Influence of Limescale on Heating Elements Efficiency

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Abstract

Electric resistances are widely used as heating elements in domestic and industrial equipment; since process water contains calcium carbonate and calcium bicarbonate, limescale plays an important role on global efficiency of water-heating systems.
Limescale is caused by the equilibrium between dissolved calcium bicarbonate and dissolved calcium carbonate:

$Ca^{2+} + 2HCO_3^- \leftrightharpoons Ca^{2+} + CO_3^{2-} + CO_2(dis) + H_2O$

Carbon dioxide dissolved in water is in equilibrium with that dissolved in the gaseous state (g):

$CO_2(dis) \leftrightharpoons CO_2(g)$

When the temperature rises, CO_2 equilibrium moves towards the gas phase and, as a consequence, the equilibrium of calcium carbonate shift to the right; as the concentration of carbonate increases, calcium carbonate precipitates as salt:

$Ca^{2+} + CO_3^{2-} \leftrightharpoons CaCO_3$

Since calcium carbonate has a very low thermal conductivity it causes a decrease of the overall heat transfer coefficient and consequently a reduction of the system efficiency; this lead to an increase in energy consumption due to the increase of the heating time.
In order to analyze these effects, a 2D-axisymmetric model of a tubular heat-exchanger has been simulated with COMSOL Multiphysics®; an inlet water velocity of 1m/s, a total power of 2 kW and a variable thickness layer of $CaCO_3$ are applied (Figure 1). The volume of water in the system is 10 liters.

Two different physics were used:
- The joule heating interface, to simulate joule heating effect and the heat transfer phenomena
- The turbulent flow interface, to simulate the fluid flow in a closed loop.

To understand the effect of limescale some graphs are reported.

In figure 2 the average liquid temperature trends with different limescale thickness are reported;

the graph shows a liquid temperature decrease of 5°C for a limescale thickness of 2mm after 480 seconds.

Figure 3 shows the average heating element temperatures and the heating power at different limescale thickness.In this graph is it is shown that limescale causes a relevant increase of the internal temperature of the heating element; for example for a limescale thickness of 2mm the temperature increase of the heating element is equal to 44°C.

Figure 4 reports the temperature profile in a cross-section of the system under investigation at 480s.The graph shows that, despite there is a relevant increase in the heating element temperature, the liquid temperature in presence of limescale is lower in presence of limescale; this is due to the very low thermal conductivity of the $CaCO_3$.

As it can be seen, limescale plays an important role on the efficiency of a heating system because it can increase the process time and consequently to an increase in the energy consumption to achieve the same results.
Assuming that our system is a simplified model of a washing machine heating system and considering a washing cycle at 60°C, the heating time increase of about 30s in the case of a limescale thickness of 1mm; as example, if every family in Italy have a washing machine, for every cycle the increase in energy consumption is about 34toe (1toe = 11.36 MWh).

Reference

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Figures used in the abstract

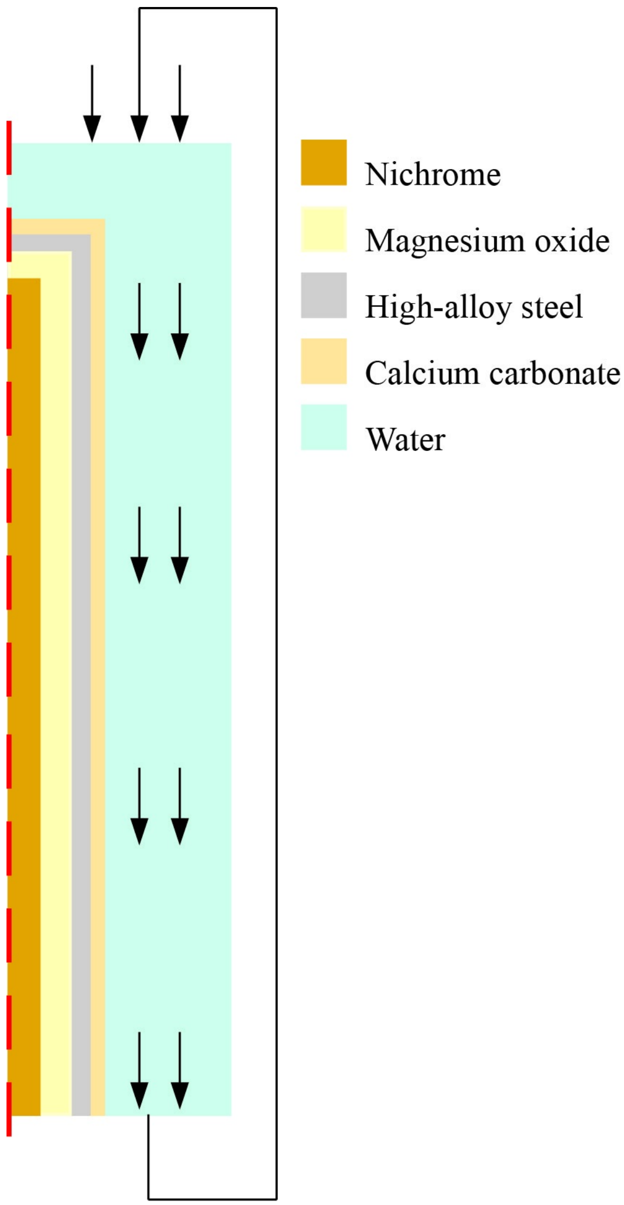

Figure 1: Geometry of the model

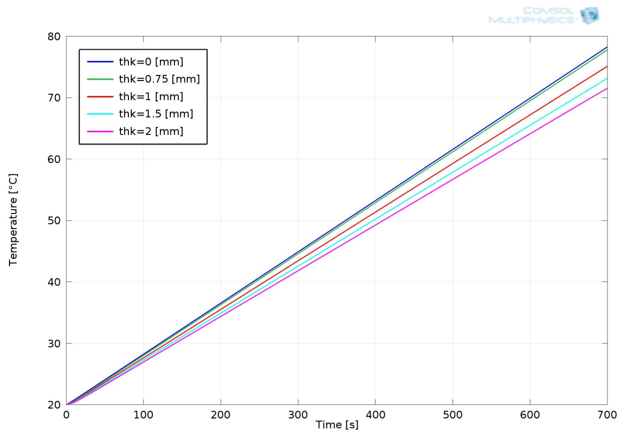

Figure 2: Average liquid temperature

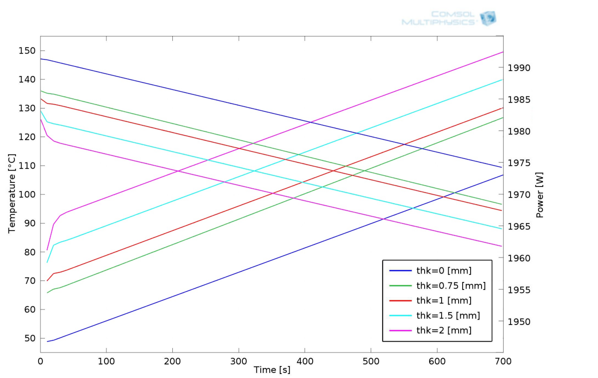

Figure 3: Average heating element temperature

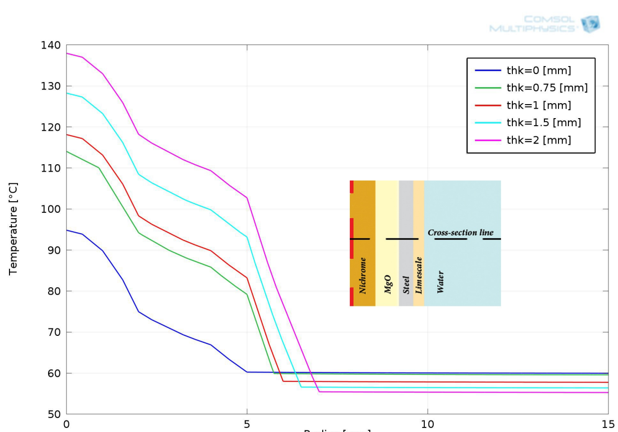

Figure 4: Temperature profile in a cross-section at 480s