Effect of irreversibilities on the performance of glass furnaces

Reinhard Conradt[*1]

[1]uniglassAC GmbH – Germany

Abstract

In many branches of glass industry, furnace operators aim at running their furnaces at a high production yield, a low specific energy demand, and a marketable glass quality. It is true, extreme quality standards can be reached at the expense of productivity and energy efficiency only, but optimal conditions for the latter two targets are located within close proximity. The optimum is located between a range of wastefully low to high pull rates (range I) and a range of overpull (range II) where the amount of heat transferred is no longer able to sustain the desired glass quality. The behaviour is a direct consequence of the fact that any thinkable furnace concept obeys the simple overall balance P-in = P-ex + P-loss, where the symbol P denotes powers in units of kW. Index "in" denotes the power input by fuel and electricity, index "ex" denotes the useful or exploited power determined by the intrinsic energy demand of the batch-to-melt conversion and the heat content of the melt at temperature level T-ex at the exit of the furnace. Both P-in and P-ex are functions of state; they are "path independent", hence, do not depend on the kind of intrinsic processes in the furnace. Index "loss" denotes the cumulative losses. The above power balance reflects both the 1st and 2nd law of thermodynamics. In specific, P-loss has the same meaning as the uncompensated heat in Clausius' concept of entropy. P-loss comprises both pull independent and pull dependent irreversibilities. While the latter ones basically consist in the heat losses through the furnace periphery, the former ones are due to intrinsic entropy generation. Four sources of intrinsic irreversibility are investigated and discussed in detail. These are: first, the heat capacity flow imbalance between hot and cold stream (furnace atmosphere and melt, respectively), second, the resistance to heat transfer (across the hearth surface and at the electrodes), third, pressure losses in the flow of furnace atmosphere, and forth, chemical irreversibility of the batch-to-melt reaction. These influences are analysed one by one for a number of full-scale industrial furnaces and industrial batches. As a result, the linear relation between power input P-in and pull rate p, P-in = a + b·p, valid in general for range I can be quantified, i.e. the constants a and b are derived from the process irreversibility in a quantitative way. This allows one, for a given furnace design and a given batch composition, to precisely predict the location of the respective optimum of furnace operation. This is underpinned by industrial case studies. The approach may be used as a tool to reduce the specific energy demand, hence, CO_2 emissions, and to assess the effects of novel furnace design like, e.g. hybrid furnaces using decreased amount of natural gas and increased levels of electric boosting.

[*]Speaker