An Experimental Study for the Effect of Vertical Forced Vibration on Pool Boiling Heat Transfer Coefficient

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ABSTRACT

In this research, an experimental study for the effect of forced vibrations on pool boiling heat transfer coefficient has been made in a glass of chamber cylindrical shape (75 mm bore and 300 mm length) and an electrical heater inside it (12 mm diameter and 80 mm length) to heat the distilled water at different values of heat flux (27.521 kW/m^2-53.08 kW/m^2) utilized to perform this work. The experimental study is carried out at a range of frequencies (2-40 Hz) and at a range of amplitude (1.8-3.5 mm).

The result obtained showed that the pool boiling heat transfer coefficient is increasing with increasing the vibration frequency within a range of (2-14 Hz), compared with that heat transfer without frequency. And, the maximum enhancement ratio is about 250% at 5 Hz and q''=27.521 kW/m^2, 231% at 6 Hz and q''=36.727 kW/m^2, 181% at 6 Hz and q''=41.83 kW/m^2 and 93% at 8 Hz and q''=53.08 kW/m^2. In general, it is found that the difference in the temperature has been maintained at the highest value of vibration frequency range of (14-40 Hz), and the value of heat transfer coefficient is significantly increasing with increasing the vibration Reynolds number (Rev).

The effect of vibration frequency has improved not only the boiling heat transfer coefficient, but also led to improve the amount of heat drawn by the cooling water (condensation) by increasing the amount of falling drops.

The following empirical relations have been obtained between the experimental heat transfer coefficient with vibration (h_v) and some of important parameters, such as excess temperature (ΔT_{exsses}) in ^oC, input heat flux (q'') in (W/m^2), and vibration frequency (f) in Hz:

$h_v = 0.246912 \times f^{0.16534} \times \Delta T^{-0.92429} \times q''^{1.0727}$ nd, the second correlation is (hv) with Reynolds vibration effect (Rev) and input heat flux (q'') in (kW/m^2)$h_v=499.747\times Rev^{0.3576}\times q''^{-2.14}$

دراسة عملية لتاثير الاهتزازات القسرية الشاقولية على معامل انتقال الحرارة بالغليان الحوضي

الخلاصة

تناول هذا البحث إجراء دراسة عملية لبيان تأثير الإهتزازات القسرية الشاقولية على معامل إنتقال الحرارة بالغليان الحوضي في داخل زجاجة إسطوانية الشكل ارتفاعها(300 mm) وقطرها(75mm) لها قاعدتان من النيكل المطلي عند نهايتيها وتحتوي بداخلها سخان كهربائي (heater) اسطواني الشكل طوله (80mm) وقطره (12mm) مثبت بالقاعدة السفلية للأسطوانة يقوم بتسخين الماء المقطر لقيم فيض حراري تتراوح بين ($27.521\ kW/m^2$) إلى (53.08 kW/m^2) أعدت لهذا الغرض. تمت الدراسة تحت تأثيرمعدل إهتزازات يتراوح بين (2-40 Hz) وقيم السعات الاهتزازية تتراوح بين (1.8-3.5mm).

النتائج التي تم التوصل لها بينت زيادة معامل انتقال الحرارة بالغليان الحوضي مع زيادة الترددات الإهتزازية من(2-14Hz) وأعظم قيمة لنسبة التحسن في معامل انتقال الحرارة عند كل فيض حراري 250% عند 5Hz و$q''=27.521\ kW/m^2$, 231%عند 6 Hz و $q''=32.727\ kW/m^2$, 181%عند 8 Hz, $q''=41.83\ kW/m^2$, 93%عند 8 Hz و $q''=53.08\ kW/m^2$.

بصورة عامة وجد ان الفرق في درجات الحرارة بين سطح السخان الكهربائي (heater) والسائل يثبت عند قيم الترددات العالية Hz(14-40) , ويزداد معامل انتقال الحرارة بزيادة عدد رينولد الاهتزازي.

كما وان تأثير الاهتزازات لم يقتصر على معدل انتقال الحرارة بالغليان فقط ولكن ادى إلى تحسين معدل الحرارة المسحوبة من ماء التبريد (عملية التكثيف) وذلك بزيادة معدل تساقط القطرات المتكثفة.

تم استنباط العلاقات التجريبية التالية التي تربط كلا من معامل إنتقال الحرارة الاهتزازي بالغليان الحوضي وبعض المتغيرات المهمة مثل (ΔT_{axsses}) , (Rev) , (q'') عند كل تردد اهتزازي (f):

$$h_v=0.246912\times f^{0.16534}\times\Delta T^{-0.92429}\times q''^{1.0727}$$

$$h_v=499.747\times Rev^{0.3576}\times q''^{-2.14}$$

Symbol	Definition	Unit
A	Heat transfer surface area	m^2
Acc.	Vibration Acceleration	m/s^2
Amp.	Vibration Amplitude	Mm
C_P	Specific Heat	J/kg. K
D	Heater Diameter	Mm
f	Vibration frequency	Hz
g	Gravity	m/s^2
h	Heat transfer coefficient	$W/m^2.C$
Δh_{fg}	Latent heat of vaporization	J/kg
I	Current	Amp
k	Thermal Conductivity	W/m. C
L	Heater Length	Mm
$m^{\cdot}$	Mass flow rate of cooling water	kg/s
N	Number of Nucleation sites	-
P	Pressure	N/m^2
$p_{Crit.}$	Critical pressure	N/m^2
Pg	Pressure inside the bubble	N/m^2
q"	Surface heat flux	W/m^2
q_w"	Water heat flux	kW/m^2
R	Bubble Radius	µm
R_p	Surface roughness	Mm
Ra	Arithmetic average roughness	-
T	Temperature	$^{\circ}C$
V	Voltage	Volt
	Greek Symbols	
α	Enhancement heat transfer coefficient in equation (4.15)	-
ν	Kinematic viscosity	m^2/s
µ	Dynamic viscosity	Kg/m.s
ρ	Density	kg/m^3

INTRODUCTION

Phase change heat transfer is a broad field that finds applications in almost all of the engineering disciplines. Boiling and condensation are two of the most important phase change processes as they are generally associated with high heat transfer rates. Boiling is an essential basic operation in thermal sciences. It is the most effective heat transfer method because of its high performance due to latent heat transport, thus allowing reducing size, weight and volume of heat exchange devices and improves the thermal performance of components for the process industry and power plants. Therefore, boiling heat transfer plays a very important role for a wide number of applications in many technological and industrial areas, including energy production. As an example: (electric power plant, Air conditioning and refrigeration, Industrial plant heat exchanger, Water treatment and purification, Petroleum refinery).The study on the boiling process can be traced back to as early as the eighteen century by the observation of the vapor film in the boiling of liquid over the heating surface by Leiden in (1756). The extensive study on the effect of the very large difference in the temperature of the heating surface and the liquid, (ΔT), was first done by Nukiyama (1934). [1]

T. Osamu et. al. (1980) [2] presented a case report about the pool boiling heat transfer from a horizontal plane heater to mercury under various system pressures and liquid levels in the presence of a magnetic field of which direction is parallel to the direction of gravity. They found with increasing the magnetic flux density, both the incipient boiling heat flux and the maximum heat flux decreased in comparison with those for the non-magnetic field. However, when the liquid level above the heating surface was thin, the magnetic field affected little the incipient boiling heat flux and the burnout heat flux.

Zaidi (1990) [3] included in his research a novel technique of vapor removal through suction is investigated. He used a (5mm by 5mm) Inconel sheet heater heated by a DC power source in a pool of saturated water. Data of suction tests were compared with non-suction test results. The results of this study suggested that the suction technique was very effective in enhancing the critical heat flux and convective heat transfer coefficient from very high heat flux surfaces. In this study, an enhancement as high as 1600% in critical heat flux over the non-suction test results was achieved.

Benjamin and Balakrishnan (1997) [4] focused on an experimental program to determine the nucleation site density with a variety of surface finishes on materials, such as aluminum and stainless steel by using distilled water, acetone,n-hexane, and carbon tetrachloride in pool boiling at low to moderate heat fluxes and high speed photography. They found a correlation for the nucleation site density in terms of the thermo physical properties of the heating surface and the liquid, and the metrological properties of the surface were developed. A correlation for the nucleation site density was obtained as

$$\frac{N}{A}=218.8\,(Pr)^{1.63}\left(\frac{1}{\gamma}\right)\theta^{-0.4}(\Delta T)^{3} \qquad \ldots..(1)$$

Pr: Prandtl number.
γ: the surface liquid interaction parameter.
θ: dimensionless surface roughness parameter

The N/A value decreased and then increased with Ra. These were explained interms of the bubble radius, the wall superheat, and the ability of the trapped vapor in the cavities to grow at a given wall superheat.

Ho-younkim et al. (2004) [5] studied the enhancement of a natural convection and pool boiling heat transfer via ultrasonic vibration. The experimental results showed that the effects of the ultrasonic vibration on the flow behavior were vastly different, depending on the heat transfer regime and the amount of dissolved gas. In the natural convection and sub cooled boiling regimes, the behavior of cavitations' bubbles strongly affected the degree of heat transfer enhancement and in saturated boiling, no cavitations' occurred. Thus, the reduced thermal bubble size departure and acoustic streaming were major factors enhancing heat transfer rate.

K. Prisniakov et al. (2004) [6] presented the results of an experimental research with action of vibrations and force gravitational fields of various intensities. The boundary frequency bands and amplitude, at which the heat and mass transfer was improved or became worse, were equal to 60 Hz, and the amplitudes were equal to approximately 3 or 5 mm. The idealized substantiations of vibration actions on heat and mass transfer of all three zones of heat pipes were given. The new concept of influence of vibrations on processes in heat pipes was offered.

M.C. Zaghdoudi and M. Lallemand (2005) [7] present an experimental study of the influence of a DC uniform electric field on nucleate boiling heat transfer. EHD effects are quantitatively investigated by performing experiments on various liquids with different properties. In these experiments, *n* pentane, R-113, and R-123 are used as working fluids and the boiling phenomenon takes place on a horizontally-oriented copper surface. It is demonstrated that the heat transfer performance of *n*-pentane, R-113 and R-123 is improved when utilizing the EHD enhancement technique. For the range of parameters investigated here, up to 160% enhancement is obtained for *n*-pentane and a corresponding 170% enhancement for R-113. However, up to 500% enhancement is obtained for R-123.

Sebastineet al. (2005) [8] present experimental work for enhanced pool boiling using carbon nanotube arrays on a silicon surface. He considered the introduction of carbon nanotube (CNT) arrays on the chip surface to delay critical heat transfer CHF, andto enhance boiling heat transfer, pool boiling experiments showed a 35% increase in CHF for CNT-coated silicon surface and 60% reduction superheat at the point of fully developed boiling. The net effect of these changes is an increase of greater than 400%in the effective heat transfer coefficient.

Baffigi and Bartoli(2009) [9] present an experimental investigation was carried out to search the effect of ultrasonic waves on heat transfer, in sub cooled boiling conditions, from a stainless steel horizontal cylinder,to distilled water. They calculated heat flux per unit surface q is equal to:

$$q''=\frac{V\,I}{2\pi RoL} \qquad \text{………….} \ (2)$$

Where:
V: voltage drop
I: Amperage
Ro: cylinder outer radius
L: distance between the sensing leads
The heat transfer coefficient calculate by the Newton's equation without and with ultrasonic waves as:

$$h=\frac{q''}{(Ts\text{-}Tl)} \qquad \text{…………….} \ (3)$$

The experimental results had shown that:
1- The heat transfer coefficient, h, increases monotonically with the Pgen, q" being equal.
2- The best condition occurs at Pgen equal to 500W.
3- h ,enhances with the ΔTsub increasing,q"still being equal.
4- Finally, for beginning cylinder temperature being equal, they had found that h increases with the temperature increasing.
Where:
Pgen=ultrasonic power generation.
ΔTsub=sub cooling degree.

Sang M. Kwark, et a. (2010) [10] presented an experimental study carried out for the effects of pressure, orientation, and heater size with nanocoated heaters during pool boiling of water using Al_2O_3 nanoparticle coated flat heaters. Theresults from the present study were as follows:

1- The CHF enhancement was found to be nearly identical for three anocoatings formed from three different average nanoparticle sizes each. Therefore, over the range of average nanoparticle size tested (75–210 nm), there was no significant dependence of nucleate BHT and CHF.
2- Both surfaces (uncoated and nanocoated) showed a similar decreasing trend of CHF as the inclination angle increased from (0-180^o).
3- A similar CHF decreasing trend was observed for both coated and uncoated surfaces as heater size increased from (0.75 cm * 0.75 cm) to (2 cm * 2 cm). This CHF reduction could be due to the longer resistive path offered to the cooler bulk fluid with increasing heater size. However, the wettability in the nanocoatingwas believed to reduce the path’s resistance, significantly enhancing CHF (90%) when compared to the uncoated surface.

EXPERIMENTAL WORK

Heat transfer to boiling liquids is a convection process which involves a change of phase from liquid to vapor. To acquire a physical understanding of the heating process in pool boiling, one would consider the heating of distilled water at one atmosphere on an electrically heated tube. The heating surface is submerged in the liquid. Heat flux (q_w) is determined from measured voltage, current, the surface area of the tube, the temperatures of the tube wall surface (T_w) and the bulk liquid (T_L) are measured by thermocouples. The electrical energy input to the heating element is controlled by the variable rheostat.

The experimental apparatus contain (Glass Chamber, Heating element, Condenser, Varic, Voltmeter, Ammeter, Digital reader, Glass thermometers, Pressure gauge, Volume Scale, High temperature cut-Out, High pressure cut-out, Relief Valve, Cooling water inlet, cooling water outlet.

EXPERIMENTAL PROCEDURE

Without Vibration

1. The unit was charged with the distilled water until the level of the water in the cylinder was (20 – 30) mm above the top of the heater.
2. The electric heater was adjusted to (30) watts, and the cooling water flow rate was adjusted until the desired pressure was about (1atm). Then, the voltage, current, vapor pressure, liquid temperature and metal temperature were observed.
3. The power was increased to (100) watts, and the cooling water flow rate was adjusted to give the desired pressure. When the test fluid started to boil vigorously, the pressure release valve steam waspulled out to release any air in the cylinder.
4. When the test fluid reached the saturation temperature and steady state conditions, the current, voltage, liquid temperature, and wall temperature were recorded.The power input was then increased at an equal intervals,and the same operation was repeated.

With Vibration

Re- application of the above steps

1. Select value of input power by controlling the value of voltage and current.
2. Shedding frequencies ranging between (2-40)Hz is controlled the amount by the function generator and be sure of the value of hanging frequency on the system by the oscilloscope.
3. The value of the temperature deference is recorded and then determined the value of the heat transfer coefficient under vibration effect. And the same operation was repeated.

Vibration system equipment contains (Exciter, Vibration head, Function generator, Power Amplifier, Digital storage oscilloscope, Vibration Meter). See figure (1)and(2)

DETERMINATION OF HEAT FLUX AND POOL Boiling Heat Transfer Coefficient

The energy generated in the heater can be calculated by using the current (I) pass through it and the voltage (V).

$$\text{Input Power}=I\times V \qquad \text{.... (4)}$$

At steady state, heat generated from the heater is transferred to the test fluid, while some is lost through natural convection from the glass surface to environment. It can be translated into the following energy balance:

$$\text{Input Power}=q_{loses}+q_{w} \qquad \text{....(5)}$$

The heat transfer to the water (q_w) is equal to the heat hauled by cooling water through the condenser and can be determined from its specific heat capacity (Cp) and temperature difference as shown below:

$$q_{w}=\dot{m}\times Cp\times(T_{out}-T_{in}) \qquad \text{.......(6)}$$

Now, the heat transfer due to the natural convection (q_{losses}) can be determined from Newton's law:

$$q_{losses}=h_{air\text{-}glass}\times A_{glass}\times(T_{bulk}-T_{ambient}) \qquad \text{..........(7)}$$

$$\text{The net of heat } (q_w) = \text{Input Power}-q_{losses}$$

$$=\dot{m}\times Cp\times(T_{out}-T_{in}) \qquad \text{........(8)}$$

Since the maximum capacity of the electric heater is (250) watt, and the area of the heater is equal to (0.00301) m^2, the mass flow rate equal to (0.005) kg/sec, the heat flux (q_w"= q_w/A) was designed to vary uniformly in six different levels.The boiling heat flux from a solid surface to the fluid is expressed from Newton's law of cooling as

$$q''_w = h\times(T_w - T_{sat}) = h\times\Delta T_{excess} \qquad .....(9)$$

Where:

T_{excess}: - ($T_w - T_{sat}$) is called the excess temperature [11]

a. The heat transfer coefficient can be found by using the following equation:

$$h = \frac{q''_w}{T_w - T_{sat}} = \frac{q''_w}{\Delta T_{excess}} \qquad ....(10)$$

b. The total surface area of heat element equal

$$A = \pi\times D\times L \qquad ....(11)$$

c.When the system work under frequency effect we must found the value of amplitude of vibration frequency can be calculated using the formula [12]

$$a = \frac{acc\times\sqrt{2}}{(2\times\pi\times f)^2} \qquad ....(12)$$

d. Vibration Reynolds number[12] .

$$Rev = \frac{2\pi \times f \times a \times L}{\nu} \qquad ....(13)$$

e. enhancement ratio

$$\alpha = \frac{h_v - h}{h} \qquad ....(14)$$

where:

h_v=heat transfer coefficient with vibration effect from eq. (10)

RESULTS AND DISCUSSION

The experimental results are presented in two categories. The first category deals with the measure of the nucleate pool boiling heat transfer coefficients for pure water with three values of mass flow rate without vibration. And,the second category deals with the measure of the nucleate pool boiling heattransfer coefficients for pure water with external vibration effect and identifies the enhancement in heat transfer coefficient.

POOL BOILING WITHOUT VIBRATION

Figure (3) shows the variation of the excess temperature (the difference between the heater wall temperature and the saturation boiling temperature for water) as a function of the input heat flux for three values of cooling water mass flow rates. This figure indicates the increasing in the excess temperature with increasing heat flux continuously in the nucleate boiling region, resulting from maintaining the saturation boiling temperature of water. But the wall temperature of the heater continues to increase, so that the difference will be increased.

Figure (4)reveals the most important curve in pool boiling heat transfer coefficient with input heat flux in the region of nucleate pool boiling with different cooling water flow rate (0.002 kg/sec, 0.005 kg/sec, and 0.01kg/sec). It can be seen that the heat transfer coefficient increase to a specific amount of heat flux and then starts to drop sharply with continuous increase in the value of input heat flux becauseincreasing the excess temperature and thermal layer around the heater surface anddecrease the rate of separation of bubbles from the heater surface to the boiling water (eq. 10).

POOL BOILING WITH VIBRATION

Figures (5- a,b,c,d,e)show the effect of the vibration frequency on the relation of pool boiling compared with state of heat without vibration when the cooling water flow rate is $\dot{m}$=0.005 kg/sec. We can see from fig. (5.a) effect of frequency (2Hz) on the temperature difference with reducing rate with respect to the case without vibration (56%-19%). The figures (5-b,c,d,e) also depict the enhancement in the heattransfer coefficient by shifting the curve of heat transfer coefficient with vibration to the left side. That's mean, with a practical value of (T_w-T_{sat}), it can obtain many values of (h) heat transfer coefficient when using different values of vibration frequency.especially with the range of frequency (2-14) Hz as percentage of reducing in the excess temperature at (4Hz) (47%-60%),(5Hz) (44%-70%), (6Hz) (44%-50%) and at(8Hz) (27% - 40%).

It is clear from figure (5- f)that effect of the reverse action of frequency on the heat transfer coefficient, with (14Hz) vibration frequency, becomes very close to heat transfer coefficient without vibration. That's means the effect of frequency on the bubble separation is decreasing (return to the nature of high frequency effect), so that the vapor bubble will remain on the surface of the heater (dry surface), and the excess temperature is increasing. Figures (5- g, h) show thebad effect of Increasing the frequency on the heat transfer coefficient because of increasing the temperature difference. Then, it decreases the heat transfer coefficient because increasing the frequency (decreasing of the amplitude of vibration) could minimize the rate of vapor bubble separation around the heater surface within the range of frequency (14-40) Hz.

Figures (6- a, b, c, d, e) illustrate the heat transfer coefficient as a function of heat flux at ($\dot{m}$ = 0.005 kg/sec). They indicate the effect of the frequency vibration on the values of pool boiling heat transfer coefficient for each heat flux. Also, it can be seen that from figure (6-a) the values of heat transfer coefficient higher than the case without vibration with range (100%-3%) at (2 Hz) and (196%-25%) at (4Hz). depending on the value of heat flux and the temperature difference between the heater surface temperature and saturation temperature of water.

The main shape of the figures (7-a,b,c) is same and shows the heat transfer coefficient with variation of vibration frequency value. It can be seen that increasing the heat transfer coefficient with increasing the vibration frequency, the maximum value depends on the heat flux over the range of (1-10) Hz, after that the heat transfer coefficient starts to decrease and remains constant over the range of (20-40).

In contrast, changing the temperature difference with a frequency vibration for each heat flux can be seen and one can note the lowest point of the temperature deference in figures (8-a,b) which give the highest value for the pool boiling heat transfer coefficient.Figure (9) show the value of frequency amplitude which is equal to 1.8mm at q''=27.521 kW/m^2, it clear the increase of heat flux increasing the frequency amplitude and the highest amount of it at the highest heat flux. In general highest values of frequency amplitude at the level of low-lying frequencies ranging from (2-12Hz) and this is the reason to reduce amount of excess temperature and increasing the values of heat transfer coefficient within this range of frequencies.

THE ENHANCEMENT RATIO IN NUCLEATE POOL Boiling Heat Transfer Coefficient

After knowing the nature of the change between the pool boiling heat transfer coefficient with a vibration frequency, it is necessary to know how much of this increase (enhancement) as a percentage of the rate without vibration. Table (1) lists and clarifies the upper and lower limits of enhancement of heat transfer coefficient at each frequency and heat flux as a percentage as in Eq.(14).

VIBRATION EFFECT ON CONDENSATION

Figure (10) show the effect of vibration frequency on increasing the amount of heat hauled by cooling water.

The fallen drop from the condenser surface to the boiling water increased, leading to the displacement of new layers of water formed on the surface of the condenser and decreasing the percentage losses from the system.

VIBRATION REYNOLDS NUMBER (REV) EFFECT

Figure (11) shows the variation of vibration Reynolds number at each vibration frequency with different values of heat transfer coefficient for three values of heat flux, it can be seen the behavior of the curve are not same with increasing of heat flux where it is increasing continuously in figure (11a), but the increasing is not continuously with all values of vibrational Reynolds number in the figure (11b, c). that's mean the velocity of vibration and the amplitude in fig,(9) to affect in the value of vibration Reynolds numbers that's lead to increase the rate of separation of bubbles from the heater surface to the boiling water.

Figure (12) show Photographic view the effect of vibration on boiling water at q"=36.727 kW/m^2 and q"=35.08 kW/m^2 with and without effect vibration frequency f=6 Hz, It is not difficult to segregate the difference between the two cases by concentration on the amount of bubble separation**.**

THE CORRELATIONS

It is convenient to collect all the previous results in one or two correlation equations to describe the behavior of heat transfer coefficient in pool boiling. The correlations are developed to express the relation between the heat transfer coefficient with the change in frequency vibration (f) in Hz, excess temperature (ΔT_{excess}) in $^{\circ}$C and heat flux (q") in (W/m^2). The first correlation is:

$$h_v=0.246912\times f^{0.16534}\times \Delta T_{excess}^{-0.92429}\times q''^{1.0727}$$

And, the second correlation is the heat transfer coefficient (h_v) and (Rev) at input heat flux (q") in (kW/)

$$h_v=499.747\times Rev^{0.3576}\times q''^{-2.14}$$

That the amount of conformal between the values of the process that was obtained from the experiments work and the values predicted from the first correlation shows in the figure (13) and (14).

CONCLUSIONS

The following conclusions can be made from the analysis of the experimental data:

1. The value of pool boiling heat transfer coefficient increases when increasing the value of input heat flux and decreasing the excess temperature.
2. Pool boiling heat transfer coefficient enhanced significantly, when there are forces vibration frequency affecting on the boiling system within the frequency range (2-14) Hz, the maximum enhancement in the heat transfer rate from 93% to 294% at different heat fluxes.

3. The increasing in the pool boiling heat transfer coefficient is very limited within the high vibration frequency value in the range of (16-40) Hz.
4. The effect of vibration frequency has improved not only the boiling heat transfer coefficient, but also led to improve the amount of heat drawn by the cooling water (condensation) by increasing the amount of drops falling.
5. Increasing the heat flux increases the frequency amplitude, and the highest amount of it is at the highest heat flux and equal to (1.8mm at q"=27.521 kW/m^2, 2.6mm at q"=36.727 kW/m^2, 2.7mm at q"=41.83 kW/m^2, and 3.5 at q"=53.08 kW/m^2).
6. Inference two correlation equations are developed to describe the behavior of heat transfer coefficient in pool boiling with the vibration effect.

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Table (1) Enhancement ratio of pool boiling heat transfer coefficient

q"(kW/m²)												
27.521	f(Hz)	2	4	5	6	8	10	14	16	20	30	40
	α %	100	184	250	200	159	108	75	65	71	45	45
36.727	f(Hz)	2	4	5	6	7	8	10	-	-	-	-
	α%	10.5	57	80	231	100	88	25	-	-	-	-
41.83	f(Hz)	2	4	5	6	7	8	9	-	-	-	-
	α%	9	50	93	173	84	181	0	-	-	-	-
53.08	F(Hz)	2	4	5	6	7	8	10	12	14	-	-
	α %	10	85	16	93	73	42	15	9.3	6.3	-	-

Figure (1) Photograph shown The Complete Experimental Rig with Vibration

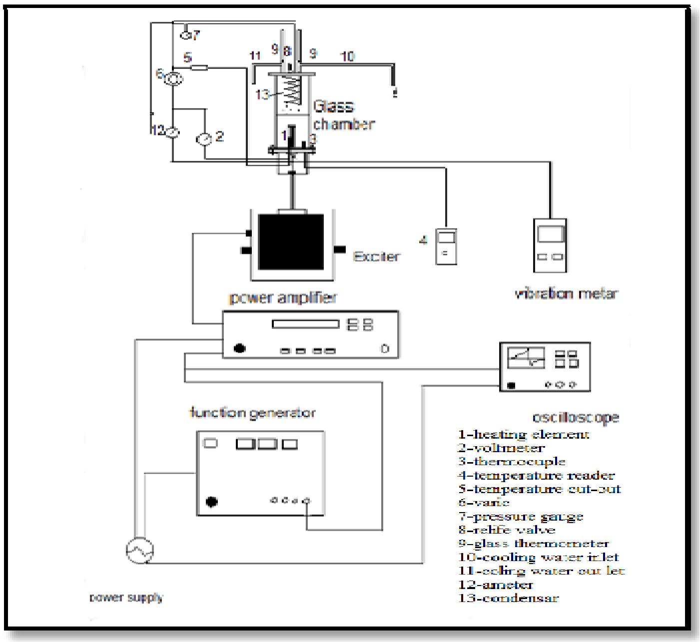


Figure (2) Schematic Diagram of the Experimental Vibration Set Up

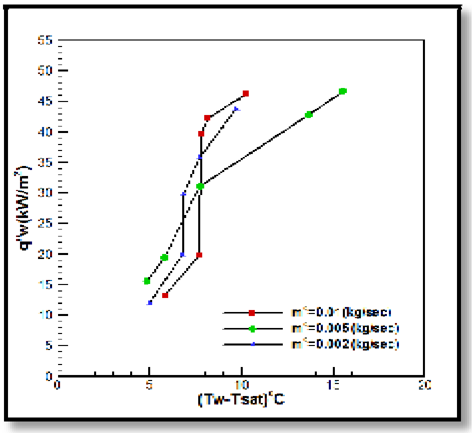


Figure (3) Pool boiling curve for water without vibration for pure water

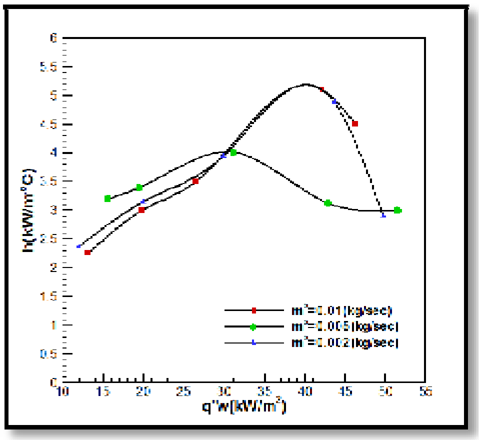
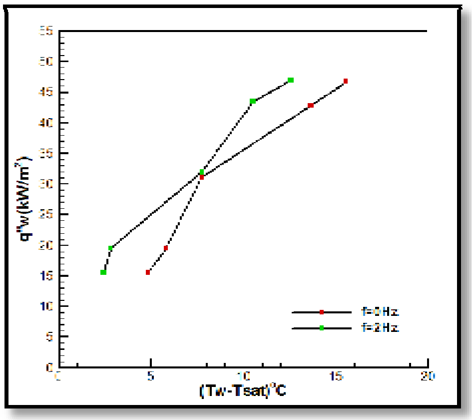
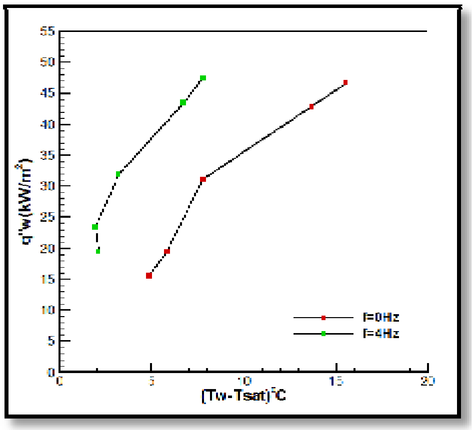


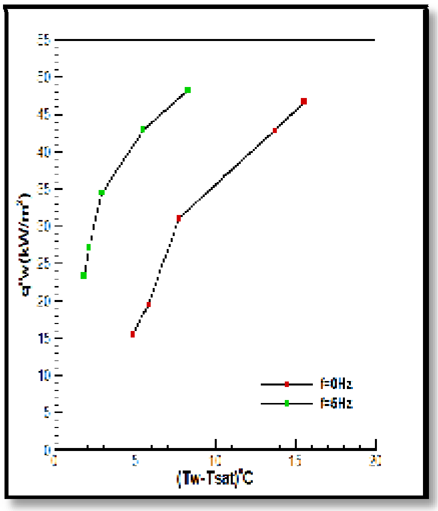
Figure (4) Pool boiling heat transfer coefficient with heat flux


q"w(kW/m²)
(Tw-Tsat)°C
f=0Hz
f=2Hz

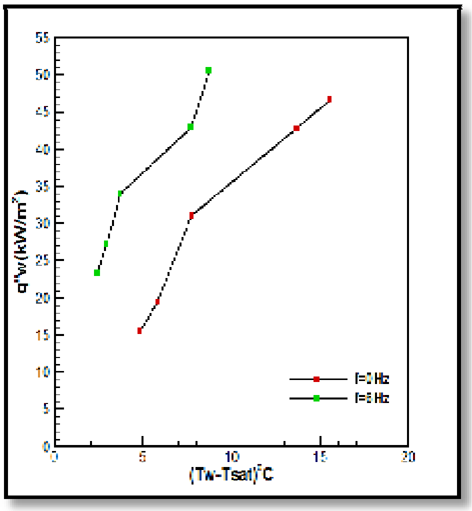
(a)


q"w(kW/m²)
(Tw-Tsat)°C
f=0Hz
f=4Hz

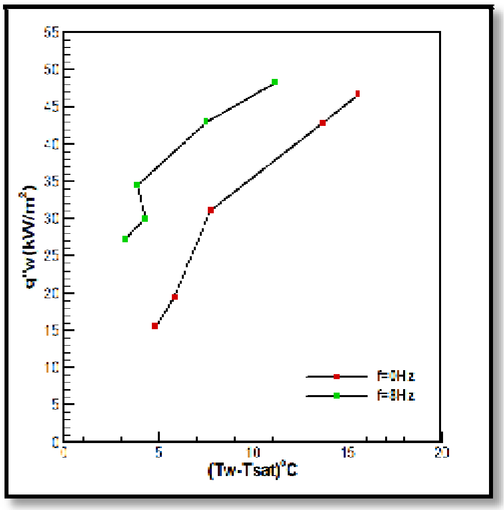
(b)


q"w(kW/m²)
(Tw-Tsat)°C
f=0Hz
f=6Hz

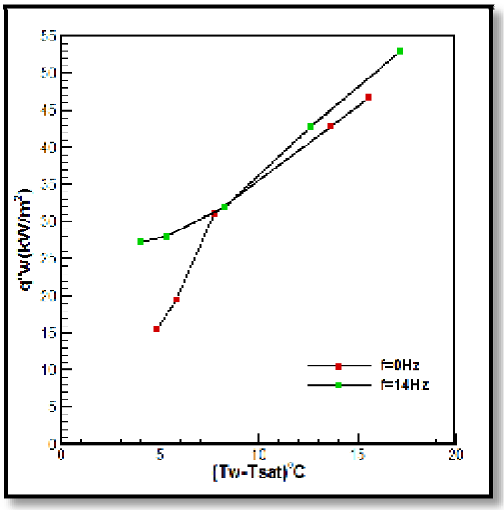
(c)


q"w(kW/m²)
(Tw-Tsat)°C
f=0Hz

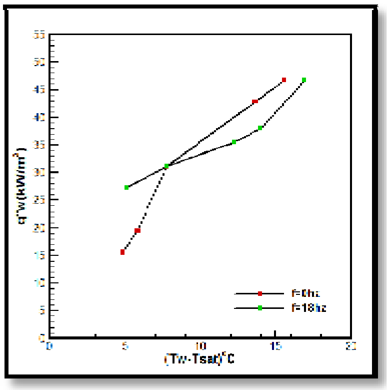
(d)



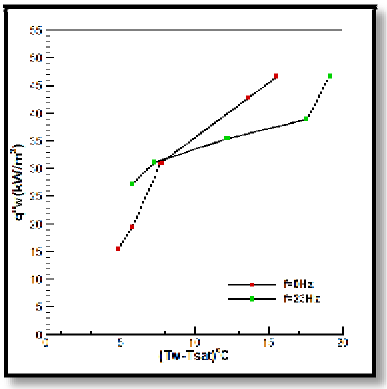
(e)



(f)

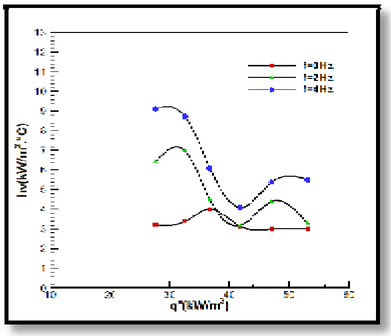


(g)

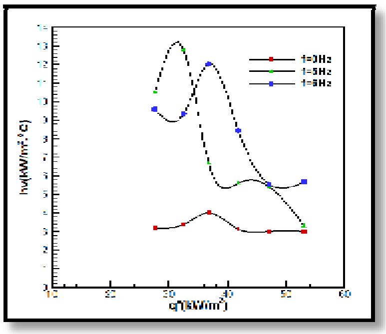


(h)

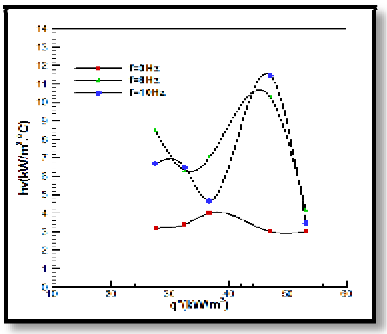
Figure(5)Pool boiling curve for water with vibration



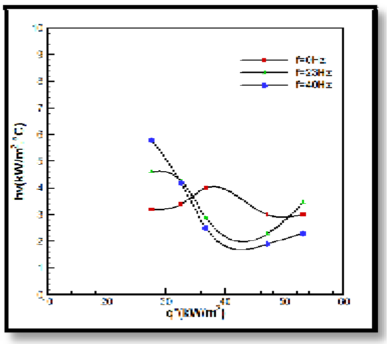
(a)



(b)

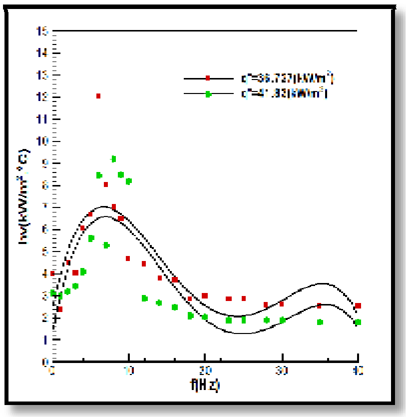


(c)

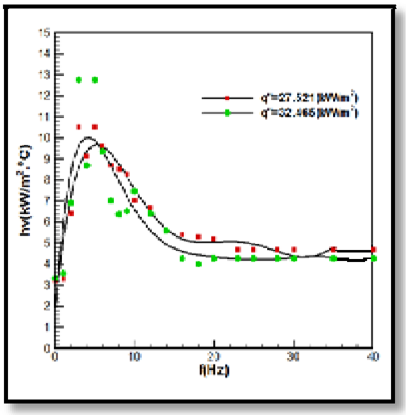


(d)

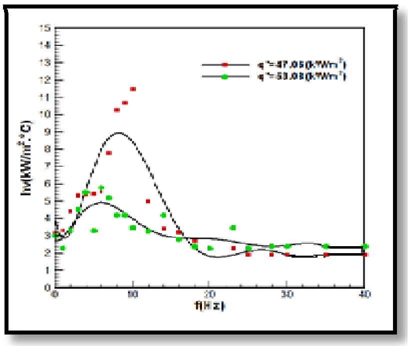
Figure (6) Variation of boiling heat transfer coefficient with heat flux for pool boiling with vibration



(a)

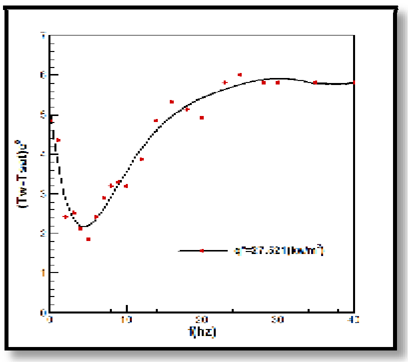


(b)

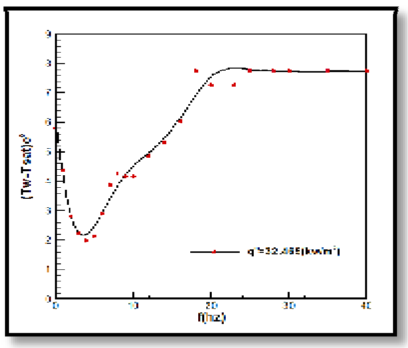


(c)

Figure (7) Variation of heat transfer coefficient with vibration frequency



(a)



(b)

Figure (8) Effect of vibration frequency on the different temperature

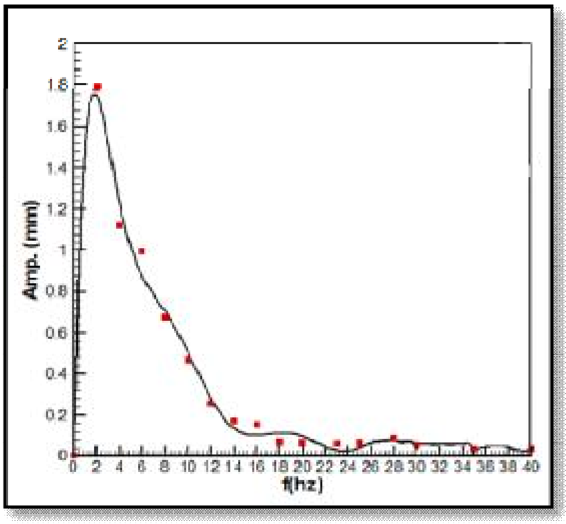


Figure (9) The vibration frequency effect on the vibration amplitude at heat flux (27.521kw/m^2)

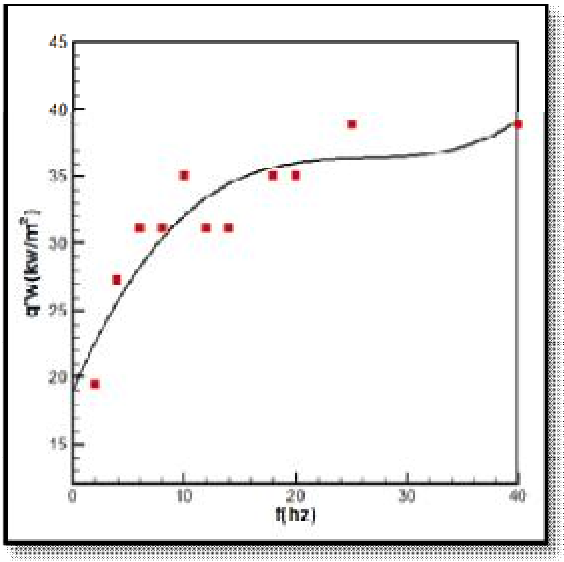
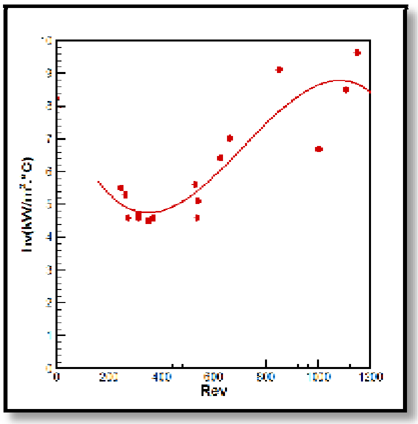
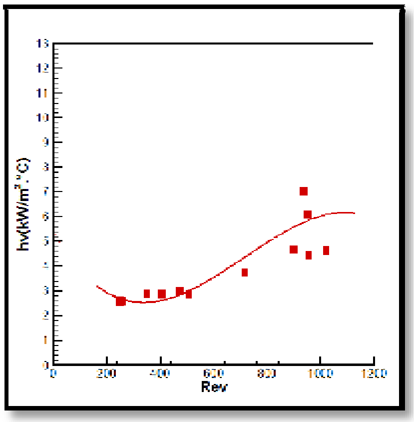


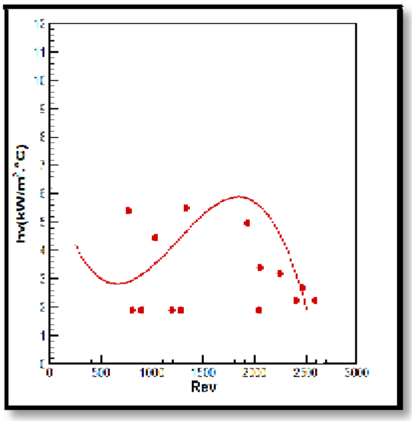
Figure (10) Vibration frequency effect on (condensation)water heat flax at input heat flux



(a) q" =27.521kW/m^2



(b) q"=36.727kW/m^2



(c) q"=47.06kW/m^2

Figure (11) Effect of vibration Reynolds number on vibration heat transfer coefficient

q "=36.727 kw/m^2

a) f=0Hz

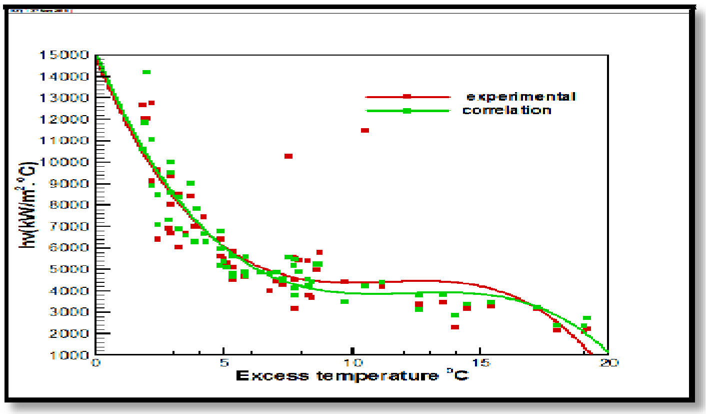
b) f= 6Hz

q"=53.08kw/m^2

c) f=6Hz

d) f=0Hz

Figure (12) Boiling Photographic view the effect of vibration on boiling water



at frequency f=6 Hz

Figure (13) Shows the amount of conformity between the theoretical and experimental results

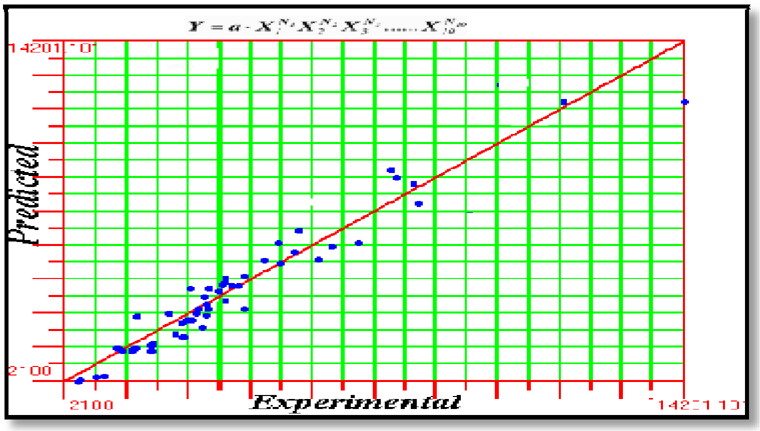


Figure (14) Show the correlation result with experimental result