Running Procedure

1) Ensure that the voltmeter and ampere voltage regulator are in the zero position.
2) Switch to the on position to start the engine.
3) Connect the arduino usb cable to a laptop that has the arduino software installed.
4) Using a flow meter control valve to adjust the water flow rate to the condenser.
5) Increase the heat input using a voltage regulator and determine the desired voltage and current strength.
6) Observe until bubbles appear on the surface of the heater.

2.5. Nucleate Boiling

The calculation is done by referring to the equation (2), (3) and (4) (Bergman, 2011):

$$\dot{q}_{nc} = \mu_l h_{fg}\left[\frac{g(\rho_l-\rho_v)}{\sigma}\right]^{1/2}\left[\frac{C_p(T_s-T_{sat})}{C_{sf}h_{fg}Pr_l^n}\right]^3 \qquad (2)$$

where:

$\dot{q}_{nc}$ = nucleate boiling heat flux (W/m^2)
μ_l = viscosity of liquid fluid (kg/m.s)
h_{fg} = enthalpy of vaporization (J/kg)
g = gravitational acceleration (m/s^2)
ρl = liquid density (kg/m^3)
ρv = vapor density (kg/m^3)
σ = surface tension (N/m)
C_p = specific heat (J/kg.K)
T_s = surface temperature (°C)
T_{sat} = fluid saturation temperature (°C)
C_{sf} = surface constant
Pr = Prandtl number
n = fluid experimental constant

Heat transfer rate of boiling:

$$\dot{Q}_{boiling} = A.\dot{q}_{nc} \qquad (3)$$

where:

$\dot{Q}_{boiling}$ = heat transfer rate (W)
A = heating surface area (m^2)

Evaporation rate:

$$\dot{m}_{evaporation} = \frac{\dot{Q}_{boiling}}{h_{fg}} \qquad (3)$$

where:

$\dot{m}_{evaporation}$ = water evaporation rate (kg/s)
h_{fg} = enthalpy of vaporization (J/kg)

3. RESULTS AND DISCUSSION

3.1. Experimental Results on Nucleic Boiling

In this test, variations in power and water volume were used as shown in Table 1. Based on Table 1, there are 5 powers used which are obtained by determining different voltage and current strengths. Various power parameters were used to determine the effect of heat flux on temperature and bubble appearance.

Table 1. Power variation in the test.

No.	Power (W)	Voltage (V)	Current A)
1	75	75	1
2	110	85	1,3
3	168	105	1,6
4	237,5	125	1,9
5	290	145	2

Temperature data collection in each test using arduino software where arduino will take temperature data every second (Prayudha, Fadhil and Novianto, 2022). There are 3 temperature sensors connected to the arduino consisting of the temperature on the surface of the heater, the temperature of the water above and below the heater. This is done to find out the temperature comparison in each different area.

Table 2. Tests at water volume = 557.6 mm³.

No.	Power (W)	Heater (° C)	Top (° C)	Bottom (° C)
1	75	97,7	97,86	55,3
2	110	94,49	94,7	57,74
3	168	99,99	103,17	99,19
4	237,5	95,43	94,19	59,69
5	290	105,14	103,69	100,52

Table 3. Tests at water volume = 778.7 mm³.

No.	Power (W)	Heater (° C)	Top (° C)	Bottom (° C)
1	75	95,76	92,4	55,01
2	110	92,9	89,67	49,16
3	168	94,94	92,48	56,09
4	237,5	93,34	93,68	56,87
5	290	99,78	101,16	90,72

Table 4. Tests at water volume = 994.7 mm³.

No.	Power (W)	Heater (° C)	Top (° C)	Bottom (° C)
1	75	56,15	47,94	42,53
2	110	60,87	52,91	40,74
3	168	69,83	62,46	56,39
4	237,5	68,24	60,45	59,12
5	290	82,08	77,18	74,79

The resulting data is the average value taken by arduino and produces temperatures as listed in Table 2 for testing water volume 557.6 mm^3, Table 3 for testing water volume 778.7 mm^3 and Table 4 for testing water volume 994.7 mm^3.

3.2. Effect of Heat Flux on Temperature with Variation of Water Volume

This section discusses the effect of heat flux on temperature as a function of the volume of water consumed. Then the graph of the effect of heat flux on temperature can be obtained in Figure 4, Figure 5 and Figure 6 with various variations in water volume.

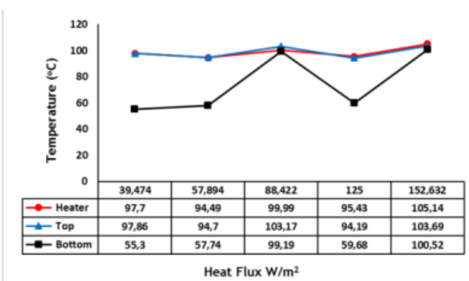

Figure 4. Graph of the effect of heat flux on temperature with water volume = 557.6 mm³

It can be seen from several experimental graphs that there are three temperatures used, namely: heater temperature in red, upper area water temperature in blue and lower water temperature in black. In some of the graphs above, the resulting temperature is strongly influenced by the heat flux given.

The water temperature will continue to increase according to the amount of heat flux input given. As well as water volume peramater also affects the length of the boiling process. In some variations of the volume of water tested, the resulting temperature produces the fact that the lower the volume of water used, the faster it reaches the boiling process, and the resulting temperature is higher. Vice versa, if the volume of water used is higher, the boiling process will take longer, and the resulting temperature is lower as illustrated in the graph.

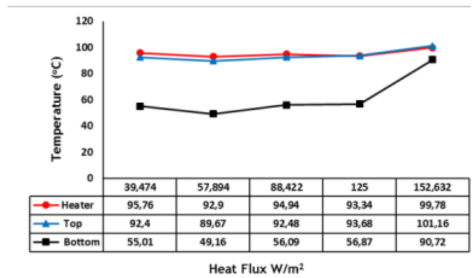

Figure 5. Graph of the effect of heat flux on temperature with water volume = 778.7 mm³

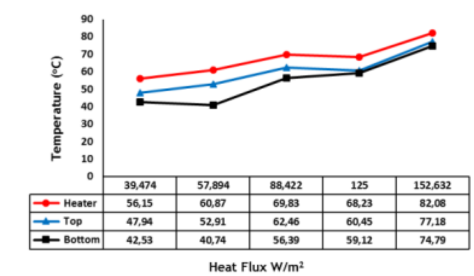

Figure 6. Graph of the effect of heat flux on temperature with water volume = 994.7 mm³

In Figure 5 and Figure 6, the bottom fluid temperature is higher and almost close to the heater surface temperature. This happens because the heater surface temperature has reached the water saturation temperature (~100° C). As a result, the boiling process (the appearance of bubbles) begins. The effect of this boiling causes very high heat transfer, causing the bottom fluid temperature to be very high.

The following is presented in Table 5 properties of water at a saturation temperature of 100° C.

Table 5. Properties of water at 100°C

Water properties	Value
Viscosity of liquid (μ_l)	0.282 x 10^{-3} kg.m/s
Enthalpy of vaporization (h_{fg})	2257 x 10^3 J/kg
Liquid density (ρ_l)	957.9 kg/m³
Liquid density (ρ_v)	0.6 kg/m³
Surface tension (σ)	0.0589 N/m
Specific heat (Cp)	4217 J/kg,K
Experimental constant (C_{sf})	0,0130
Prandtl number	1,75

From this data, it can be calculated:

- Nucleate boiling heat flux by equation (1):

$$\dot{q}_{nucleate} = (0{,}282\times10^{-3})(2257\times10^{3})\left[\frac{9{,}81\times(957{,}9-0{,}6)}{0{,}0589}\right]^{\frac{1}{2}} \times\left(\frac{4217(102-100)}{0{,}0130(2257\times10^{3})\times1{,}75^{1}}\right)^{3} = 11{,}27\times10^{4}\,\frac{W}{m^2}$$

- Heat transfer rate of boiling by equation (2):

$$\dot{Q}_{boiling} = A.\,\dot{q}_{nucleate}$$
$$\dot{Q}_{boiling} = 1{,}9\times10^{-3}m^2 \times 1{,}1{,}27\times10^{4}\,\frac{W}{m^2}$$
$$\dot{Q}_{boiling} = 214{,}13\,W$$

- Water evaporation rate by equation (3):

$$\dot{m}_{evaporation} = \frac{\dot{Q}_{boiling}}{h_{fg}}$$
$$\dot{m}_{evaporation} = \frac{214{,}13\,W}{2257\times10^{3}\,J/kg}$$
$$\dot{m}_{evaporation} = 9{,}49\times10^{-5}\,kg/s$$

3.3. Variation of Water Volume and Power on Temperature

The variation of water volume at each power against temperature produced graphs in Figure 7 at 75 Watts, Figure 8 at 110 Watts, Figure 9 at 168 Watts, Figure 10 at 237.5 Watts and Figure 11 at 290 Watts. From some of the graphs produced above, the parameter volume of water used greatly affects the temperature of the water produced, the more volume of water used, the lower the temperature produced and the longer it takes to reach the boiling process. Conversely, the less volume of water used, the faster it reaches the boiling process, and the resulting temperature is high.

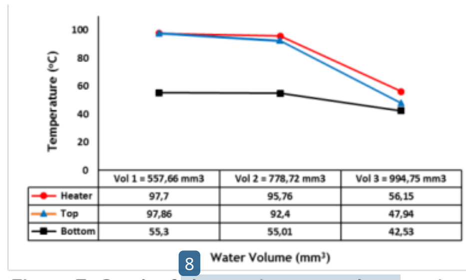

Figure 7. Graph of changes in water volume against temperature at 75 Watts of power.

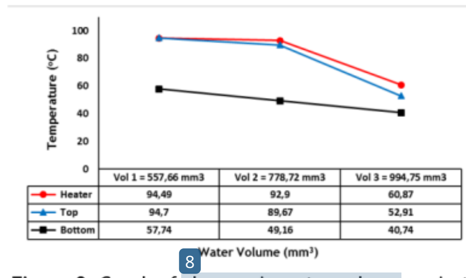

Figure 8. Graph of changes in water volume against temperature at 110 Watts of power.

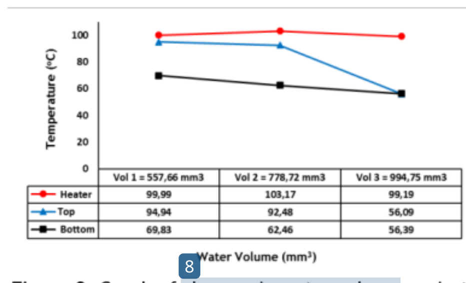

Figure 9. Graph of changes in water volume against temperature at 168 Watts of power.

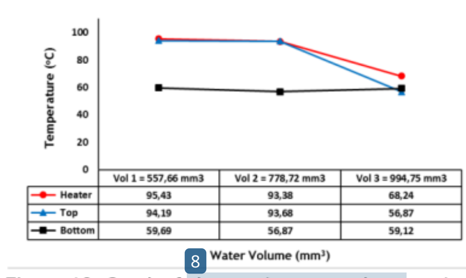

Figure 10. Graph of changes in water volume against temperature at 237.5 Watts of power.

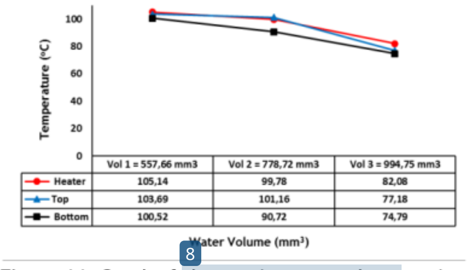

Figure 11. Graph of changes in water volume against temperature at 290 Watts of power.

In some variations, the power parameters used also affect the temperature and the appearance of bubbles. With the smallest power parameter of 75 Watts, the appearance of bubbles that float reaches the top of the surface and takes longer to reach its saturation temperature. Whereas at the highest power, 290 Watts, the bubbles that appear are more numerous and faster, so that the change in the phase of water from liquid to vapor will occur more quickly.

3.4. Effect of Calorific Flux on *Bubble* Emergence Frequency

Testing the effect of heat flux has been carried out with different power variations and different water volumes. The graph below shows the effect of heat flux on the frequency of bubble appearance/minute. The data collection process is carried out when the bubble appears and rises to the top of the surface.

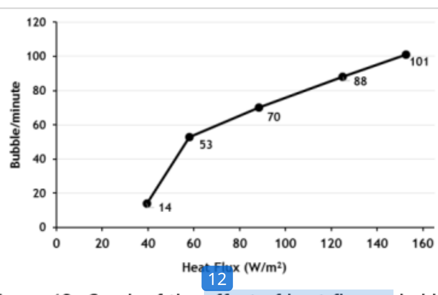

Figure 12. Graph of the effect of heat flux on bubble appearance/minute.

From Figure 12, it can be seen that at low heat flux, the frequency of bubble appearance is quite small, and the higher the heat flux given, the higher the frequency of bubble appearance, so that the event of bubble appearance is quite a lot and will continue to increase.

The above phenomenon has been investigated by Derewnicki where he reported that rapid heating produces bubbles spontaneously on the heating surface (Derewnicki, 1985).

The frequency of bubble appearance from a rate of 14 bubbles per minute at 39,474 W/m^2 increased linearly to 101 bubbles per minute at 152,632 W/m^2. By mathematical analysis, an increase of 1 bubble per minute occurs at every 1.3 W/m increase in heat flux^2.

This is in accordance with the theory that the rate of heat transfer in water will affect the rate of evaporation of water, where the higher the heat transfer rate will be directly proportional to the rate of evaporation of water. This water vaporization rate will cause the appearance of bubbles which indicates the boiling process in water and will evaporate.

4. CONCLUSION

The power used greatly affects the boiling process. The greater the power used, the faster the boiling process is achieved. This leads to a faster bubble appearance process. It was found that in addition to power affecting the frequency of bubble appearance, the volume of water also affects the frequency of bubble appearance and the length of the boiling process. The higher the volume of water used, the longer the boiling process occurs and the smaller the frequency of bubble appearance per minute.

In this test, using varying heater power 75 W, 110 W, 168 W, 237.5 W and 290 W. The frequency of bubble appearance from a rate of 14 bubbles per minute at 39,474 W/m^2 increased linearly to 101 bubbles per minute at 152,632 W/m^2. Thus, an increase of 1 bubble per minute occurs at every 1.3 W/m increase in heat flux^2. The heat transfer will be greater if there is the appearance of bubbles, where latent heat plays a major role.

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