Modelling the thermal efficiency of condensing boilers working in steady-state conditions

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Condensing boilers offer substantial energy savings because of their high efficiency compared to non-condensing boilers, which are designed in order to avoid flue gas condensation and thus low temperature corrosion. Non-condensing boilers exit flue gas temperature is typically between 150°C and 180°C, which leads to up to 10% of sensible heat loss. Condensing technology consists of cooling the exhaust stream below the dew point so that the water vapour produced by the combustion process can condense. The latent heat can be partly recovered as well as some of the sensible heat. Thus, the thermal efficiency of the boiler is significantly increased. This technology is, nowadays, a standard technology for space heating in many countries. It is, for example, the most dominant boiler technology in the Netherlands [1]. However it is not always well used to have the best working conditions. To ensure continuous condensing operation, heat exchange surfaces must be high enough and, therefore, return water to the boiler must be below the dew point. That means that the heating system must be designed to lower the heating water temperature (underfloor heating systems for example).

There has been few published work over the condensing behaviour of domestic boilers. Some researchers focused on heat transfer coefficient of vapour-gas mixtures with a large amount of non-condensable gas and high moisture content [2-4]. Che et al [2, 3] recommends to take the convective heat transfer coefficient with condensation 1.5-2 times the corresponding convective heat transfer coefficient without condensation. Liang et al [4] found that convective heat transfer coefficient increases as the gas-vapor mixture flow rate and the mass fraction of water vapor increase. In their experimental range, this coefficient was 1-3.5 times that of forced convection without condensation. From another point of view, Hanby [5] presented a general boiler model that covers the condensing heat transfer regime using the sensible to total heat transfer method for cooling coils and using parameters fitted with manufacturers data. The present work uses a similar method (general boiler model combined to a cooling coil model) as the exact geometry of boilers is generally unknown. The key parameter required is the overall heat transfer coefficient between the combustion products and the water.

The structure of the developed model is composed of a conventional boiler model with a main counterflow gas-water heat exchanger (HX1), at which a condensing heat exchanger is added (HX2) (Figure 1) [6]. Knowing the oxygen content in the flue gas and the natural gas composition, adiabatic temperature (T_{adiab}) is calculated as well as the combustion products composition. Prior to the second heat exchanger (HX2), the exhaust gas are converted to equivalent wet air as the wet heat exchanger is simulated by a cooling coil used in air treatment. The main difference with Hanby's model [5] lies in the cooling coil model. The coil is divided into 5 parts and each part simulated by Morisot's model [7].

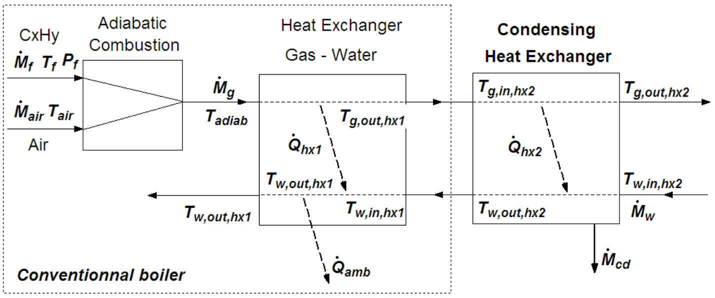

Figure 1: Structure of the model

Six parameters are needed for calculation and these parameters are fitted with experimental data: one test in dry regime and one test in wet regime. Steady-state tests have been performed on two household boilers (a gas-fired and a fuel oil boiler), whose nominal outputs are 24 kW in order to fit the model parameters and check the model behaviour. It seems that the model gives the correct trend for the thermal efficiency prediction. For the gas boiler, below the dew point (52°C), the efficiency gradually rises and sharply increases below until 106%. The trend is the same for the fuel oil boiler. In this case, the dew point temperature is lower (47°C). Below the dew point, the efficiency rises until 104%. Calculated thermal efficiency has been compared to the measured one for each test. These points are shown on Figure 2. For both boilers, in dry regimes, the calculated efficiency is greater than the measured one. However, the estimated efficiency stays within measurement uncertainty (2%).

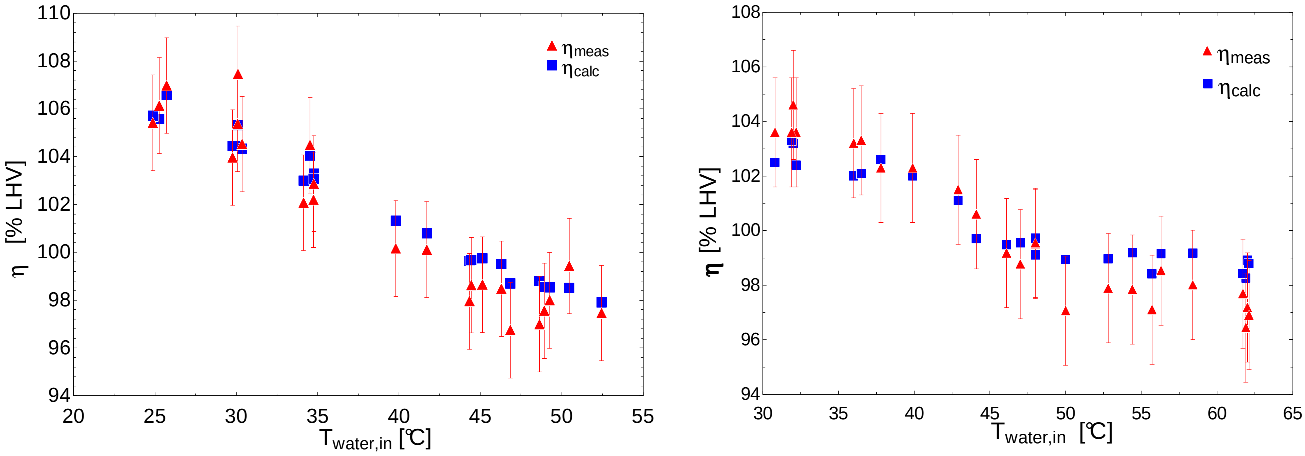

Figure 2: Model boiler efficiency compared to measured efficiency at different boiler water inlet temperatures
Left: for the gas-fired boiler – Right: for the oil-fired boiler

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