GLASS PACKING MATERIALS USED FOR INTENSIFICATION OF HEAT TRANSFER AT BOILING ON TUBULAR SURFACES

by

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Original scientific paper
https://doi.org/10.2298/TSCI150728203P

The paper presents the results obtained in determining the partial heat transfer coefficient at boiling on vertical and horizontal tubular surfaces surrounded by different types of glass packing material. In both cases, an intensification of heat transfer can be noticed as compared to the boiling on the same installation performed without glass packing materials. During the experiments pseudo-critical values of thermal flux appear on the vertical and horizontal heating tube with glass packing materials, and the boiling heat transfer coefficient, α, has lower critical values than that on nucleate ordinary boiling. This denotes a differential heating mechanism, determined by the presence of the glass package around the heating tube. The heat transfer intensification is greater with the horizontal tube than with the vertical one.

Key words: *glass packing materials, heat transfer, tubular surface, boiling*

Introduction

Various theoretical and experimental investigations refer to the intensification of transport operations, in general, and of the heat transport, in particular. Agitated vessels are used very commonly in the industrial production in order to improve the heat transfer. [1] The desired results are reduction in the consumption of materials and energy, minimum time operation, reduction of the size of installation, *etc*.

As one of the most effective heat transfer modes, boiling heat transfer for applications in cooling and energy conversion systems has been studied extensively during the past century [2].

The boiling heat transfer is one of the most known and applied intense operation, and the literature presents articles regarding its intensification and heat transfer performance. These include roughness, wettability, and porosity. The presence of a porous layer on the material surface has been considered as the most important factor by far [3].

Pool boiling is a condition where boiling occurs from a heated surface submerged in a large volume of stagnant liquid. Nucleate boiling region is characterized by the formation of vapor at preferred sites, *nucleation sites*, on a heating surface that is submerged in the liquid and maintained at a temperature above the saturation temperature of the liquid [4].

Heat transfer at boiling may be influenced in different ways, such as different pressure conditions [5], use of vibrations, and oscillations, respectively [6], the inclination of the heating surface and its geometry variation [7-10], the covering of the heating surface with porous layers,

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pulverized metals, and other methods for artificial realization of a large number of possible nucleating centers [7, 11, 12], the effect of liquid additives [13], the use of an electric field, or a centrifugal field [14]. The literature also presents different possibilities for intensification of heat transfer at boiling by using so called *static promoters* such as different form of bars, equidistantly placed on the plane horizontal heating surfaces, as well as different material particles, immersed in the boiling liquid [11]. Some authors present experimental results of local heat transfer coefficients for boiling of different fluids in a small diameter smooth tube [15], or in pool boiling on nanostructured surfaces [16-20], or the effect of concentration of nanofluids on pool boiling [19].

Critical heat flux (CHF) is the condition where the vapor generated by nucleate boiling becomes so large that it prevents the liquid from reaching and re-wetting the surface. Pool boiling CHF is the point where nucleate boiling goes through a flow regime transition to film boiling with a continuous vapor film separating the heater and the liquid [20]. Boiling heat transfer coefficient was established for different experimental conditions inside a horizontal tube [21].

Because of the lack of comparative study upon the intensification possibility of the heat transfer at boiling using the same heating tubular surface, vertical and horizontal, respectively, surrounded by different types of glass package, it was considered useful to make some experimental determinations in this direction.

Experimental

The experiments were performed in two glass boiling vessels with $H = 0.150$ m and $D = 0.055 \times 0.002$ m, one containing a vertical and the other a horizontal cylindrical stainless steel tube, having the external diameter of 0.0112 m, the thickness of the wall of 0.001 m, and the length of 0.0505 m. The packed bad surrounding the heating tube filled his glass vessels: in the vertical position of the tube up to 0.10 m and in the horizontal position up to 0.08 m.

High amperage alternating current is supplied through thick Cu connectors attached to the heating tube. The control of the thermal flux resulting from the Joule-Lenz effect is achieved by adjusting the amperage of the electrical current supplied. The schemes for the experimental facility are presented in figs. 1 and 2.

The glass vessels were filled with water and then the heating process began by applying an appropriate current. After reaching the boiling state, the following parameters are measured: the current, the voltage differential on the heating tube, the boiling temperature and the heating tube inside face temperature. These measurements permit the calculation of the thermal flux, q, the temperature of the heating tube external face, and the boiling heat transfer coefficient [22].

Table 1. Characteristic values of the glass packing materials

Type of the package	Dimensions [mm]	Free volume [m^{3}m^{-3}]	Specific surface [m^{2}m^{-3}]
Raschig rings	8 × 9.3 × 1	0.7	875
Large beads	6.37	0.42	509
Small beads	4	0.4	850

The glass packing materials are: Raschig rings, and 2-D beads, which have the characteristics presented in tab. 1.

The partial heat transfer coefficient at boiling, α, can be calculated:

$$\alpha = \frac{q}{t_e - t_b} \tag{1}$$

where α is the partial heat transfer coefficient at boiling, q – is the specific thermal flux, t_e – the temperature of the exterior face of the heating tube, t_b – the boiling temperature.

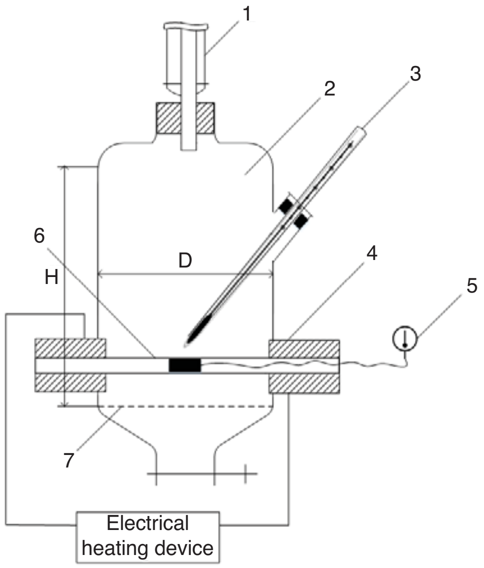

Figure 1. Scheme of the experimental facility having the horizontal heating cylindrical stainless steel tube
1 – refrigerent; 2 – boiling vessel; 3 – thermometer; 4 – Cu electrical connection; 5 – thermocouple; 6 – heating tube; 7 – packing support

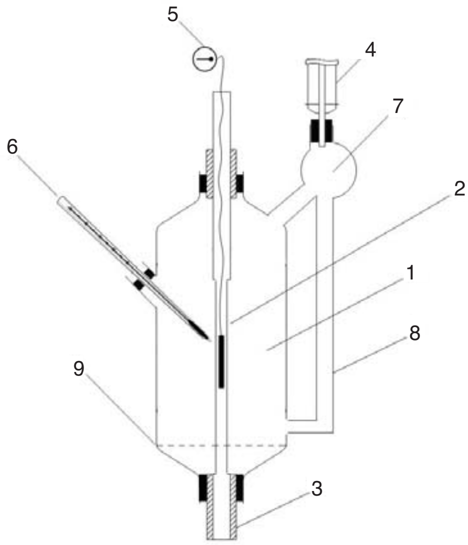

Figure 2. Scheme of the experimental facility having the vertical heating cylindrical stainless steel tube
1 – boiling vessel; 2 – heating tube; 3 – Cu electrical connection; 4 – refrigerant; 5 – thermocouple; 6 – thermometer; 7 – drops separator; 8 – re-circulation tube; 9 – packing support

Results and discussion

Experiments for determining the values of the heat transfer coefficient, α, at boiling of water were performed on both vertical and horizontal heating surface, with and without glass packing materials.

Table 2 presents limits of the specific thermal flux, q, values, as well as of the heat transfer coefficient, α, between which the experiments were performed.

Table 2. The variation limits of the specific thermal flux and of the heat transfer coefficient

Position of the heating tube	Type of packing material	Variation limits of the specific thermal flux, q [kWm^{-2}]	Variation limits of the heat transfer coefficient, α [Wm^{-2}K^{-1}]
Vertical	–	63-170	6760-14100
Vertical	Raschig rings	63-165	10000-14100
Vertical	Large beads	63-165	14100-15140
Vertical	Small beads	63 -165	14620-16030
Horizontal	–	100-200	9600-16000
Horizontal	Raschig rings	125-206	20000-29000
Horizontal	Large beads	120-218	35000-42000
Horizontal	Small beads	100-210	26300-39000

The obtained results processed on the experimental installation, are presented in the logarithmic diagrams in figs. 3 and 4.

It can be noticed that in all cases, with or without glass package and with vertical or horizontal heating tube, a section of a growing straight line appears, followed by a maximum, more or less evident, which denotes an increase of the α values at boiling.

Simple equations were established for determining the heat transfer coefficient α at boiling, in the crowing domains, having the general form as in eq. (2), which are presented in tab. 3:

$$\alpha = a q^n \tag{2}$$

where a and n are coefficients, α is the partial heat transfer coefficient at boiling, and q – the specific thermal flux.

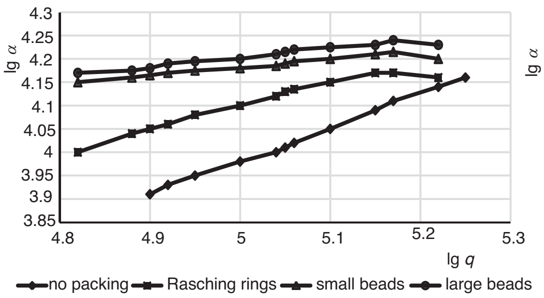

Figure 3. Variation of the α coefficient at boiling of water with the specific thermal flux, q, using the vertical heating tube surrounded by different glass package

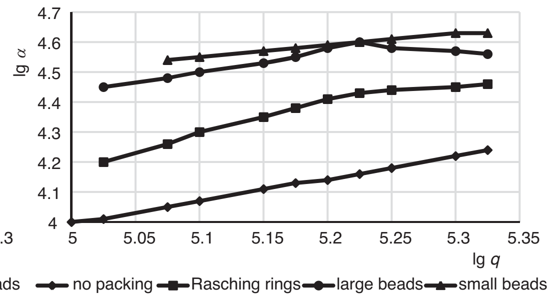

Figure 4. Variation of the α coefficient at boiling of water with the specific thermal flux, q, using the horizontal heating tube surrounded by different glass package

Table 3. The established equations for calculating the heat transfer coefficient, α, at boiling

Type of the package	Horizontal tube	Vertical tube
No package	$\alpha = 3.1\ q^{0.7}$	$\alpha = 3.056\ q^{0.7}$
Raschig rings	$100 < q < 1\ 58 : \alpha = 0.02\ q^{1.176}$ $158.5 < q < 211.5 : \alpha = 91.3\ q^{0.47}$	$\alpha = 39.355\ q^{0.5}$
Large beads	$\alpha = 2.63\ q^{0.8}$	$\alpha = 2.317 \cdot 10^3\ q^{0.167}$
Small beads	$\alpha = 460\ q^{0.37}$	$\alpha = 2.238 \cdot 10^3\ q^{0.167}$

When the horizontal tube was used, the growing of the α coefficient at boiling with the thermal flux, q, is always greater than that when the vertical heating tube was used. This fact can be explained by different fluid circulating mechanism in the limit layer, resulting after the departure of the bubbles, respectively of the superheated liquid jet.

Because of the same reasons, the maximum critical values for α (α_c) at boiling and of the thermal flux, q (q_c), are lower with glass package than those without package. These values are considered to be *pseudo-critical* – α_{pc} and q_{pc} – and are presented in tab. 4.

There can be seen an intensification of the heat transfer at boiling in the presence of the glass packing materials around the heating tube. Table 5 presents the comparative values of the heat transfer coefficient, α, at boiling, for some specific thermal fluxes, q, in the valid limits of the established equations, for the studied cases, reported to the boiling with no package, as well as the growing rate of the heat transfer.

Table 4. The critical values at boiling of water on tubular heating surfaces surrounded by glass packing materials

Boiling of water on tubular surfaces		Vertical heating tube		Horizontal heating tube	
		α_c, and α_{pc} [Wm^{-2}K^{-1}]	q_c, and q_{pc} [kWm^{-2}]	α_c, and α_{pc} [Wm^{-2}K^{-1}]	q_c, and q_{pc} [kWm^{-2}]
No package – *critical values*		46520	1163	46520	1163
Packing materials – *pseudo-critical values*	Raschig rings	14900	141.3	≅28510	≅211.5
	Large beads	15900	152.4	38900	178.0
	Small beads	17000	155.0	41900	211.5

Table 5. Comparative values for *α* coefficient at boiling

Specific thermal flux, q [kWm^{-2}]	Heat transfer coefficient at boiling, α [Wm^{-2}K^{-1}]							
	No package	Raschig rings	Rate of growing for α, [%]	Large beads	Rate of growing for α, [%]	Small beads	Rate of growing for α, [%]	
25	3640	6220	71	12570	245	11905	227.2	Vertical tube
50	5900	8800	48.9	14110	139	13345	126	
100	9600	12445	29.65	15850	65	14960	55.9	
150	12700	–	–	16956	33	16000	25.5	
100	9600	15170	55	26300	170	32600	230	Horizontal tube
150	13000	24440	88	36400	180	37800	190	
200	16000	28310	77	–	–	42000	160	

The highest increase is obtained at boiling on vertical and horizontal tubes surrounded by glass beads. Reporting to the change of the boiling mechanism, this phenomenon must be connected to the smaller free volume of the beads, in compare with the one of the glass Raschig rings.

Figures 5-7 present the logarithmic diagrams of the comparative variations of α at boiling, as a function of the thermal flux, q, on the same vertical or horizontal heating tube, surrounded or not by glass packing materials.

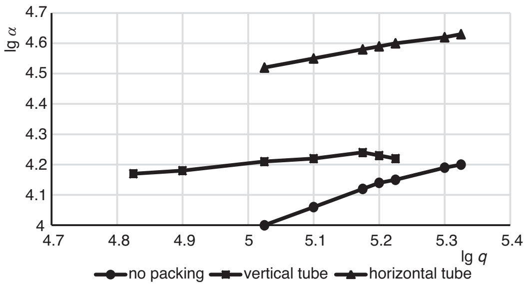

Figure 5. Comparative variations of *α* at boiling, as a function of the thermal flux, *q*, on tubular surface with Raschig rings

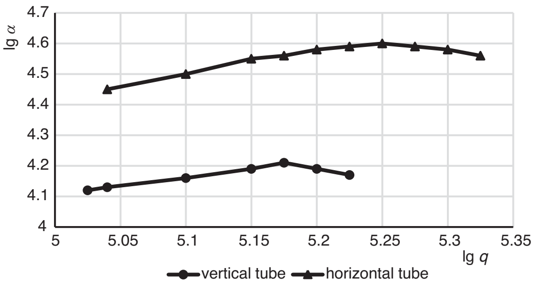

Figure 6. Comparative variations of *α* at boiling, as a function of the thermal flux, *q*, on tubular surface with large beads

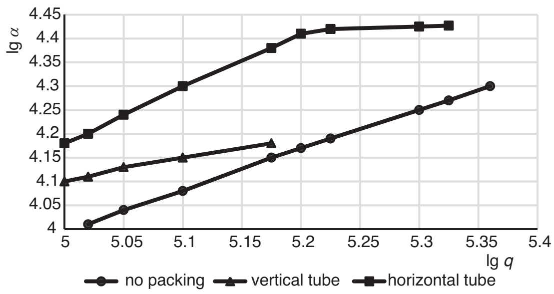

Figure 7. Comparative variations of α at boiling, as a function of the thermal flux, q, on tubular surface with small beads

Conclusions

The boiling heat transfer coefficient, α, in the presence of some glass packing materials which surround the heating tube, depends on the nature of the glass package, on the position of the heating tube, and grows with the increase of the specific thermal flux, q. This variation is different from the one performed without package.

The maximum critical values for α coefficient at boiling are systematically smaller and appear at lower heat fluxes, when working with the heating tube surrounded by glass packing material, irrespective of its nature or the heater position, with respect to the boiling with no glass package. These values were named *pseudo-critical* values.

Empirical equations for the calculation of the heat transfer coefficient, α, at boiling of water as function of thermal flux, q were proposed.

When the vertical or horizontal heating tube is surrounded by glass packing material, irrespective of its nature, the intensification of the heat transfer at boiling is approximately 2.4 times greater than working with no package.

Nomenclature

q – specific thermal flux, [Wm^{-2}]
t_e – temperature of the exterior face of the heating tube, [K]
t_b – boiling temperature, [K]

Greek symbols

α – partial heat transfer coefficient at boiling, [Wm^{-2}K^{-1}]

Subscript

c – critical
pc – pseudo-critical

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Paper submitted: July 28, 2015
Paper revised: December 3, 2015
Paper accepted: December 8, 2015