DEPENDENCE OF TUBE BUNDLE HEAT TRANSFER ON FOAM FLOW PARAMETERS

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Foam is generated during some cases of gas flow and liquid contact. There exists different kind of foam: turbulent-dynamic, structural, fire-fighting and static stable foam flow. Dynamically stable foam is very unstable two-phase system. It exists during the gas foaming only. If the delivering of gas stops, the turbulent foam immediately destroys into pure liquid and gas (if a foam is generated from the pure liquid) or turns into the statically stable foam (in the case of the surfactant solution). Statically stable foam flow is generated when gas and liquid solution of surfactants comes into contact. Statically stable foam (cellular foam) consists of gas bubbles, which have a shape of regular polygons, separated each from other by the thin liquid films.

The apparatus with a two-phase flow are used in evaporation, concentration, burning processes as well as in a variety of technological systems for wastewater treatment or utilization[1-2]. Due to the relatively small dimensions, low energy and material consumption these apparatus are suitable to use in advanced technologies like nuclear power plant heat exchangers, food industry, chemical and oil processing industry. The heat exchangers in which static stable foam flow is used have a lot of merits, for example, heat transfer rate is relatively high, foam flow rate is low, etc.

Properties and usage possibilities of dynamic foam flow have been widely investigated[3]. At the same time properties of the static stable foam are poorly investigated.. In most cases conclusions and results of the theoretical investigations can be used to steady static stable foam layer and are not suitable for investigation of processes which take part in the foam flow. Especially poor investigations have been made of heat transfer and hydrodynamic processes, which occur when static stable foam flow removes heat from different surfaces. Heat transfer processes from single tube and single line of tubes to static stable foam flow were experimentally investigated. It is clear that investigation of heat transfer of tube line can not be completely treated as modeling of processes in real heat transfer apparatus which consists of greater number of heat transfer surfaces. In order to meet these problems experimental investigations of heat transfer from vertical bundle of horizontal tubes to upward static stable foam flow were performed.

EXPERIMENTAL PROCEDURE

The experimental arrangement (Fig. 1) consisted of the following parts: foam generation (experimental) channel, two regulating valves for gas and liquid, two rotameters for gas and liquid respectively, two reservoirs for liquid storage and constant liquid level keeping, air fan, transformer and stabilizer for electric current.

Experimental channel consisted of the following: riddle at the bottom of the channel and experimental section. Foam flow was generated on riddle. The liquid with surfactants was delivered from reservoir on riddle, while gas flow was delivered through riddle. When gas and liquid came into contact, foam flow was created. Schematic view of experimental section can be seen in Fig. 1.

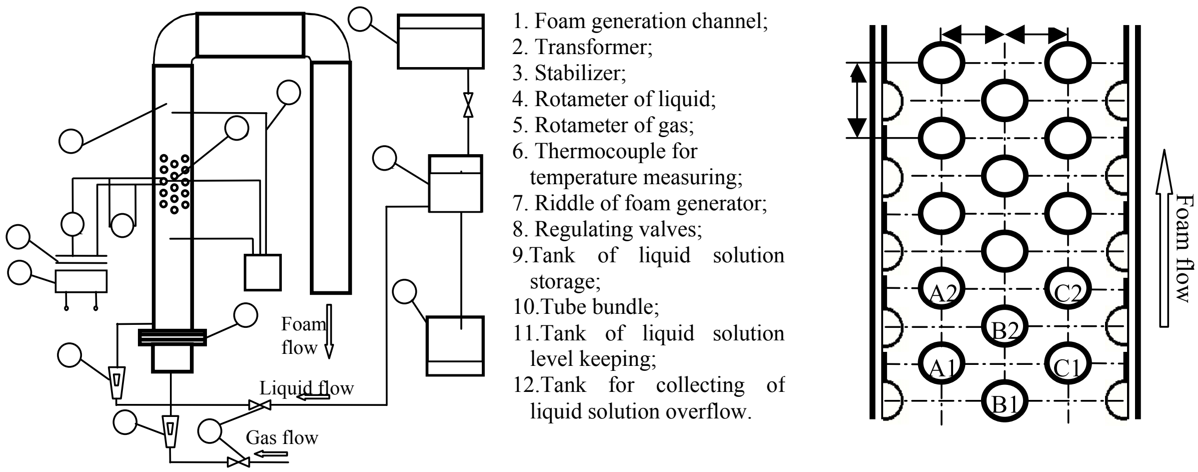

Figure 1. Experimental arrangement and experimental section of foam channel

The bundle of tubes consisted of three vertical rows with five tubes in each. Spacing among centers of tubes $s_1 = s_2 = 0.035$m. All tubes had an outside diameter of 0.02 m. The heated tube was made from copper and had an outside diameter of 0.02 m also. The endings of tube were sealed and insulated to prevent heat loses through them. The tube was heated electrically.

The temperature of foam flow was measured by two calibrated thermocouples: one in front of the bundle and one behind. The temperature of heated tube surface was measured by eight calibrated thermocouples. Six of them were placed around central part of heated tube and two of them were placed in both sides of tube at the 50 mm distance from the central part.

The water solution was used in experiments. Concentration of surfactants was kept constant and it was equal to 0.5 %.

EXPERIMENTAL RESULTS

Experimental results of heat transfer for B4 tube in the middle line of tube bundle (Fig.1) are presented in Fig. 2.

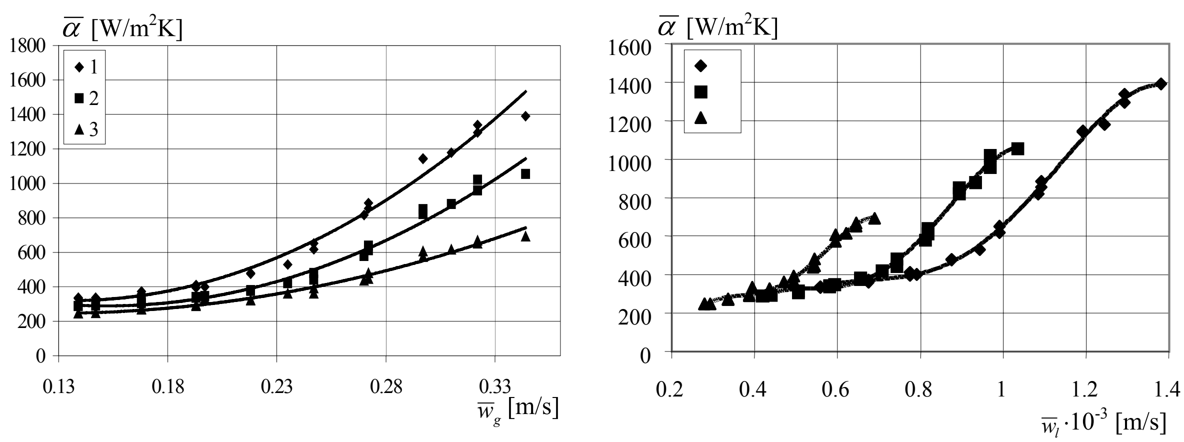

Figure 2. Heat transfer of the first tube of the middle tube line of the bundle

β : 1 - 0.996; 2 – 0.997; 3 – 0.998

The experimental results showed that heat transfer rate depends both on the average gas and liquid velocity and on the mean volumetric void fraction β of the foam flow. It was noticed that heat transfer intensity increases with increase of gas and liquid velocity and decrease of volumetric void faction. With increase of gas and liquid velocity foam flow becomes more vortex and more intensive destruction of laminar boundary layer on heated tube takes place. Influence of volumetric void fraction reduction on heat transfer intensity is more significant at bigger gas velocities. When these two factors (bigger gas velocity and reduced void fraction) are combined, effect of foam flow vortex is much bigger. The character of dependencies is the same for all tubes of the bundle.

In Fig. 3 experimental results of the heat transfer for middle line of the tube bundle are plotted against gas velocity. Fig. 3a and 3b represents heat transfer results for the middle tube line when volumetric void fraction β= 0.996 and 0.998 respectively.

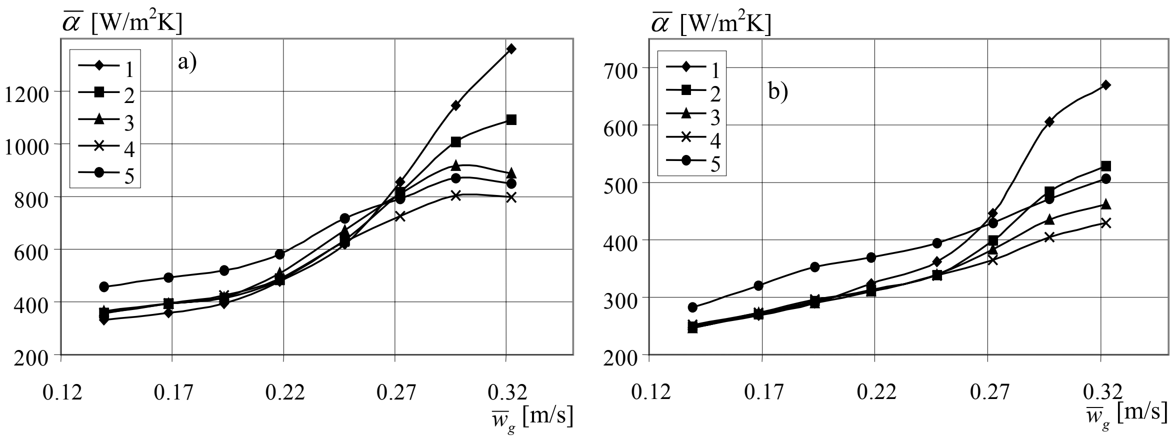

Figure 3. Heat transfer of the middle (B) line of the tube bundle; a): β= 0.996; b): β= 0.998
1, 2, 3, 4, 5 - B1, B2, B3, B4, B5 tube correspondingly

It was noticed that when the foam flow is wetter (β = 0.996) in initial period of gas velocity augmentation influence of tube position in the line on heat transfer intensity is insignificant. Only the heat transfer intensity of the fifth i.e. last tube of the tube bundle is different than for other tubes. In case of dryer foam (β= 0.998) heat transfer intensity of the fifth tube in the line of tube bundle is significantly different from other four tubes also. When gas velocity is higher (starting at 0.24 ÷ 0.25 m/s) influence of tube position becomes more significant and the highest heat transfer rate is for the first tube in the middle (B1) line of the bundle.

CONCLUSION

Heat transfer of tube bundle to upward static stable foam flow has been investigated. Influence of specific gas and mean velocity and volumetric void fraction has been established.

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