Flow Boiling in Vertical Annular Tubes Filled with porous medium

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Abstract:

Experimental investigation was carried out on the forced convection boiling heat transfer in uniformly heated vertical annular tube filled with a porous medium of beads.The study is concerned mainly with the effect of beads species, beads size, and annular gab thickness of the tube on the heat transfer process. The experimental test were carried out with three different species of beads (stainless steel beads of 8, 6 and 4mm mean diameter), and three different size of the annular gab of the tube (10, 20 and 30 mm gab thickness). The experimental results were compared with the case without a porous medium. The results show that, heat transfer is enhanced by the porous medium specially in the region of low heat flux, and this enhanced effect depends on the species and size of the beads. Beads that have high thermal conductivity (stainless steel beads) have enhancing effect greater than beads that have low conductivity (gravel., and polymer beads). Also, the heat transfer enhancing effect has increased with decreasing the size and the annular gap size of the beads and annular gap.

Key Words (Heat Transfer, boiling, Cylinder Section and Water Flow)

1-Introduction

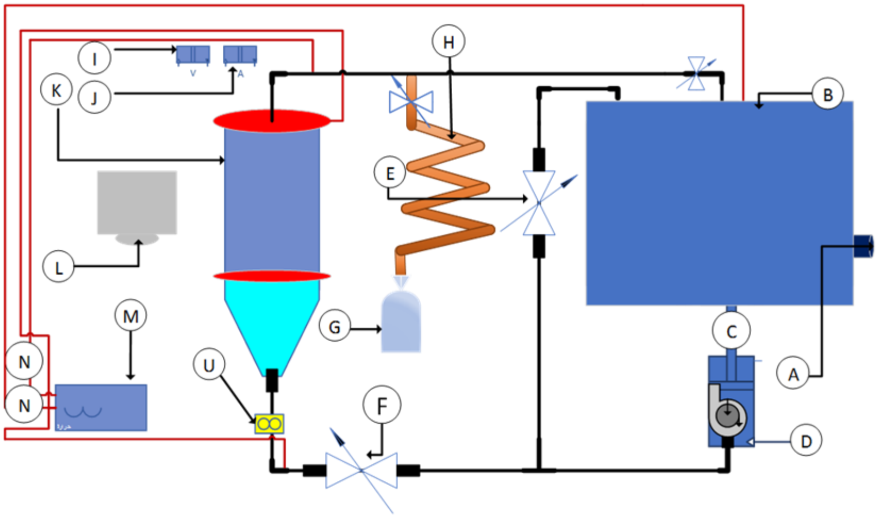
Heat transfer in various porous media is an area of quite active study in heat transfer engineering. Many experimental investigations on boiling heat transfer in a porous medium layer have been performed and it has been qualitatively understood that nucleate boiling heat transfer can be greatly enhanced on a smooth heat-transfer surface covered by a porous medium layer, and that the critical heat flux of nucleate boiling (CHF) also decreases greatly. Previous studies mostly focused on pool boiling on a plate heated surface [1, 2] and vertical heated surface [3-6] (with a closed bottom, an opened top, and a side face) where flow directions of liquid and vapor are opposite each other. For flow boiling in tubes where the flow directions of liquid and vapor are the same, any study has beenmade. Especially, despite the importance of critical heat flux of nucleate boiling which is related to safety design for actual engineering processes, no experimental and theoretical study on the CHF has experimental studies were carried out for natural convective boiling heat transfer and critical heat flux (CHF) in uniformly heated vertical annular tubes filled with a porous medium made of stainless steel beads and polymers beads and gravel beads submerged in saturated water liquid. The heat transfer experimental results were compared with those for the case without a porous medium. an experimental work of forced heat convection has been conducted for water flowing through a vertical porous annuli. Three various sizes of glass ball porous media and porosities are utilized. The outer cylinder is made of Teflon (TPFE) while the inner cylinder is made of polished copper and it is electrically heated from inner with four various input power levels[7].

2 - The objective of the current work:

The objective of this work is to study the effect of beads specie, beads size, and annular gab thickness of the tube on the boiling heat transfer process.

3 - Experimental Apparatus and Instruments

An experimental setup has been designed and constructed at the Heat Engine Laboratory, Faculty of Engineering, Mansoura a University. Schematic diagram of the setup is shown in Fig .(1).The flow boiling of water in porous media occurs in the test section (k) where the water flows from the tank (B) to the test section (K)by the pump (D).The tank (B) is equipped with an electric heater (A)(1 KW Power) which is provided with a thermostat to set the water tank temperature near or equal to the boiling point . The flow rate of water input to the test section (K) is controlled by the valve (F). The excess How of water return to the tank (B) Through the valve (E) to reduce the back pressure on the pump. The steam exit from the teat section (K) is condensed in the condenser coil (H) and the condensate is collected in the vessel (G). To change the heat flax in the test section, the electric heater (Z), see Fig. (3), is connected to a variable tansformer (L) capable of providing electric volts from 0.0 to 240 with endless steps. The power of the transformer is measured by the ammeter (J) and voltammeter (I).

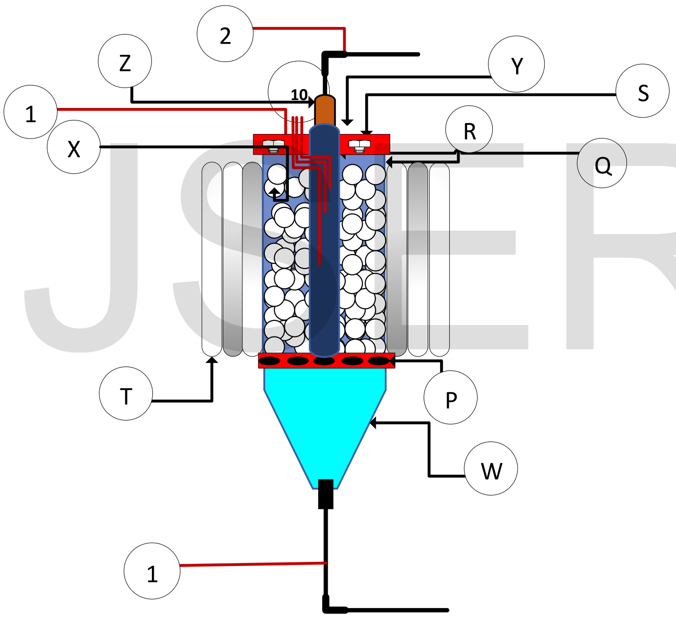


A-electric heater, **B**- water tank,**C**- connecting pipe,**D**-water pump, **E**-valves, **F**-non return valve, **H**-heat exchanger, **K**- vessel containing test section, **N**-thermo couple,**U**- flow meter

Fig . (1) Schematic diagram of the experimental setup

The temperature measuring device (M) is a temperature recorder type (YOKOGAWA) with 24 channels capable of reading and recording the temperature of different thermocouples type (J) with a minimum reading of 0.1℃ and an accuracy of ± 0.3 %.

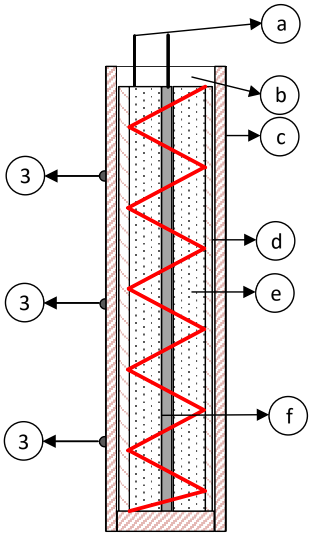
The test section (K) is shown in fig (2). It consists of a Cylindrical heater (Z),(16mm dia, 150mm height ,600 w power) fixed centeraly inside a vertical copper tube (R) which is filled with spherical particles formusating the porous medium (X) ,Top of the vertical tube is closed by steel dioc (S) with four bolts (Y). Bottom of the vertical tube is closed by wired base(P) and connected to the mater inlet line with steanless conical connection (W). The vertical tube is insuleted by three layers glass wool (T).



R-Cylinder tube, **S**-Clinder cover, **Q**-copper tube, **Z**-electric heater **X**-porous media, **P**-a wired base, **W**- cone, **y**-screws, **T**- glass wool, (1,2,3,4,5,6,7,8,9,10) Thermo couple,

Fig. (2) structre of the test section

structre of the electric heater is shown in Fig. (4). The electric heater is surrouinded by mica sheet (d) and measurremantsinserted inside copper yube(c) (20mm dia,150mm height). Themperatures of water inlet and water / vapaure outlet are measured by the Thermodynamic probes(1) and (2).Temperatures at the heater surface is measured by three Thermo couple probes(3) disitributed on the prephery of the copper tube. Flow rate of meter inlet to the test section is measured by the digital flow meter (u).See Fig (1). The experimental test were carried out with three different spacing of beads (stain less-steel beads of 8 , 6 , and 4 mm diameter polymer beads of 8 mm diameter , and gravel beads of 8 mm diameter)and three different size of the annular gab of the tube (10 ,20 , and 30 mm gab thickness. The length of annular tube was fixed at 150 mm and the pressure was atmospheric pressure. In every test electric power was increased gradually. The average wall temperature of the heated tube was determined from the average measured values by the three thermo couples...



a-electric wire,**b-**epoxyg glue,**c-**copper tube,**d-**mice ,**e-** fine sand particles, **f-**thermo couples probes

Fig. (3) Electric heater

4-Data reduction:

power input to heater

$Q = V \times I$

The heat flux

$$q_{add} = (V \times I)/A_s \ \ w/m^2 \qquad (1)$$

h: Heat transfer coefficient, T_W:temperature of heater surface, T_b :bulk temperature of porous media

$$q_{add} = h(T_w - T_b)$$

$$A_s = \pi \times D_i \times L \qquad (3)$$

A_s: Surface area of copper tube (m^2)

Di: diameter of tube Copper (m)

L: high of tube Couper

5- Results and Discussion:

. Experimental results on boiling heat transfer of annular tube filled with a porous medium of beads are represented in Figs.(4-7).

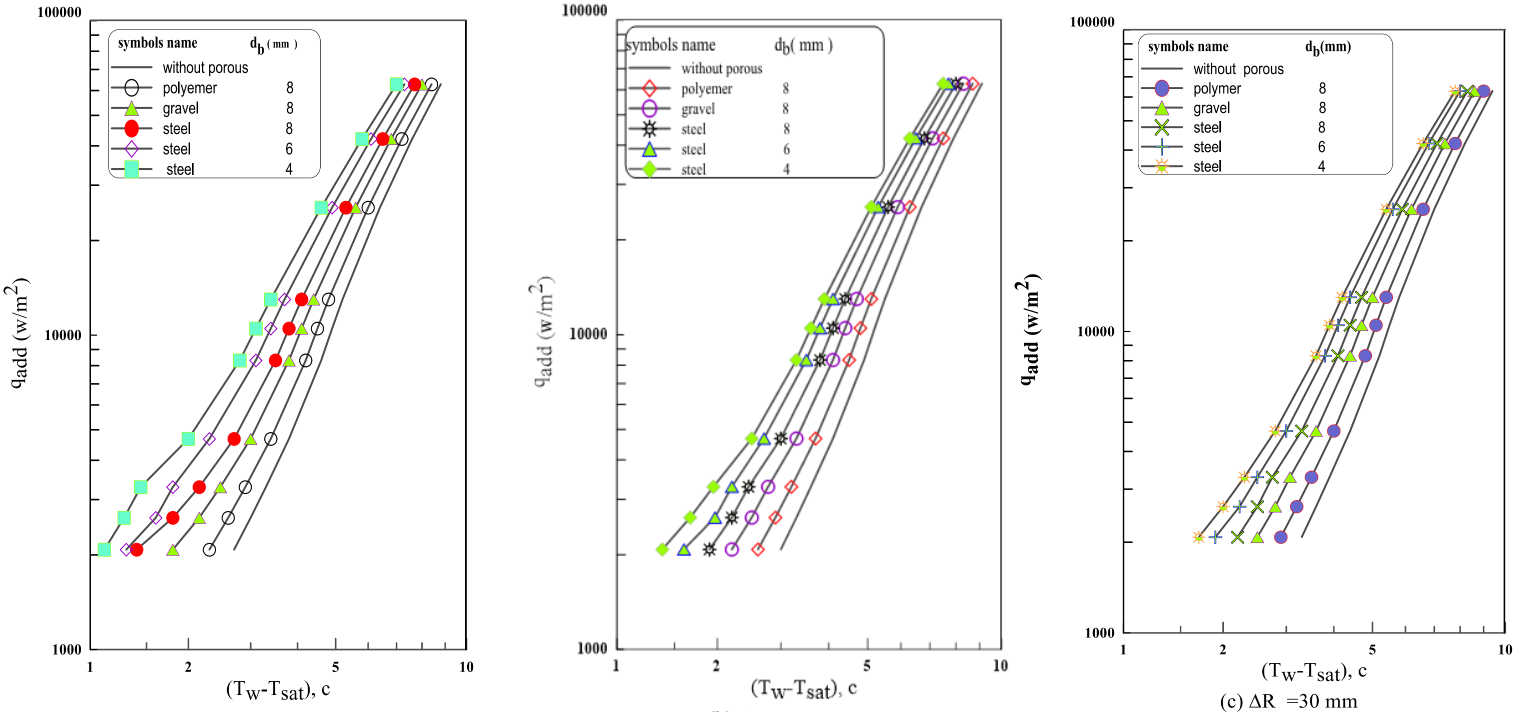
The results are presented for three different species of beads (stainless-steel beads of 4, 6, and 8 mm dia., gravel beads of 8 mm dia., and polymer beads of 8 mm dia.,). Fig. (4) (a, b, c) represents the boiling curve (q vs ΔT) for annular gabs of 10 . 20 .and 30 mm. Fig. (5) (a. b. c) represents the relation between heat transfer coefficient and heat flux. The solid line represents the results for tube filled water only (without beads).

The results show that the boiling heat transfer coefficient with beads is relatively increased, especially in the region of low heat flux (single phase forced convection region), as compared with that case without beads. The increase in heat transfer coefficient with beads of stain less -steel is greater than that with gravel and polymer beads. This because the thermal conductivity of stainless steel is higher than that of polymer and gravel. Also, it is clear that the increase in heat transfer coefficient with small size of beads (4 mm) is greater than that with big size (8 mm). However, it is expected that further decrease in beads size (less than 4 mm dia.) may decrease the heat transfer coefficient. The reasons why the porous layer touching the heated surface enhance boiling heat transfer may be explained as: (1) it increases surface gasification cavities and hence increases the number of in incipient bubbles ,(2) it extent the heat transfer surface area ,(3) it form a relatively thick temperature boundary layer, by means of which incipient boiling can easily take place at quite low superheats,

However, because a porous medium blocks the separation of bubbles from the heated surface and the supplying of fresh liquid to the heated surface , the existence of a porous layer may also decrease the boiling heat transfer .As the diameter of the beads becomes smaller , the positive and negative enhancement effects, became stronger. Due to the reciprocal restriction of such positive and negative effects, there exist on optimal geometry size corresponding to the maximum heat transfer coefficient.

In the region of low heat flux, enhanced effect are always ascend ant and heat transfer is enhanced to different degrees for various size of the porous medium. This enhanced effect decreases gradually with increasing heat flux, or with increasing bubbles.

Fig. (6) (a, b, c) represents the Effect of annular gab thickness of tube on heat transfer coefficient for stainless - steel beads of 4, 6, and 8 mm diameter. Fig. (7) (a, b, c) represents the Effect of annular gab thickness of tube on heat transfer coefficient for gravel beads, polymer beads, and bare tube. It is seen that the heat transfer coefficient with narrow gabs (10 mm) is greater than that with large gaps (20, and 30 mm), especially in the region of low heat flux, this because the size of the gabs affects directly the flow sections and hence affects the flow velocity.

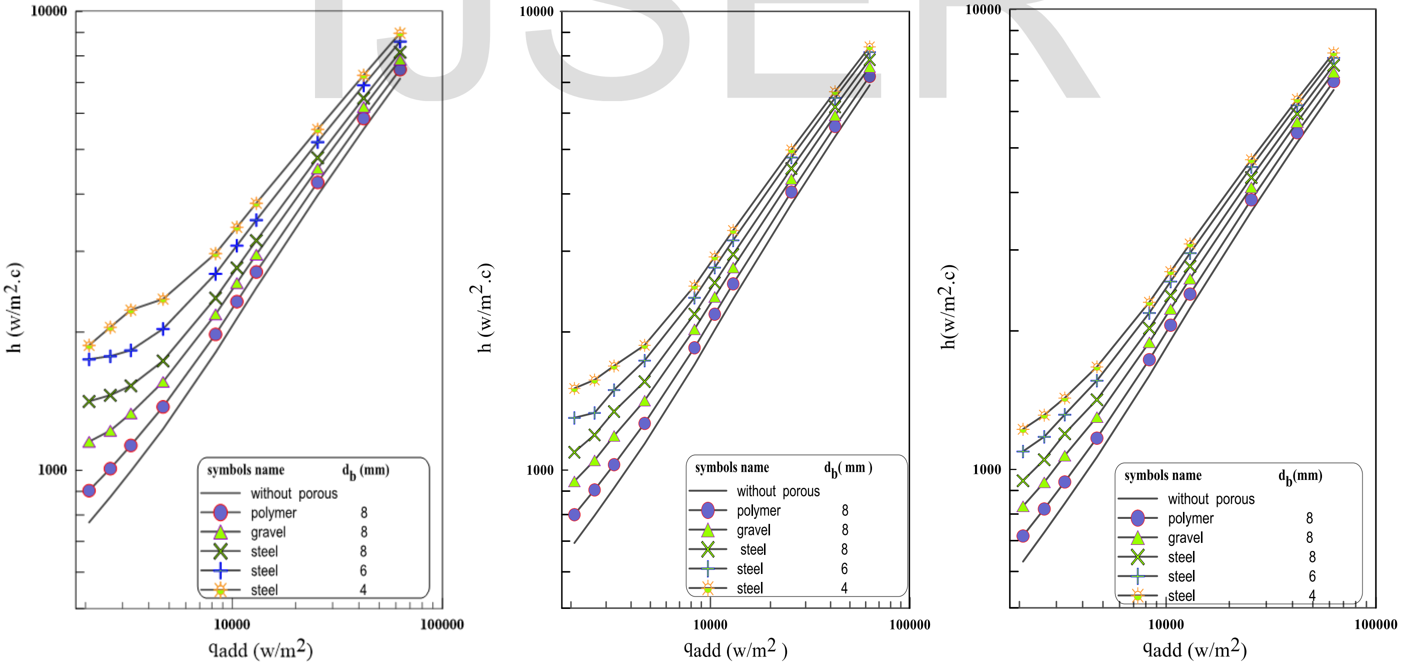


(a) ΔR =10 mm

(b) ΔR =20 mm

(c) ΔR =30 mm

Fig. (4) Boiling curve of annular tubes filled different species and size of bead.

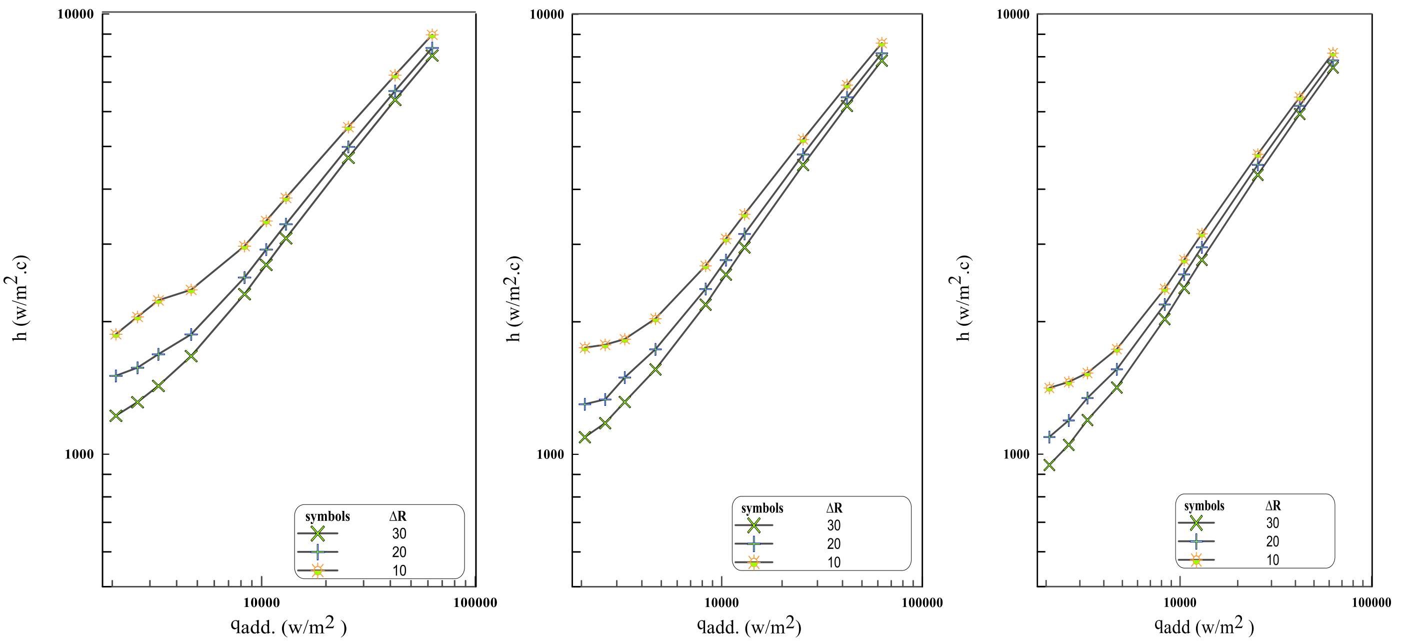


(a) ΔR=10 mm

(b) ΔR=20 mm

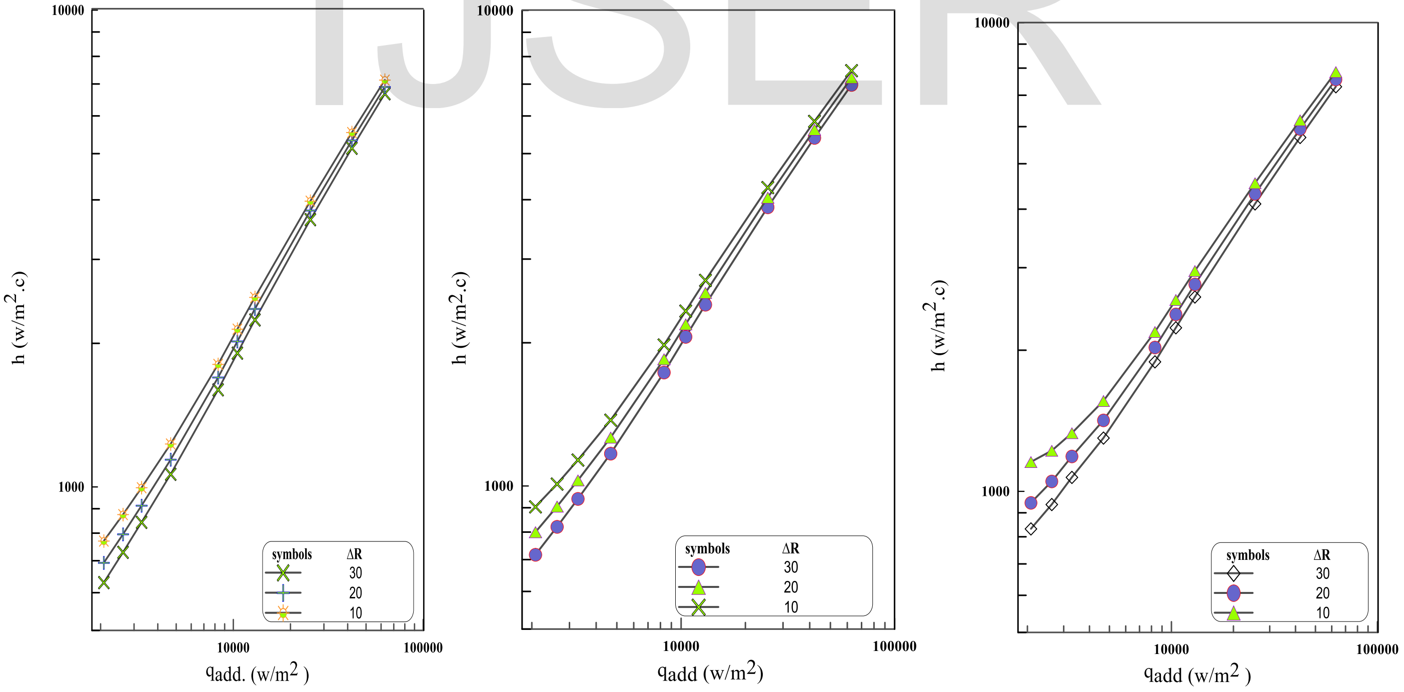
(c) ΔR=30 mm

Fig. (5) heat transfer coefficient as a function of heat flux for annular tube filled with different species and size of beads.



(a) stainless steel beads d= 4mm (b) stainless steel beads d= 6mm (c) stainless steel beads d= 8 mm

Fig. (6) heat transfer coefficient as a function of heat flux for annular tube filled with different species and size of beads



(c) bare tube (e) polymer beads, d= 8 mm (d) gravel beads, d= 8 mm

Fig. (7) Effect of annular gab thickness of tube on heat transfer coefficient for gravel and polymer beads of 8 mm diameter beads and bare tube.

Conclusions

From the presente experiment, data at the following conclusion are made.

1-porous medium of beads can enhance boiling heat transfer in the annular tubes and the enhanced effect is more effective in the region of low heat flux (i. e single phase region)

2-Beads that have high thermal conductivity (stainless-steel beads) have enhanced effect greater than that have low thermal conductivity (gravel and polymer beads)

3-three exit optimal diameter of stainless-steel beads corresponding to the most effective enhanced heat transfer.

4-Boiling heat transfer coefficient in narrow gab (10 mm thickness) is greater than that is the large gab (30 mm thickness), especially in the region of low heat flux.

Nomenclature

Symbol	Definition	units
A	Flow section area of empty annular tube	m^2
A_b	Mean flow section area of the tube filled with beads	m^2
c	Mean flow velocity	m/s
D_h	Hydraulic diameter of the annular tube	m
D_{hb}	Hydraulic diameter of the annular tube filled with beads	m
D_i	Inner diameter of the annular tube (diameter of the heated tube)	m
D_o	Outer diameter of the annular tube	m
G	Mass flux of water flow	$kg/(m^2.s)$
h	Heat transfer coefficient	$w/m^2.{}^oc$
I	Intensity of electeric current	amper
k	Thermal conductivity	W
L	Annular tube length	m
m	Mass flow rate	kg/s
n	Number of beads filled the annular tube	dimmensionless
Nu	Nusslet number	dimmensionless
Q	Power input to the heated tube	W
q	Heat Flux of the heated tube	W/m^2
Re	Reynolds Number	dimmensionless
S	Wetted perimeter	m
S_b	The average cicumference at any section of the tube filled with beads	m
T_b	Bulk temperature of water	${}^oC$
T_w	Wall temperature of the heated tube	${}^oC$
V_g	Volume of the annular gap	m^3
V_w	Volume of water fills the annular gap fiiled with beads	m^3
ε	Porisity of beads gfilled the annular tube	dimmensionless
ν	Kinematic viscosity	m^2/s
ΔT	Temperature difference	${}^oC$

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