Air cooling by the pilot plant silicon carbide shell and tube heat exchanger

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The processes of cooling gasses by semi-operating shell and tube heat exchangers for subsequent application in processes of removal of gaseous air contaminants via liquid absorber is the major topic of this work. The aim of the work is to verify the theoretical convenience of silicon carbide as a better heat transfer surface material compared with borosilicate glass, traditionally used chemically resistant material characterized by two orders of magnitude worse thermal conductivity. This work compares experimental data for both materials as well as results from the theoretical computational model using the *j* factor, the correction factors for the baffles, and the correction for air humidity condensation (according to the *Perry's chemical engineers' handbook*).

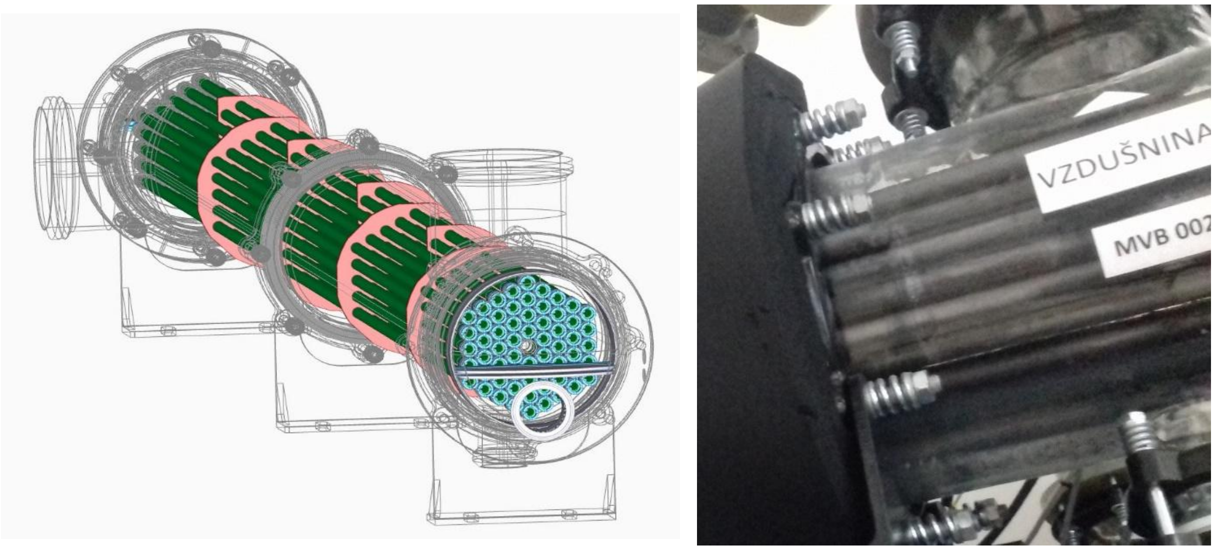

Figure 1: Shell and tube heat exchanger with SiC heat transfer surface used for experiments

Heat transfer on two pilot plant shell and tube heat exchangers (see Figure 1) with glass or carbide heat exchange surface and eight plastic baffles was examined under constant conditions by cooling the air by 50% propylene glycol in tubes with flow about 3 kg/s. Coolant flowed in 60 tubes of an inner diameter of 11 mm. Coolant flowed through the exchanger three times, the speed about 1,8 m/s was reached. So only laminar flow rates were available for experiments, Reynolds number was about 1100. The inlet coolant temperature was chosen to be just above 0 °C, about -7 °C and about -15 °C for the experiments. Air flowed in shell of inner diameter 0,2 m. The air flow could be regulated by frequency changer, 150–300 kg/h were used for experiments with a step of 25 kg/h. This corresponds to the off-layer speed up to 3 m/s, when the Reynolds number is about 3000. The inlet air temperature was chosen to be about 15 °C, 35 °C, 55 °C and about 75 °C. The humidity of air could be increased by water stream influx with intensity 1,5 kg/h or 2,5 kg/h. Both heat transfer media flowed in a recycling loop.

Outlet temperature of streams and outlet air humidity were measured as well as air pressure drop in the exchanger, flow rate of both streams, input temperature of streams and pressure, temperature and humidity in the laboratory. So, then the experimental value of the heat transfer coefficient k ($W \cdot m^{-2} \cdot K^{-1}$) could be calculated from the air flow ($kg \cdot s^{-1}$), heat capacity of air ($J \cdot kg^{-1} \cdot K^{-1}$), temperature change of air (K), heat losses (W), mean temperature difference between heat transfer media (K) and heat transfer surface (m^2) from the following equation,

$$\dot{m}_{\text{air}} \cdot c_{p,\text{air}} \cdot \Delta T_{\text{air}} \pm \dot{Q}_{\text{losses}} = k \cdot \Delta T_{\text{LMTD}} \cdot S \,. \tag{1}$$

Heat losses to the surroundings from this uninsulated heat exchanger were estimated based on calculations from dimensionless criteria (Reynolds, Grashof, Prandtl and Nusselt numbers). Due to these losses, the temperature profile in the exchanger was changed significantly, so that the mean temperature difference did not longer correspond to the commonly used logarithmic computational relationship (LMTD). LMTD value needs to be corrected when losses are included.

Although the main resistance to heat transfer in these experiments is neither the coolant nor the heat transfer material but the air, silicon carbide has nevertheless proved its worth. For glass, the experimental heat transfer coefficient was about 25 % higher at maximum flow than the theoretical model indicates. In the case of silicon carbide, the experimental value is about 44 % higher than the theoretical. But, in the case of the lowest examined air flow, for carbide, the experimental data are only 8 % higher than the theoretical, and, for glass, the experimental data are 1 % lower than the theoretical. It was also confirmed that with increasing amounts of condensing humidity in the exchanger, the heat transfer coefficient of the dry air decreases by up to 4 % during the performed experiments (the outlet air temperature increases slightly). At lower temperatures and lower flow rates, the values of the heat transfer coefficient are affected by heat losses, so the experiments using thermal insulation will follow.

While the heat transfer experiments on these exchangers will be completed, this air-cooling process will be situated directly in front of the process of separation of gaseous impurities from gas into liquid using a scrubber, more effective at lower temperatures. Separation of some pollutants could also take place by condensation in the exchanger at very low temperatures, or high pressures.