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INFLUENCE OF PIPING SINGULARITIES ON HEAT TRANSFER IN FLOW OF SURFACTANT SOLUTIONS

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ABSTRACT

Small amount of additives like e.g. surfactants can significantly suppress friction in turbulent flow of water. However the drag reduction is accompanied by a considerable decrease of heat transfer. Both drag reduction and good heat transfer are desired properties of systems employed in district heating systems. We investigated therefore the drag reduction properties of some surfactant mixtures with sodium salicylate. This contribution presents the results of drag reduction by three cationic surfactants. There was also investigated heat transfer effectiveness in these surfactants, particularly heat transfer behind singularities which were a valve and a tube bend. The singularities have negligible effect on heat transfer in water alone. They influence heat transfer coefficient only in the imminent part of the tube. The heat transfer enhancement is rather small.

INTRODUCTION

Active drag reduction (D.R.) is a phenomenon in which a small addition of an additive in the turbulent flow of liquids causes friction reduction, often very substantial (Zakin et al. [1], Bewersdorf [2], Myska et al. [3]). Turbulent characteristics of the flow are changed or suppressed, however, turbulence still persists even though the flow shows some marks of laminar flow. Efficient additives can be made when special surfactants are mixed with a counter ion. The mixture produces molecules which associate into micelles with particular properties. When a certain concentration is exceeded, spherical micelles transform into rods or threads. At present this shape is considered as a main cause of the phenomenon.

D.R. in flow of heat transfer liquids may serve as a significant means for pumping energy savings in industry as well as in heating and air conditioning of district housing systems. However, it has been found that D.R. is accompanied with a decrease of heat transfer and therefore it is necessary to strive not only for D.R. itself but also for heat transfer enhancement (Zhou et al. [4], Sestak et al. [5], Myska et al. [6]). Our main interest is to find how to increase heat transfer when micellar additives are used. This is possible for example by increase of turbulence with the aid of common parts of piping like bends or valves installed at the tube entrance.

DRAG REDUCTION PROPERTIES OF INVESTIGATED SURFACTANTS

The quality of D. R. by micellar additives is determined by a complete system in which the phenomenon takes place. The system involves geometrical conditions (like tube diameter, calming or perturbing spots in the flow etc.), physico-chemical properties (temperature, solvent properties etc.) and additive properties (surfactant structure, surfactant and counter ion concentration etc.).

Best D.R. is achieved when mass concentration of both components in the mixture (i.e. the surfactant itself and counter ion) equals. Small surplus of counter ion as well as an increase of over-all concentration can increase the durability of the additive.

In Figs.1, 2 and 3 is compared D.R. effectiveness of three cationic surfactants with which we experimented. Viscoelastic micellar solution of NaSal/CTAC (Hexadecyltrimethyl ammonium chloride – CTAC in mixture with Sodium salicylate – NaSal), Fig.1, and viscoelastic solution of NaSal/CTAB (Hexadecyltrimethyl ammonium bromide - CTAB), Fig.2, were experimented with in a 10.5 mm I.D. tube together with non-viscoelastic micellar solution of the mixture NaSal/AR 50 (AR 50 is Oleyltrimethyl ammonium chloride, commercial Arquad SV 50), Fig.3.

Maximum D.R. in solutions of NaSal/AR 50 and NaSal/CTAC was obtained with concentrations 4.0/1.6 mM. Results with NaSal/CTAB in Fig.2 show that also this surfactant yields best D.R. at a concentration below 4.3/1.7 mM. Drag reduction at the bulk velocity 2 m/s is approximately 67% - 71% in all solutions.

Increase of concentration in NaSal/AR50 solution to higher concentration 12.5/5.0 mM showed a tiny decrease in effectiveness while in the solution of NaSal/CTAB this concentration caused quite a spectacular behavior with a great decrease of D.R. effectiveness.

Concentration 4.0/1.6 mM in all tested surfactants yields both the good D.R. and the long durability. Increasing the concentration ratio of the components, ζ = counter ion/surfactant, does not change D.R. effectiveness but it can improve the durability of the mixture.

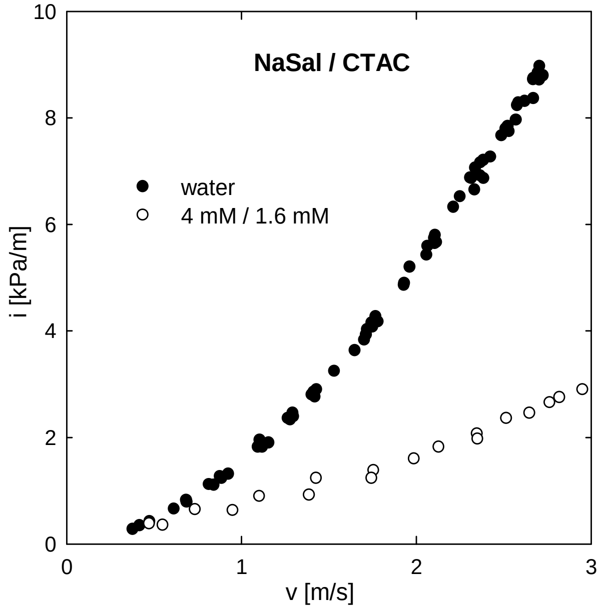

Figure 1 Pressure gradient dependence on bulk velocity of CTAC mixture in the 10.5mm tube

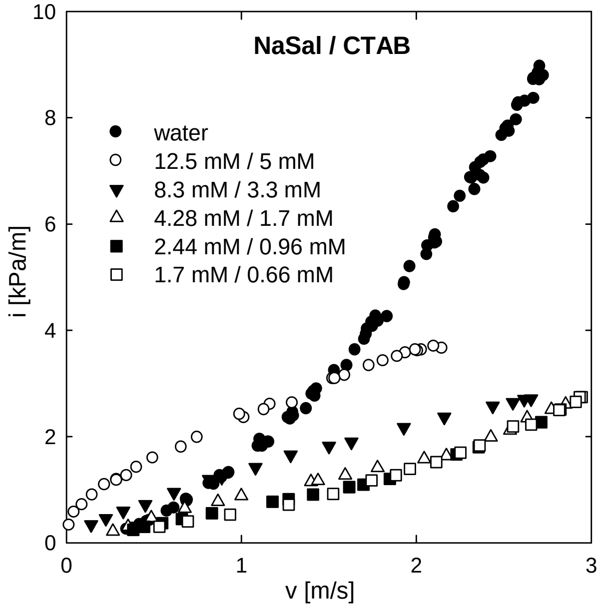

Figure 2 Pressure gradient dependence in CTAB mixture (table shows the concentration)

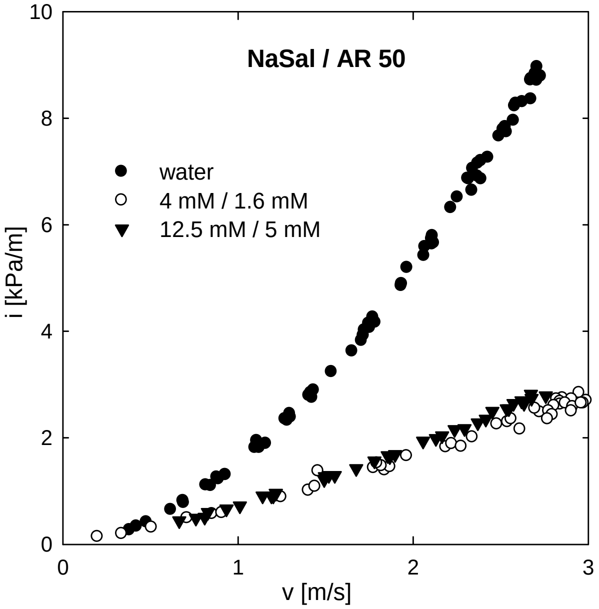

Figure 3 Pressure gradient dependence in AR50 mixture

DRAG REDUCTION IN FLOW THROUGH SINGULARITIES

Measurement of local pressure loss was made on a stand with closed hydraulic loop and constant level tank. Surfactants were the same as named above; investigated were surfactant concentrations, 0.625, 1.25, 2.5 and 5.0 mM, the ratio ζ was kept constantly 2.5.

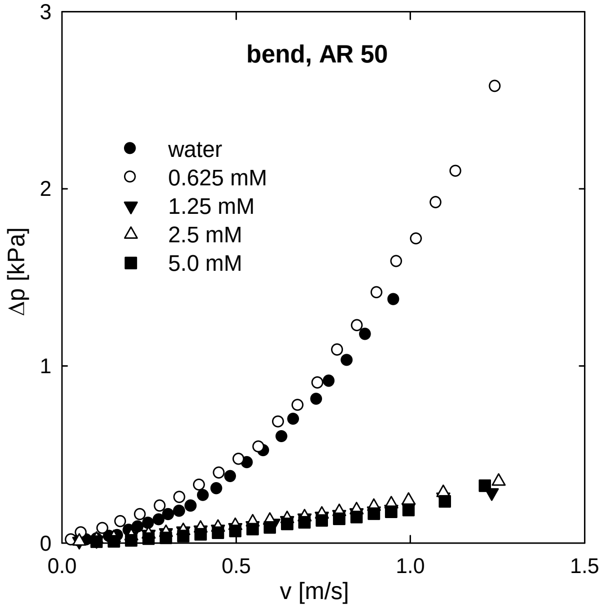

Figure 4 Pressure drop for flow of AR50 in the 180° bend (the table inside the figure shows the surfactant concentration)

All three cationic additives yield similar pressure drop results in a straight tube at concentrations below 4.0/1.6mM, but pressure drop results of the flow of single surfactants at higher concentrations may differ. However, different results were obtained from the flow through singularities at all concentrations. Tested were circular 180° bend with 16mm I.D. and radius R = 225mm, and a conventional 15mm I.D. saddle valve with a 90° change of flow direction. The valve was either half or full open. Results are in Figs. 4 – 7.

Pressure loss dependence on bulk velocity in the bend is plotted in Figs.4 and 5 for AR50 and CTAC. Similar pattern as for CTAC was obtained with CTAB. Figs.6 and 7 show pressure loss in full open valve for AR50 and CTAB, similar result as the CTAB gives CTAC.

We conclude that both CTAB and CTAC increase pressure losses. However, pressure loss for AR50 is either not increased or may be even decreased.

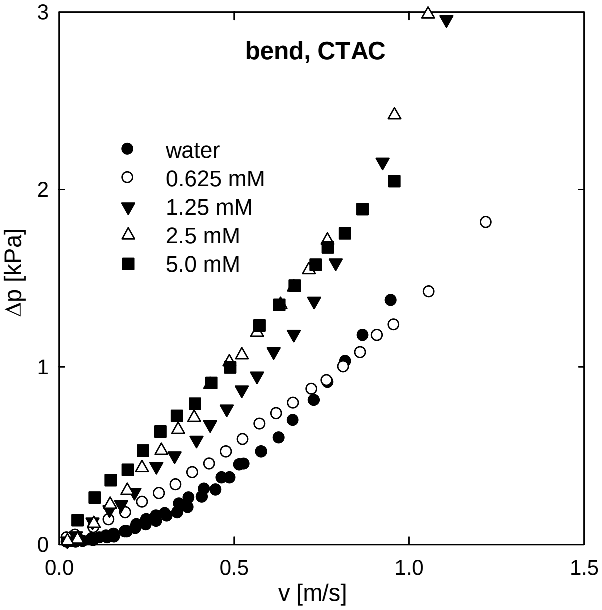

Figure 5 Pressure drop for flow of CTAC in the 180° bend

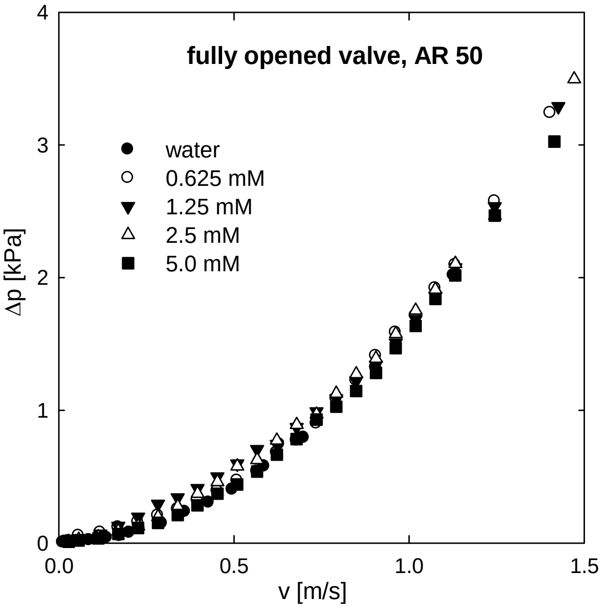

Figure 6 Pressure drop for flow of AR50 through the fully-opened saddle valve

HEAT TRANSFER BEHIND BOTH SINGULARITIES

Heat transfer experiments required building of an other facility. It was a closed hydraulic loop with a positive displacement pump and continuously variable flow rate control. In order to increase turbulence and thus the heat transfer, either the bend or the valve were placed in front of the entrance in the tube. After passing the complete test section the solution flows into a storage tank where it is heated or cooled. Then it enters the pump suction. The complete test section consists of a Cr-Ni stainless steel tube 2.5m long with 16mm I.D. together with preset singularities. Wall thickness of the tube is 1.5mm. A convergent piece with 400mm long calming tube piece was installed before the complete test section. Measurements were made with three different concentrations of AR50 (2.5, 3.27 and 4.55 mM). The range of Reynolds numbers was 8,000 to 100,000 and the heat flux through the tube wall was 22 and 40 kW/m^2. Measuring tube was heated electrically by high intensity AC currents.

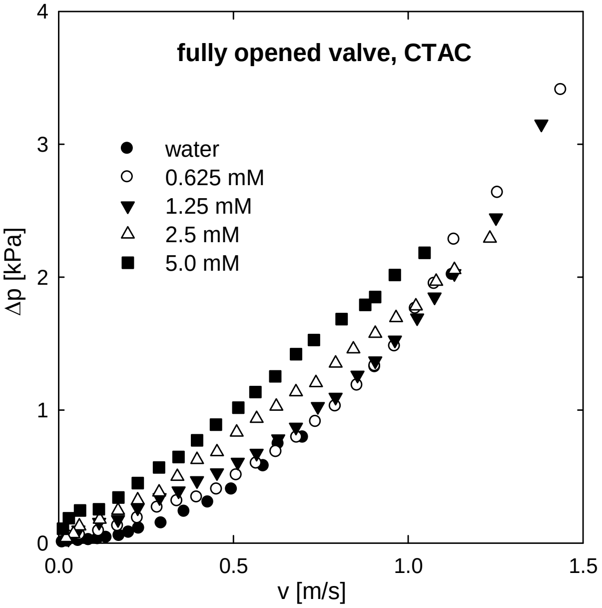

Figure 7 Pressure drop for flow of CTAB through the fully-opened saddle valve

A mixing chamber for measurement of the mean calorimetric temperature was attached to the exit from the straight tube. Tube wall temperatures were measured by 18 thermocouples located in the horizontal symmetry axis of the tube. Mean mixing temperature was determined using a simple calorimetric calculation because the resistance heating generates constant heat flux conditions at the tube wall. Flow rate of the solutions was measured by induction flow meter Krohne.

The determined courses of local Nusselt number, Nu, along the tube for flow of water only and water with the surfactant provide detailed information on heat transfer and its changes caused by installation of both elements in the inlet of the tube. An example of local Nu variation along the axial length of the straight tube and with preset fully opened valve is shown in Figs. 8 and 9. Decrease of Nu caused by presence of the additive NaSal/AR50 in water is large. But on the other hand the relative Nusselt number (calculated as ratio of Nusselt number just behind the inlet, Nu_0, to local Nusselt number, Nu, along the pipe) is much higher in water with the surfactant, see Fig. 10. Fig.11 shows negligible difference if the valve is open or half open. It also shows negligible influence of surfactant concentration on Nusselt number, its slight increase at the lowest concentration is probably due to a low viscosity of the solution.

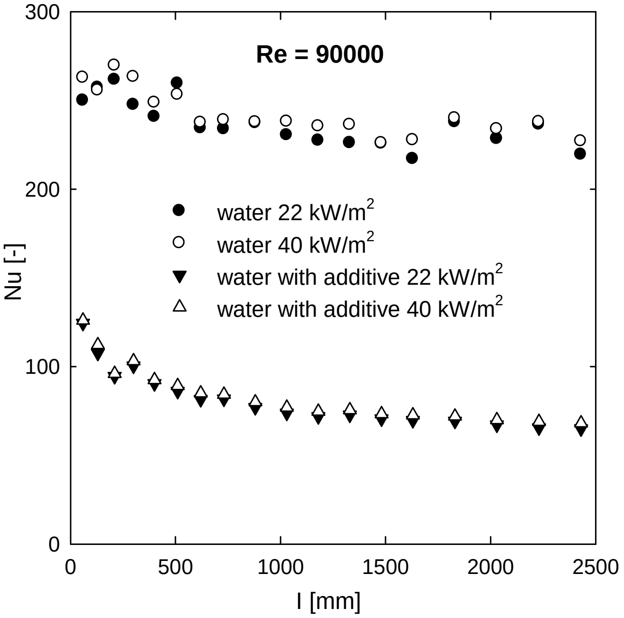

Figure 8 Variation of the local Nusselt number with axial distance in the straight 16mm tube preceded by fully opened saddle valve, Re=90000, concentration of AR 50 is 3.27 mM

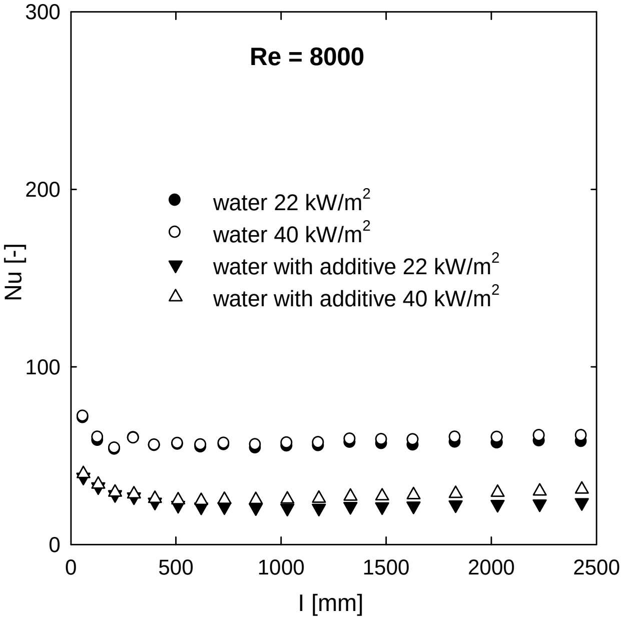

Figure 9 Variation of the local Nusselt number with axial distance in the straight tube preceded by fully opened saddle valve, Re=8000, conc. of AR50 is 3.27 mM

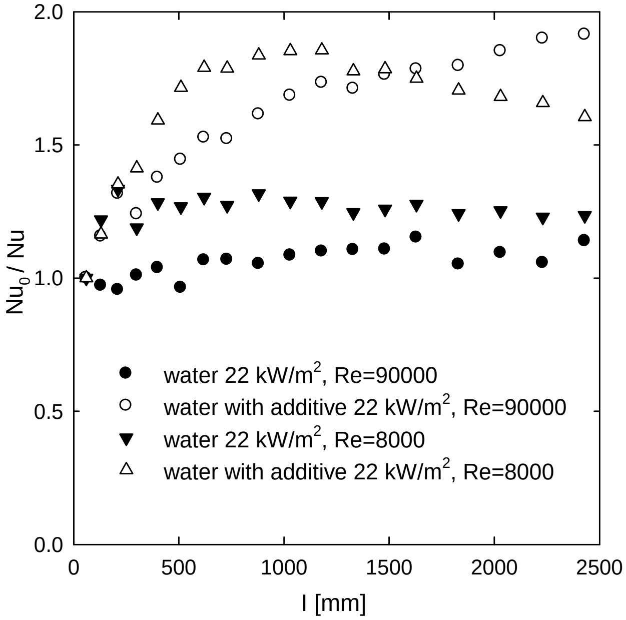

Figure 10 Variation of the relative Nusselt number with axial distance in the straight tube preceded by fully opened saddle valve, conc. of AR50 is 3.27 mM

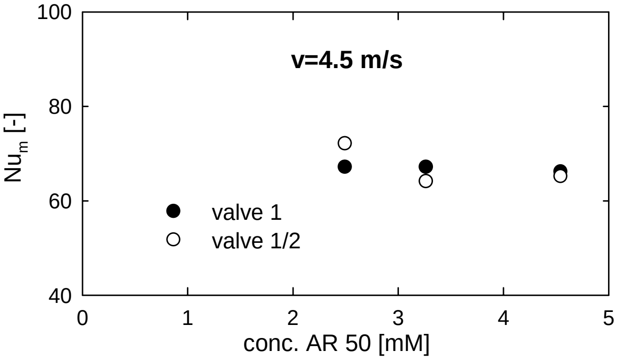

Figure 11 Influence of the AR 50 concentration upon the mean value of Nusselt number when the saddle valve is placed in front of the test section of the straight tube

Influence of elements preceding the tube inlet upon mean Nusselt number is shown in Figs.12 and 13. Fig.12 presents the dependence of the mean Nusselt number on bulk velocity of water for different elements. There is no visible influence of the elements on Nu, data are scattered within the ±5% interval for the tube itself. The term pipe in Figs.12 and 13 means direct joint of the calming and measuring parts. It follows from Fig.13 that a positive effect of flow of water with the additive may be expected at high flow rates only. Heat transfer increase in the tube behind preset elements compared to the tube alone is not significant because the calming part is short.

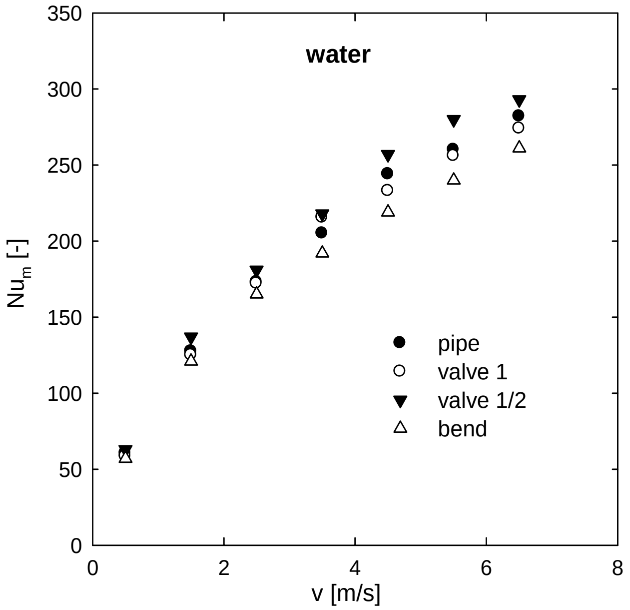

Figure 12 Variation of the mean Nusselt number with the mean velocity of water

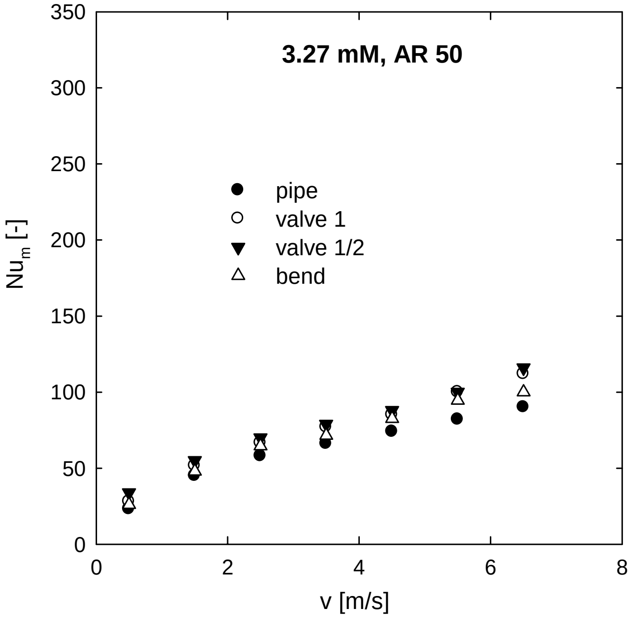

Figure 13 Variation of the mean Nusselt number with the mean velocity of water with a surfactant additive in the entrance region of a pipe (0.5 m).

CONCLUSION

Following conclusions may be drawn from the comparison of the local Nusselt numbers:

- Piping elements preceding the tube inlet do not exert any influence upon the heat transfer through the tube wall for flow of water only. There is only some influence just behind the elements.
- It was confirmed that also drag reducing surfactants CTAB, CTAC and AR 50 decrease the heat transfer, however, concentration of the additive has almost no influence upon the heat transfer. It may influence, analogous to pressure losses, other properties such as e.g. durability of drag reduction ability, critical value of the shear stress etc.
- Piping elements placed in front of the tube inlet do exert a positive influence upon heat transfer in the entry region of the tube if surfactant additives are employed. Relative heat transfer enhancement in this entry region, if compared with flow of water without additive, is significant.

Acknowledgement

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