Eng. & Tech. Journal, Vol.29, No.16, 2011

A Study for the Influence of Change in Ratio of Cross Sectional Area to Constant Perimeter of Thermosyphon's Condenser

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Received on: 6 /4/2011
Accepted on: 3/11/2011

Abstract

This experimental study investigated the change in cross-sectional area (csa) of thermosyphon's condenser to it's a constant perimeter (RAP) and effect of that at the thermal performance. Geometries shapes deform from circular to elliptical and flat to make a change in csa at a same perimeter of all geometries shapes where a different value of RAP are got. At each RAP a different rate of heat input in evaporator and different filling ratio of working fluid (distill water) are applied. Threshold angle (working angle) where the condensate of distilled water vapor begin to return to evaporator, this angle are examined with the horizontal level for three geometries shapes (three RAP). The results indicated that the flat two phase closed thermosyphon(FTPCT)(low RAP value) and elliptical two phase closed thermosyphon (ETPCT) had a higher and more stable heat transfer coefficient $\bar{h}$ (condenser air side) with the high and mid filling ratio from than of the circular two phase closed thermosyphon(CTPCT). That refer to more useful length of condenser to absorb heat from evaporator and prevent it from causing a rise in temperature. The high filling ratio with low rate of heat level in evaporator lead to unuseful area in thermosyphon's condenser and lowering its pressure, while low filling ratio with high rate of heat caused a chaotic flow inside TPCT and rising the evaporator and condenser temperatures.

Keywords: Thermosyphon, Condenser, cross-sectional area.

دراسة التأثير في تغيير نسبة مساحة المقطع إلى المحيط الثابت لمكثف الثرموسايفون

الخلاصة

من خلال هذه الدراسة العملية تم التحقق من تأثر الأداء الحراري للثيرموسايفون عند تغيير مساحة مقطع مكثفه نسبتا إلى المحيط الهندسي العامل لذلك المقطع (RAP) وللحصول على مساحه مقطع متغيره لمحيط ثابت تم تغيير الشكل الهندسي لأنبوب المكثف من الدائري إلى البيضوي والمسطح وبذالك تم الحصول على قيم مختلفة من (RAP) كما استخدمت قيم معدلات مختلفة من الحرارة المولدة في المبخر بالإضافة إلى تغيير مقدار شحنة المائع العامل (الماء المقطر) مما ولد نسب ملء مختلفة. حد العتبة للزاوية العاملة نسبة إلى وضع الأفق تم اختبارها لإيجاد الزاوية التي يبدأ عندها بخار الماء المكثف بالرجوع إلى المبخر. مما سبق أظهرت النتائج إن معامل انتقال الحرارة للمكثف من جهة الهواء $\bar{h}$ وفي اغلب الاختبارات تكون أعلى وأكثر استقرارا عند قيم (RAP) منخفضة ومتوسطة كما في (FTPCT)و (ETPCT)نسبتا إلى (CTPCT) مما يشير إلى أهمية استخدام قيم منخفضة لها لتأمين طرح الحرارة المسحوبة من المبخر وبالتالي منع ارتفاع درجة حرارة المبخر مع الأخذ بنظر الاعتبار حجم مجرى المائع العامل,كذلك أظهرت الدراسة إن استخدام نسبة ملئ عالية مع معدل حرارة منخفض يؤدي إلى ظهور مناطق غير عاملة في المكثف مع انخفاض في ضغطه في حين إن استخدام نسب ملئ منخفضة مع معدلات حرارة عالية يؤدي إلى جريان غير منتظم ضمن مقاطع الثيرموسايفون.

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Introduction

A conventional thermosyphon or two-phase closed thermosyphon (TPCT) is a wickless heat pipe. It is a device that can transfer heat From equipments and reduce moisture in air conditioning systems, or be used anywhere that requires an even distribution of temperature. The thermosyphon consists of three parts, which include the evaporator, adiabatic and condenser as in Fig.1. The evaporator of the thermosyphon is the part which is always at the bottom because the condensate returning to this section assisted by gravity. The operating process begins at the evaporator section which is filled with working fluid. The working fluid is a saturated liquid, which is heated by a heat source such as a hot bath or electrical heating element. The saturated liquid then changes to vapour and moves up to the condenser section. After that, the vapour in the condenser section transfers the heat to a heat sink such as cooled water or immersed in air channel. As a result, the vapour condenses to a liquid and flows down to the evaporator section.

There were many studies that attempted to investigate heat transfer characteristics of the TPCT in order to improve thermosyphon performance. D.A.Reay [1] review many experimental studies the for heat transfer characteristics of a TPCT at difference working fluid with difference cross-sectional geometries beside the study of maximum heat flux in thermosyphon, pressure drop between condenser and evaporator with inclined angle, filling ratio effect. Amatachaya et al [2] investigated

experimental the effects of cross-sectional geometries, working fluid filling ratio on thermal performance of thermosyphon at different rates of heat input. I. Khazaee [3] investigated experimentally Parameters such as filling ratio, aspect ratio, heat input and the coolant mass flow rate affect to the geyser boiling in thermosyphon. S.Rittidech [4] determine the effect of dimensionless parameters on heat-transfer characteristics at vertical flat thermosyphon at normal operation conditions with different working fluid and filling ratio with input heat rates to limit the maximum heat flux in thermosyphons. Yunus.A.Cengel[5], R.C.Sachdeva[6] and Donald .R.Pitts[7] studied the effect of diameter of circular pipes, ellipse and flat shape cross sectional area of condenser on the heated tube performance . see Fig.2.

Experimental set up

In order to construct the TPCT unit, standard copper tubes with outside diameter 7.93mm and inner diameter 7mm used as a thermosyphon’s condenser with a constant circumference of 24.9mm. Special deform Tool is used to deform the circular csa of condenser pipe to the elliptical and flat shapes Fig.3. The exact csa of deform condensers are calculated by filling the condenser tube with distilled water and then measuring the distilled water volume then divided by length. Table.1 refer to inner and outer diameters with the csa for each geometrical shape. Special heater (800 watt) built in aluminum tube that has 3/8 inches nominal diameter with arc path Fig.4. This heater tube welded with other aluminum tube (evaporator), the three condensers (circular ,elliptical and flat) are connected in-turns to the secondary aluminum tube and filled with distilled water (3,6 and 9) cubic centimeter (CC), with different volumes of the three condensers. There are a different filling ratios at each condenser. Evaporator insulated primary with asbestos rope and secondary with rubber, heater wire is connect to the digital calibrated voltmeter and ammeter. Electrical heater is connect to the voltage regulator (1000 V.AC) to change heat generation, also AC.V.STABILIZER to ensure the stable voltage supply. then thermosyphon's condenser immersed in the air duct that made from perspex and insulated by cork with 25mm in thickness. Duct dimension w=206, H=8 and L=540 mm . Centrifugal fan is used to blow the air in duct. A digital thermometer are connected to an personal computer to record the measuring temperature, seven thermocouples probes type-K used to measure the temperature and distributed as shown in Fig.4. Inlet and out let air, surface of evaporator, the surface of condenser at positions 0.07,0.14,0.2m and one at the end of condenser. The end of condenser supplied with analog calibrated gage pressure and connected with the condenser by gate valve with 3cfm two-stage vacuum pump to remove the none condensable gases (air) from thermosyphon to obtain a vacuum pressure. Air duct supply with base connected from one side with protractor to limit working angle. Four approximate value of heat rates are used in this experimental tests (10,15,20 and 25 watt)

Theoretical consideration

In this study, it was assumed that there was no heat loss from the TPCT and it is completely insulated. Therefore, heat that transferred to the evaporator section was equal to that transferred from the condenser section.

Heat added to the evaporator section was calculated as follow:

$$Q = V * I \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The heat reject from condenser is:

$$Q = \bar{h} * A_s * (T_S - T_a) \ldots\ldots\ldots\ldots.. (2)$$

Therefore the average value of $\bar{h}$ for heat that transfer from condenser's surface to air side is:

$$\bar{h} = \frac{Q}{A_s*(T_S - T_a)} \quad \ldots\ldots\ldots\ldots\ldots..(3)$$

$$T_s = \frac{(T_{s1} + T_{s2} + T_{s3})}{3} \quad \ldots\ldots\ldots\ldots\ldots (4)$$

T_S = *the avarge temperature of condenser surface*

A_s = *surface area of condenser* (m^2)

, T_a = *inlet air temperature* (C)

Average Nusselt number for flow cross cylinder, ellipse and flat pipe can be expressed compactly as:

$$Nu_{c,e,f} = \frac{\bar{h}\,D}{k} = C Re_D^m Pr^n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Re_D: *Reynold number depend on high diameter of* A_{cs} *of condenser*

$$Re = \frac{\rho u D}{\mu} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(6)$$

where D = consider the high of A_{cs} *of condenser as shown in Fig.* 2

$$Pr = \frac{\mu\, Cp}{k} \quad \ldots\ldots\ldots.(7)$$

Multiple linear regression technique are used to calculate the constant number (c, m, n)in equation (5)

Arrange the set of Re, Pr and Nu in matrix as shown

$$\begin{bmatrix} L & \sum x_{1,i} & \sum x_{2,i} \\ \sum x_{1,i} & \sum x_{1,i}^2 & \sum x_{1,i}\, x_{2,i} \\ \sum x_{2,i} & \sum x_{1,i}\, x_{2,i} & \sum x_{2,i}^2 \end{bmatrix} \begin{Bmatrix} a_o \\ a_1 \\ a_2 \end{Bmatrix} = \begin{Bmatrix} \sum y_i \\ \sum x_i\, y_i \\ \sum x_{2,i} y_i \end{Bmatrix} \quad \ldots\ldots(8)$$

$$y = a_o\ x_1{}^{a1}\ x_2^{a2} \quad \ldots\ldots x_K^{aK} \quad \ldots\ldots(9)$$

$y = Nu, x_1 = Re, x_2 = Pr\ a_o = c, a1 = m, a2 = n$, $L = number\ of\ the\ set$.

$K = extended\ dimension$

Where the standard error $Sy/_x$ evaluated from:

$$Sy/_x = \sqrt{(S_r/(L-(k+1))\ )} \quad \ldots.(10)$$

Calculate sum. Of the square of residual S_r as:

$$S_r = \sum_{i=1}^{n}(y_i - a_o - a_1 x_{1,i} - a_2 x_{2,i})^2 \quad \ldots..(11)$$

Experimentally the measuring cross sectional area of the deform circular pipe ,ellipse or flat condenser depend on measuring the volume of distilled water and divided by length of the condenser .

Results and discussion

Figures 5(a-m) present results of the circular csa thermosyphon (high RAP value), while Fig.6(a-m) present results of elliptical csa, and Fig.7(a-m) present results of flat csa (low RAP). In each group (a-d),(e-h),and(j-m) refer to the dose of working fluid for volume 3,6,9 CC. The steps in heat input increasing at approximately(10,15,20 and 25 watt)at each RAP with different working fluid dose.

Temperature distribution along the condenser surface and it's pressure behavior.

Figures 5(a-d) show stability in temperature at low rate in heat input with increasing time also a simple fluctuating in pressure appear and there is no big difference between Te,Ts. at increasing in RHI. Results refer also to increase in evaporator and condenser surface temperature. Large difference in temperature between Te, Ts appear. High fluctuating in pressure refer to the chaotic flow inside the thermosyphon .

Figures 5(e-h) show 6CC working fluid dose at low RHI. The results refer to the unuseful area in condenser because the heat rejected at high pressure(high fill ratio) therefore the difference in temperature appear at surface of condenser. For more increasing in RHI more stable behavior in surface temperature, evaporator temperature and pressure with noticeable convergence in surface temperature value. The last set in the group refer to convergence behavior. While the first set at 3CC and low RHI it can be seen that the circular csa needs more time to be stable. At increasing in RHI convergence in temperature value can be noticed with stable value and increase in pressure. The second set of (6CC) results refer to a little increase in instability with decrease in each of surface's condenser temperature ,evaporator temperature and this lead to decrease in pressure. high thermal efficiency appear at the last set of this group .

Figures 7(a-m) show increase in thermal efficiency than others with more stability in behavior along the working time. Increase in thermal efficiency leads to decreases in condenser and evaporator temperature with decreases in working pressure, this group needs short time to arrived to the stability zone.

Heat transfer coefficient($\bar{h}$) and rate of heat input.

Figure 8(a-c) show the relation between $\bar{h}$ air side with RHI at 3CC working fluid with different geometric csa (different RAP). The elliptical csa Appeared to has less $\bar{h}$ than circular of the 3CC dose shows. Increasing value of $\bar{h}$ in elliptical geometrical, and more special value of $\bar{h}$ with 9CC dose for both flat and elliptical geometers.

The temperatures difference between evaporator and condenser.

Figure 9(a-c) show the relation between $(T_e - T_c)$ value against the time for different RAP (different geometries shape). Where the experimental results refer to the convergence between the two temperatures (small difference value) and that mean $(T_e \cong T_c)$ at low and mid RAP where a big thermal performance can be acquire. Small temperature difference for low and mid RAP (flat and elliptic geometric csa) refer to very high and regular change phase rate. Filling ratio effect can be clearly noticing.

RAP effect

In Fig.10 relation display big value of Nusselt number for circle geometry from than ellipse and flat shape, while the dose proportional to the Nusselt number. Where at almost time $\bar{h}$ for FTCPT and ETCPT are higher and more staple from CTPCT, and that appear the effect of RAP. Real change for shape geometry (make a change in The effective diameter) as shown in fig.2. Decrease in effective diameter (increase in RAP) at the same air flow rate make a decrease in Reynolds number show fig.10. At each RAP the same range of Pr number are appear approximately. Where Pr number depend on thermo physical property and that lead to the proportion relation with Nu number. filling ratio

Behavior of flow

To estimate the behavior of flow from fig.11(a-b) show the relation between evaporator and surface of condenser temperature with operating time. At high fill ratio and low RHI there is more stability in temperature. At low fill ratio and high RHI there is a reverse behavior of Te inverse with Ts with little time delay. this behavior in temperature refer to chaotic in the path of working fluid.

Threshold angle (working angle)

In these experimental work there is no real study to find the effective working angle (where the cohesion and adhesion effect). Only working angle are tested for different RAP with different filling ratio. Threshold angles results refer to 11.5 degree for CTPCT and 16.5 degree for each ETPCT and FTPCT.

Conclusions

From the results of different RAP (different geometrical csa), the effect of heat input, filling ratios on thermal performance of the CTPCT, ETPCT and FTPCT, can be concluded that:

1. The temperature variation along the wall surface of the condenser of the FTPCT was nearly uniform and convergence more than ETPCT and CTPCT.
2. High average value of $\overline{h}$ (air side)and more stability appears in FTPCT and ETPCT synchronized with temperate value at different dose and indicated a regular evaporation and condensation in thermosyphon.
3. convergence of T_c from T_e for FTPCT and ETPCT appear the stability in evaporator temperature by a regular heat flow rejection more than CTPCT.
4. Threshold working inclined angle 11.5^o at CTPCT while 16.5^o at each ETPCT and FTPCT.
5. The decrease in evaporator temperature for FTPCT and ETPCT caused by decreasing in RAP where the change in the condenser core volume and the geometrical shape of the perimeter.

References

[1] D.A.Reay "Heat Pipes" ,B&H, Fifth Edition(2006).

[2]P.Amatachaya,W.Srimuang"Comparative heat transfer characteristics of a flat two-phase closed thermosyphon (FTPCT) and conventional two- phase closed thermosyphon (CTPCT)" international communications in heat and mass transfer,37(2010)293-298.

[3]I.Khazaee,R.Hosseini,H.S.Noie"Experimental investigation of effective Parameters and correlation of geyser boiling in a two-phase closed Thermosyphon" Applied thermal Engineering ,30(2010)406-412.

[4]S.Rittidech,W.Srimuang "Correlation to predict heat transfer Characteristics of a vertical flat thermosyphon(VFT) at normal operating Conditions", International journal of heat and mass transfer,53(2010)5984-5987.

[5] Yunus.A.Cengel "Heat and Mass Transfer A practical Approach" Tata McGraw-Hill, Third Edition (2007).

[6]R.C.Sachdeva "Fundamentals of Engineering Heat and Mass Transfer, NEW AGE TERNATIONAL PUBLISHERS,Third Edition(2008).

[7] Donald.R.Pitts "Schum's Outline Of Theory And Problemsw Of Heat Transfer" Mc Graw-Hill, Second Edition(1998).

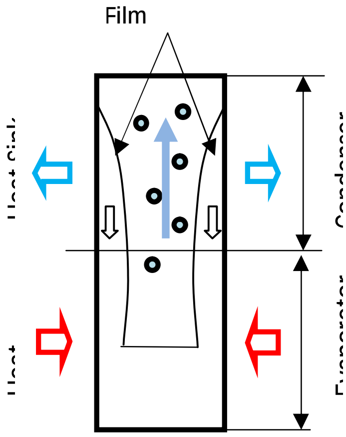


Figure (1) Simple thermosyphon section

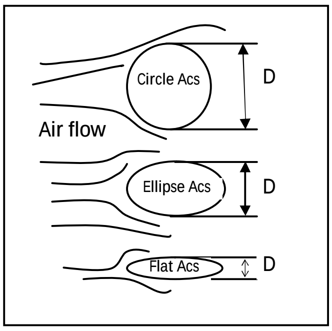


Figure (2) The effective diameter in different

Figure (3) Condenser's

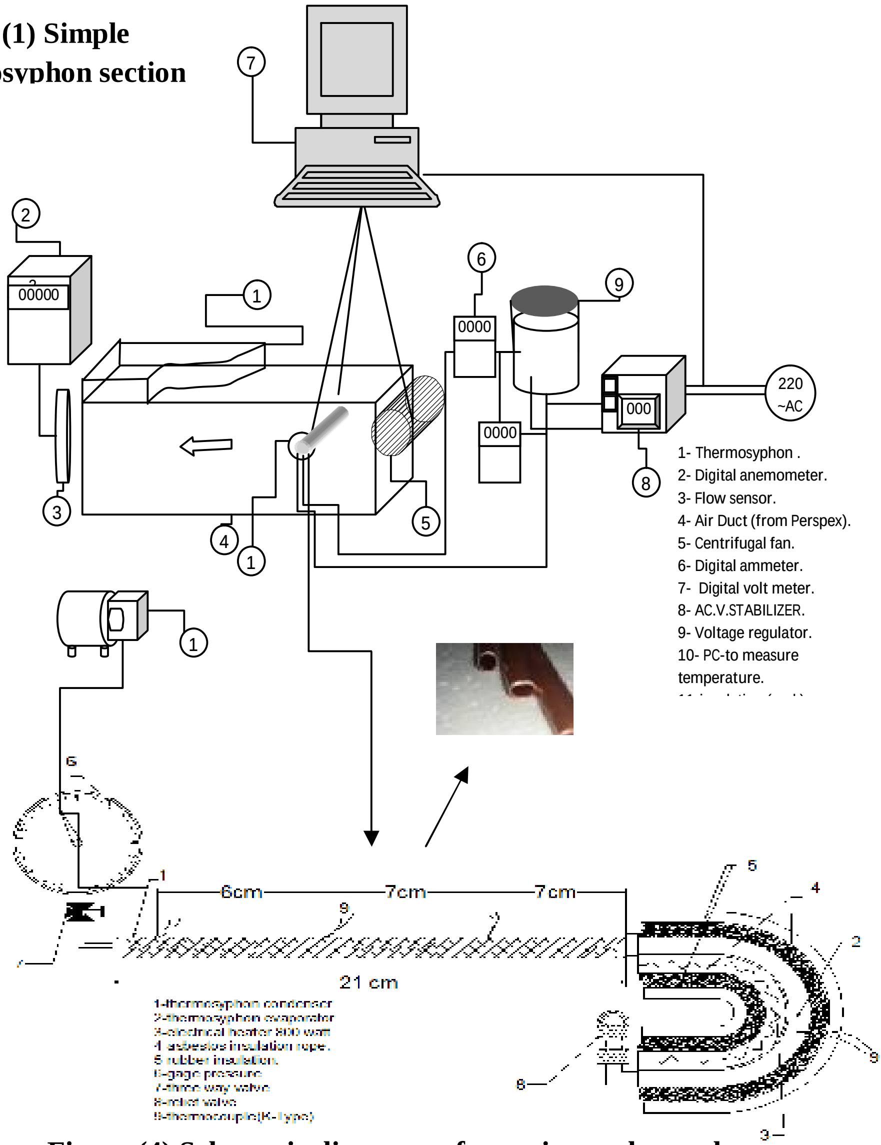
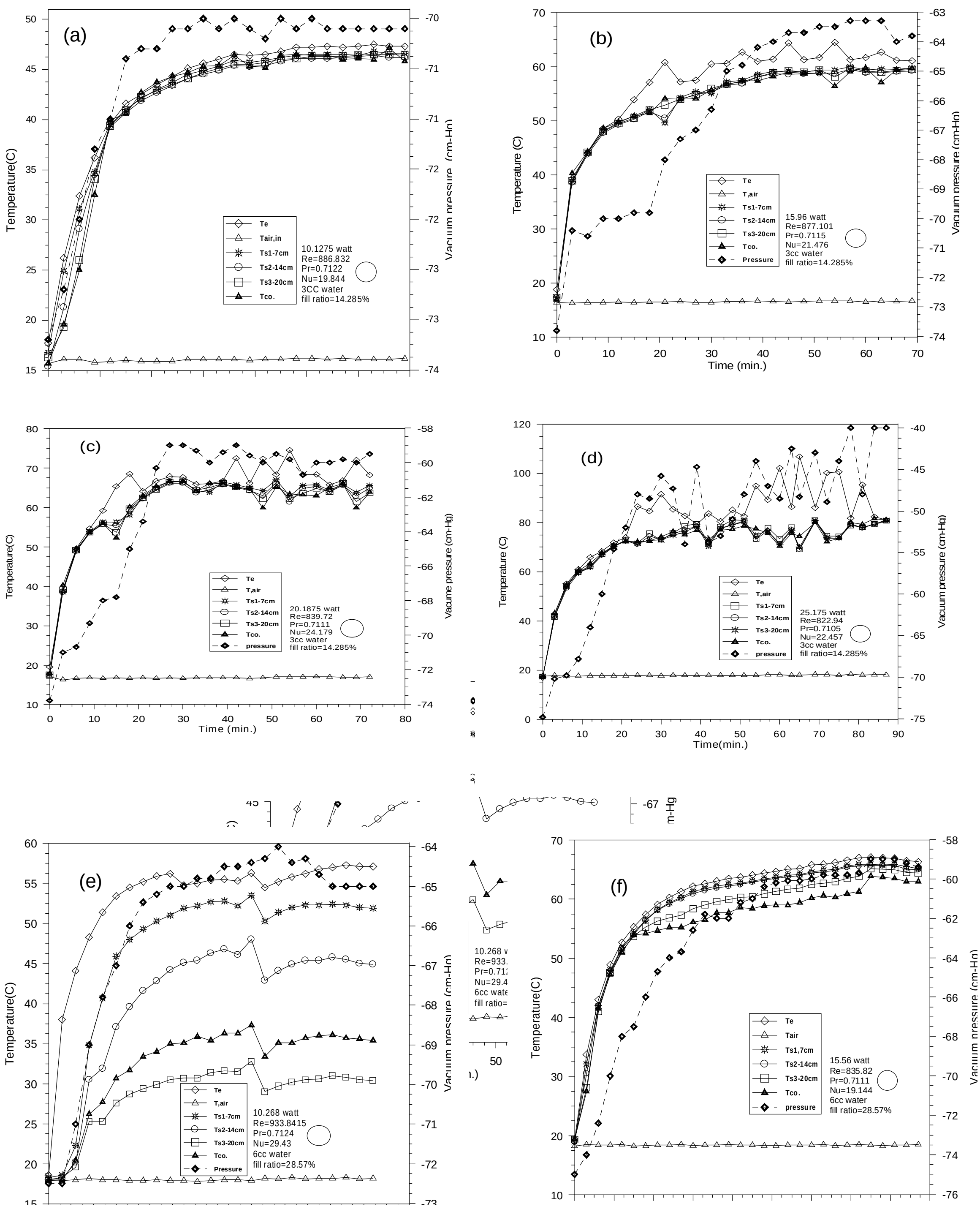
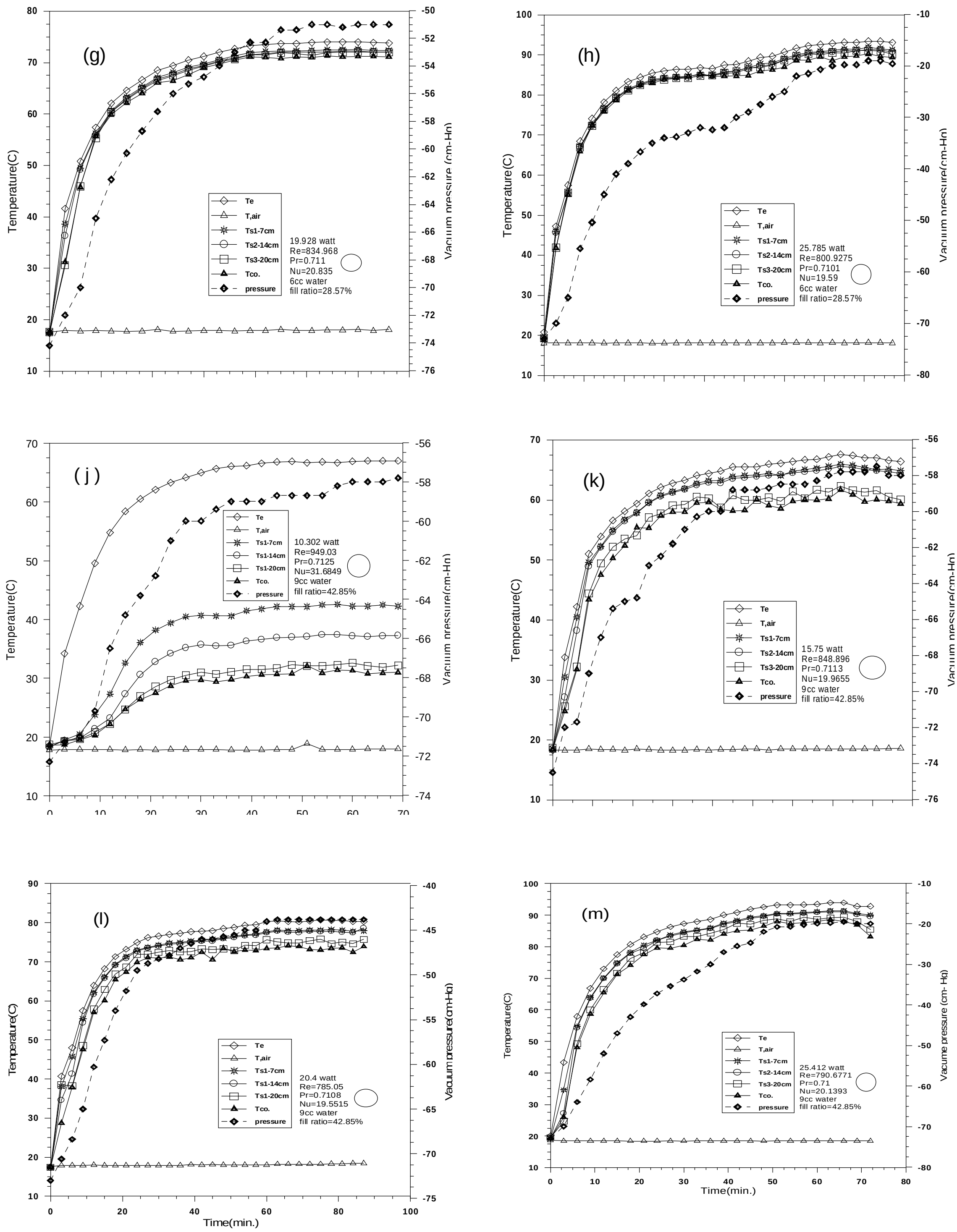


Figure (4) Schematic diagrams of experimental two phase



Fiure5(a-m) The variation of temperature with time for different filling ratio and different heat


(g)
Temperature(C)
Vacuum pressure (cm-Hg)
Te
T,air
Ts1-7cm
Ts2-14cm
Ts3-20cm
Tco.
pressure
19.928 watt
Re=834.968
Pr=0.711
Nu=20.835
6cc water
fill ratio=28.57%
(h)
25.785 watt
Re=800.9275
Pr=0.7101
Nu=19.59
6cc water
fill ratio=28.57%
(j)
10.302 watt
Re=949.03
Pr=0.7125
Nu=31.6849
9cc water
fill ratio=42.85%
(k)
15.75 watt
Re=848.896
Pr=0.7113
Nu=19.9655
9cc water
fill ratio=42.85%
(l)
20.4 watt
Re=785.05
Pr=0.7108
Nu=19.5515
9cc water
fill ratio=42.85%
(m)
25.412 watt
Re=790.6771
Pr=0.71
Nu=20.1393
9cc water
fill ratio=42.85%
Time(min.)

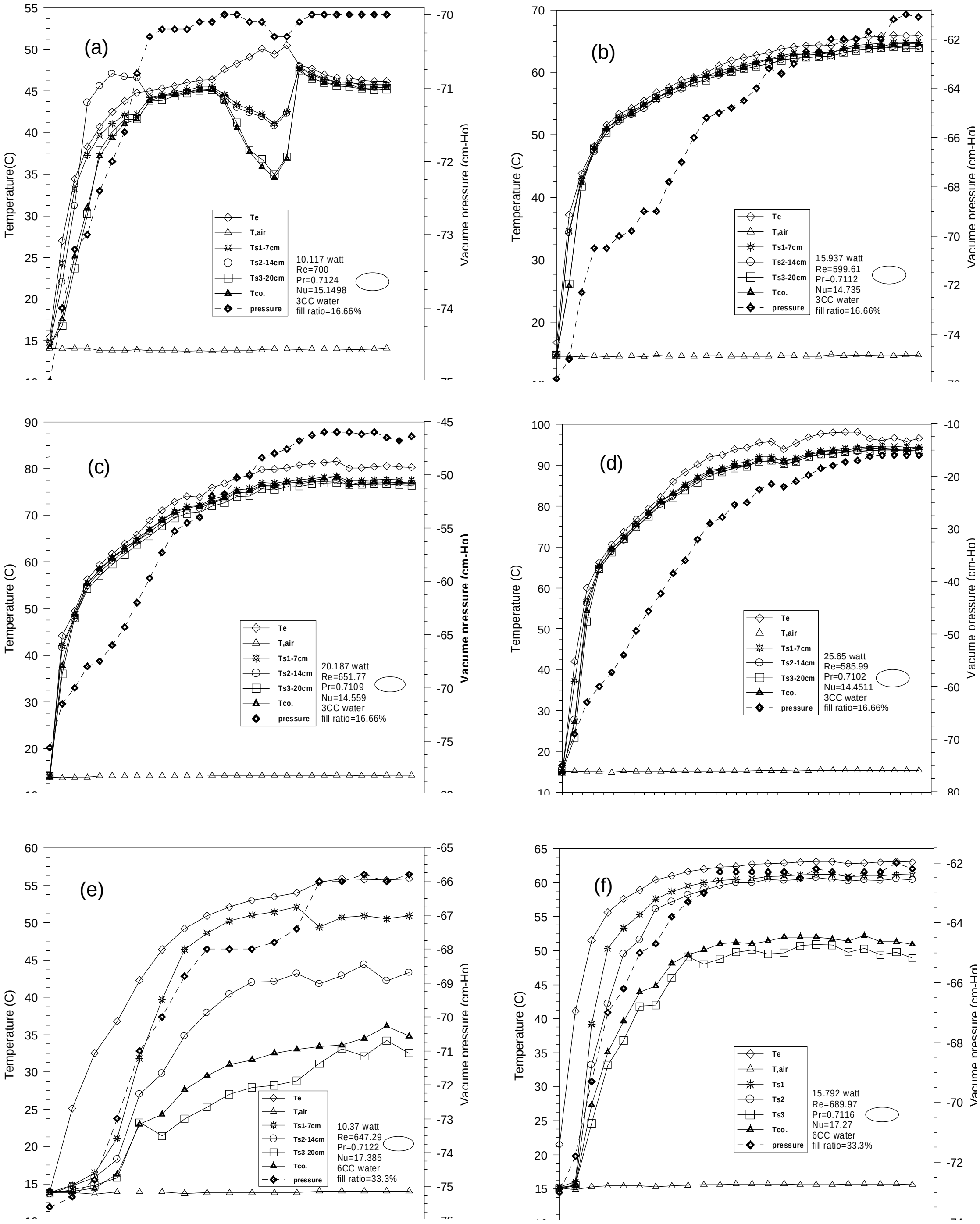
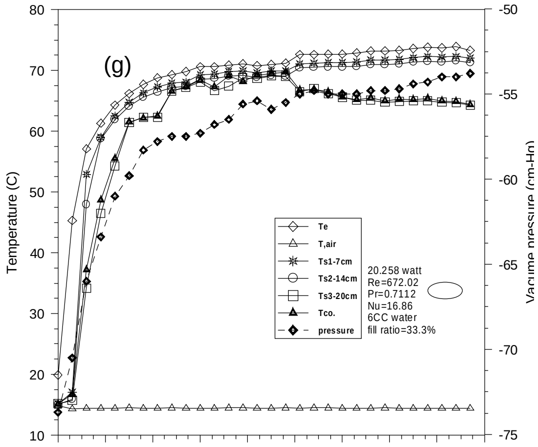
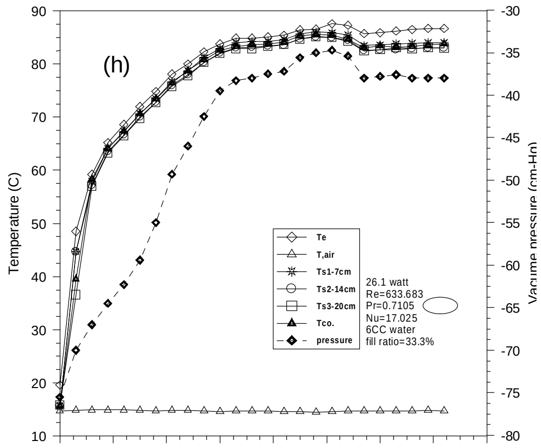
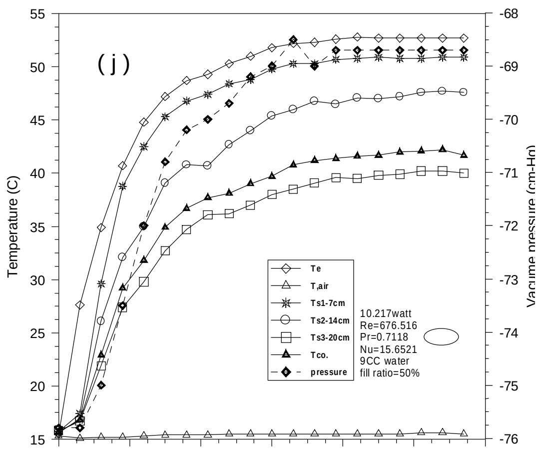
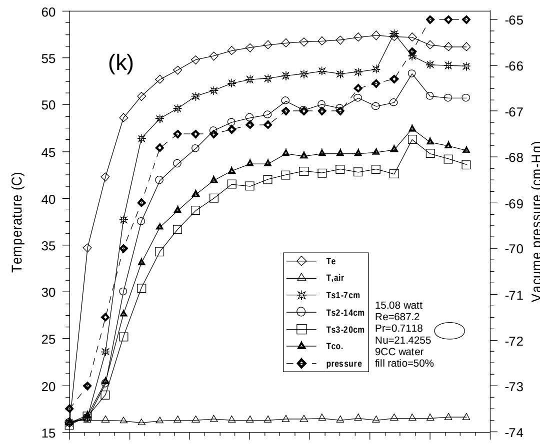


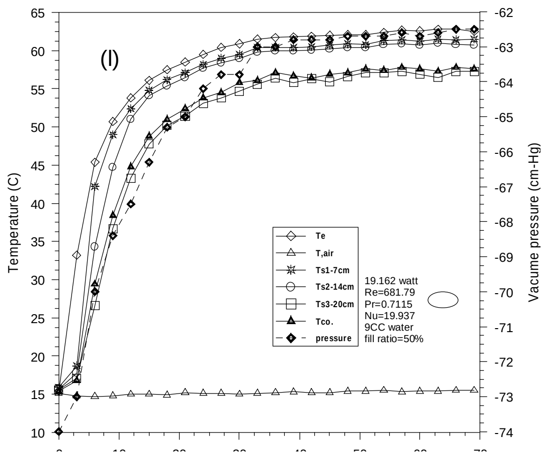
Figure6 (a-m) the variation of temperature with time for different filling ratio and different heat

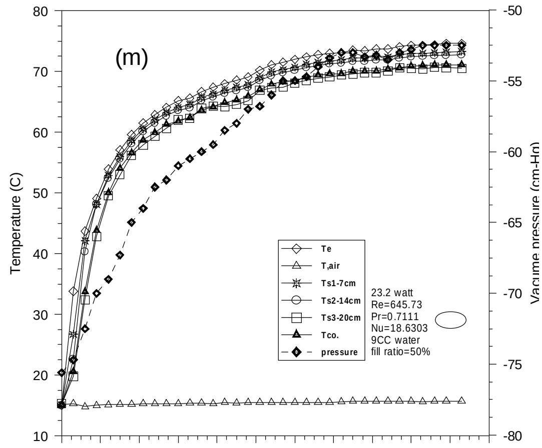

(g)
Temperature (C)
Te
T,air
Ts1-7cm
Ts2-14cm
Ts3-20cm
Tco.
pressure
20.258 watt
Re=672.02
Pr=0.7112
Nu=16.86
6CC water
fill ratio=33.3%


(h)
Temperature (C)
Te
T,air
Ts1-7cm
Ts2-14cm
Ts3-20cm
Tco.
pressure
26.1 watt
Re=633.683
Pr=0.7105
Nu=17.025
6CC water
fill ratio=33.3%


(j)
Temperature (C)
Te
T,air
Ts1-7cm
Ts2-14cm
Ts3-20cm
Tco.
pressure
10.217watt
Re=676.516
Pr=0.7118
Nu=15.6521
9CC water
fill ratio=50%


(k)
Temperature (C)
Te
T,air
Ts1-7cm
Ts2-14cm
Ts3-20cm
Tco.
pressure
15.08 watt
Re=687.2
Pr=0.7118
Nu=21.4255
9CC water
fill ratio=50%


(l)
Temperature (C)
Vacume pressure (cm-Hg)
Te
T,air
Ts1-7cm
Ts2-14cm
Ts3-20cm
Tco.
pressure
19.162 watt
Re=681.79
Pr=0.7115
Nu=19.937
9CC water
fill ratio=50%


(m)
Temperature (C)
Te
T,air
Ts1-7cm
Ts2-14cm
Ts3-20cm
Tco.
pressure
23.2 watt
Re=645.73
Pr=0.7111
Nu=18.6303
9CC water
fill ratio=50%

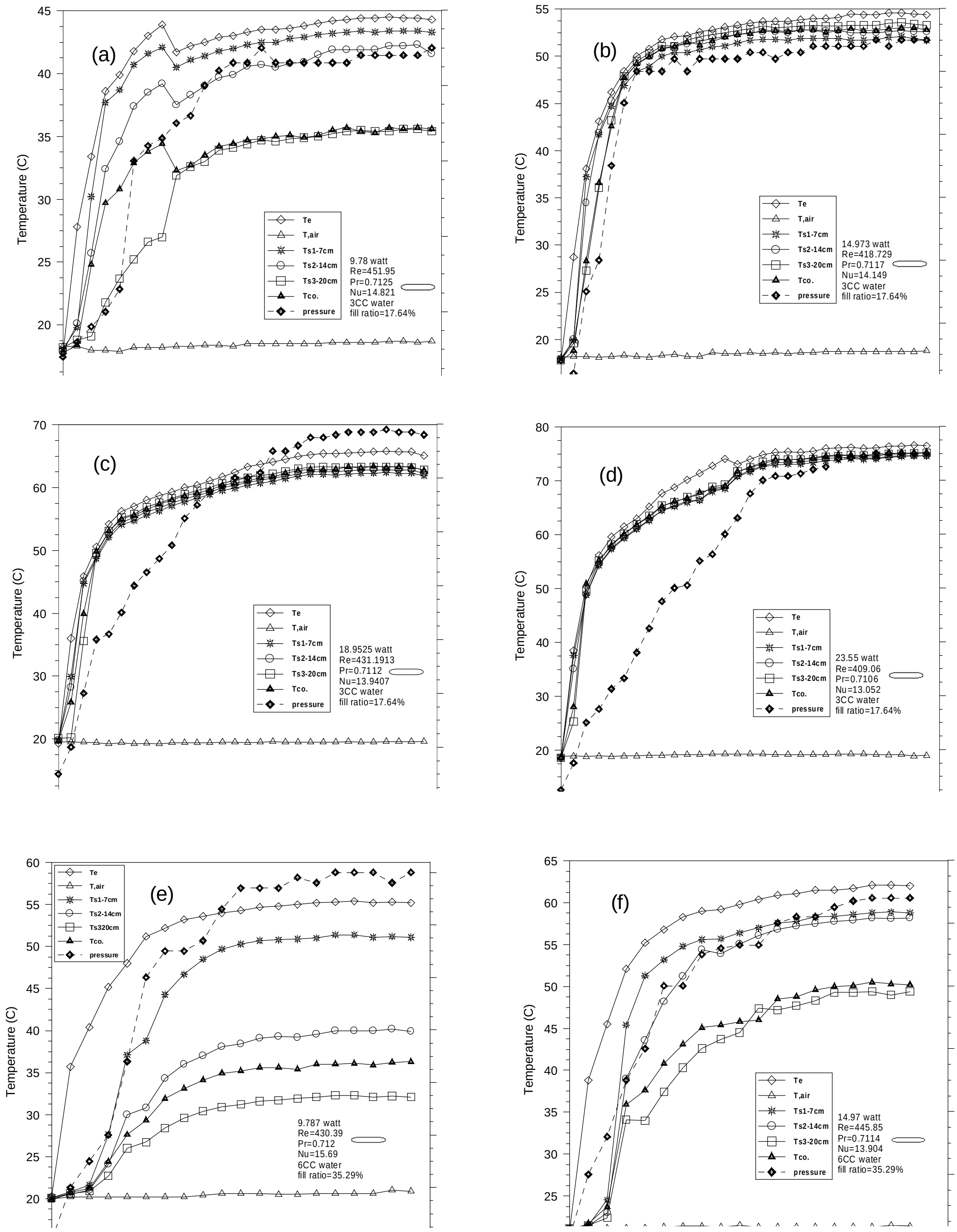
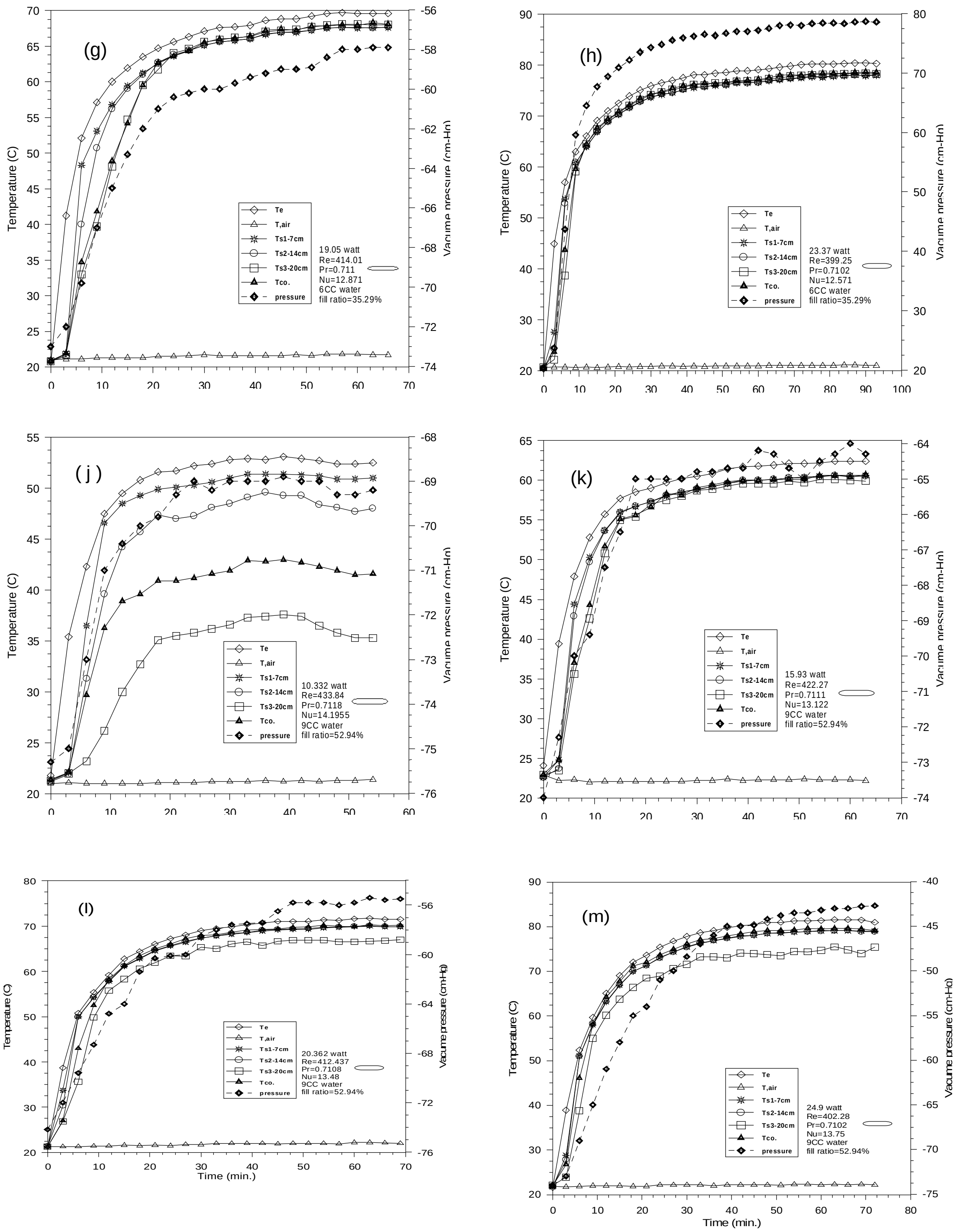


Figure7 (a-m) the variation of temperature with time for different filling ratio and different heat


(g)
Temperature (C)
19.05 watt
Re=414.01
Pr=0.711
Nu=12.871
6CC water
fill ratio=35.29%
(h)
Temperature (C)
23.37 watt
Re=399.25
Pr=0.7102
Nu=12.571
6CC water
fill ratio=35.29%
(j)
Temperature (C)
10.332 watt
Re=433.84
Pr=0.7118
Nu=14.1955
9CC water
fill ratio=52.94%
(k)
Temperature (C)
15.93 watt
Re=422.27
Pr=0.7111
Nu=13.122
9CC water
fill ratio=52.94%
(l)
Temperature (C)
Vacume pressure (cm-Hg)
20.362 watt
Re=412.437
Pr=0.7108
Nu=13.48
9CC water
fill ratio=52.94%
Time (min.)
(m)
Temperature (C)
Vacume pressure (cm-Hg)
24.9 watt
Re=402.28
Pr=0.7102
Nu=13.75
9CC water
fill ratio=52.94%
Time (min.)
Te
T,air
Ts1-7cm
Ts2-14cm
Ts3-20cm
Tco.
pressure

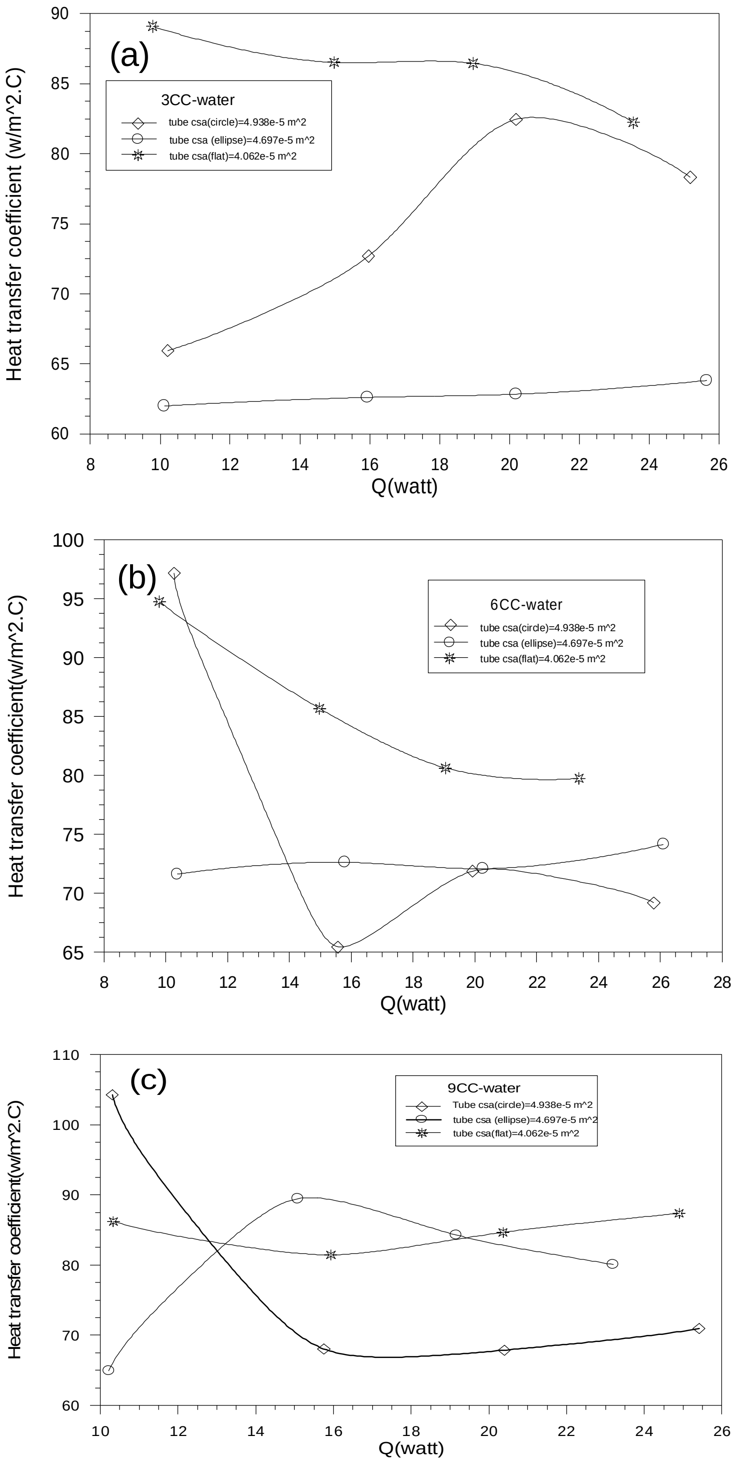


Figure8 (a-c) Air side heat transfer coefficient for different dose, geometry and rate of heat input.

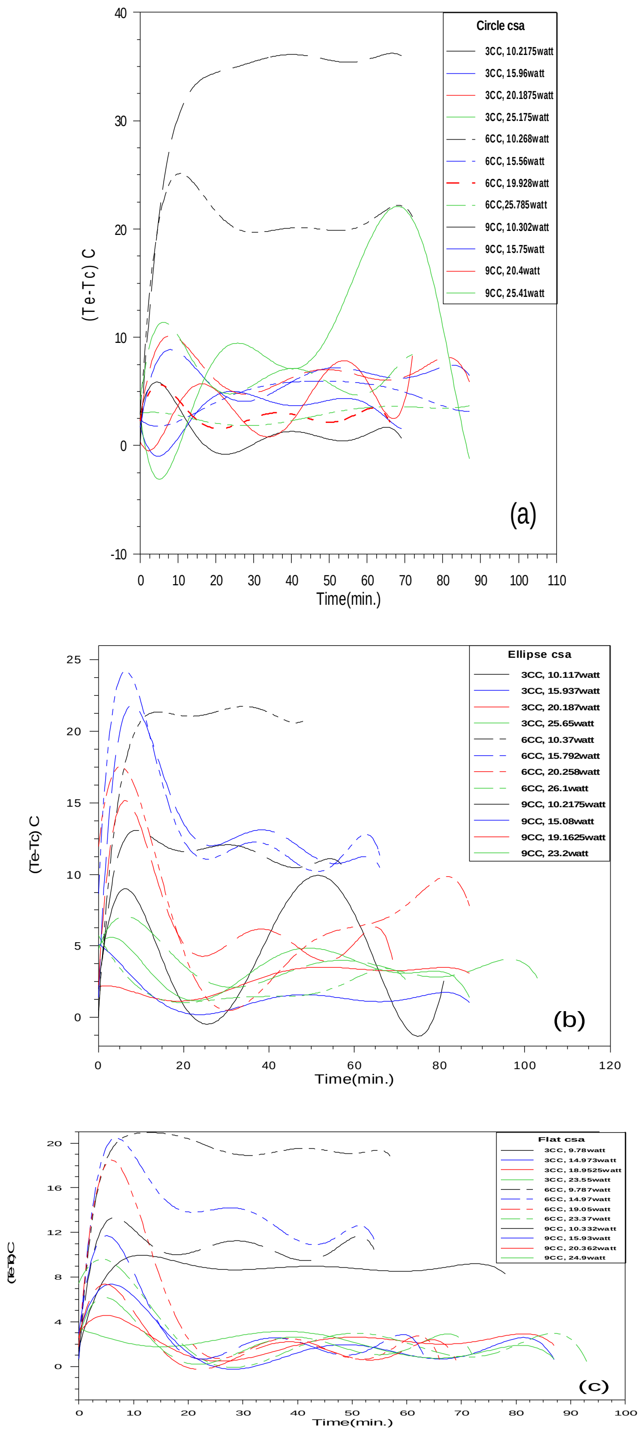
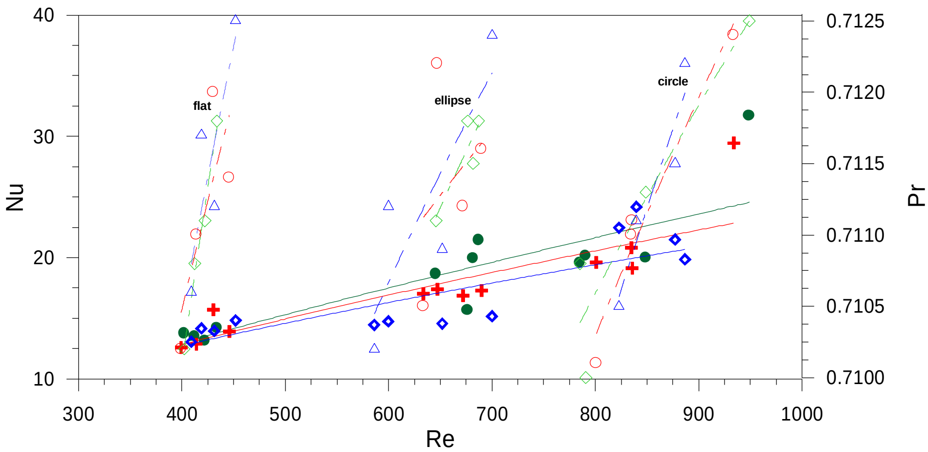


Figure9 (a-c) Temperature difference between evaporator and condenser for the three geometry (three RAP) , against time,(a-circ



ular b-elliptical c-flat shape)

		3CC water	6CC water	9CC water
Circle csa of condenser	c	0.0230635	0.0038072	2.64608
	m	1.07616	1.37323	0.290312
	n	0.33	0.33	0.33
	Sr	0.00175112	0.0167995	0.003008
	Sy/x %	4.1846%	12.96%	5.484%
Ellipse csa of condenser	c	4.71375	18.4716	0.006628
	m	0.193996	0.005729	1.23814
	n	0.33	0.33	0.33
	Sr	0.000747	0.00055422	0.05062
	Sy/x %	2.733	2.354	22.49
Flat csa of condenser	c	5.71103e0+6	8.53834e-8	1.8595e-6
	m	-1.83005	2.88723	2.4371
	n	0.33	0.33	0.33
	Sr	0.008038	0.0116	0.02466
	Sy/x %	8.96%	10.77%	15.7

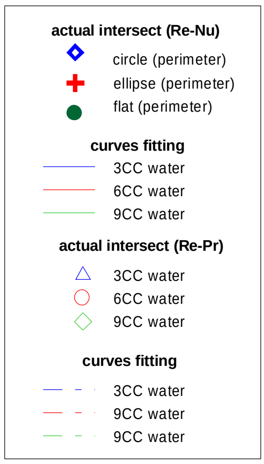


Figure (10) variation of Nu,Pr with Re at different values of air flow rates and heat input for all csa geometry

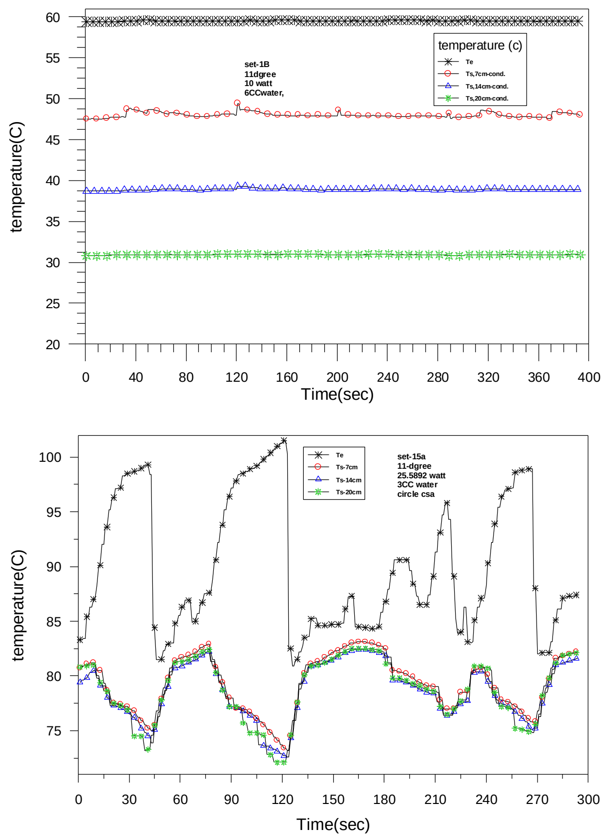


Figure (11) flow behavior (a) uniform flow and (b) alternative chaotic flow