Inverse Prediction of Phase Change Banks in High Temperature Furnaces

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An inverse heat transfer procedure for predicting the time-varying thickness of phase-change banks on the inside surface of the walls of high temperature furnaces is presented. Fig. 1 shows the schematic of such furnace and exemplifies the direct and inverse problems. The main feature of the inverse method is its unique capability of making fast predictions so that it can be easily integrated to existing real-time control systems of industrial facilities. The method rests on fast computing state-space models (direct model) that are designed to mimic the response of a full finite-difference model of the phase change problem. A Kalman filter coupled with a recursive least-square estimator (inverse method) is shown in Fig. 2 and is employed to estimate the time-varying phase front position from the data collected by a temperature and/or heat flux sensor located in the furnace wall. The inverse heat transfer procedure is thoroughly tested for typical phase change conditions that prevail inside industrial facilities. As an example, Fig. 3 presents the exact and inverse bank thickness when using a temperature sensor located at outer surface of the brick wall. The effect of the sensor type (temperature sensor or heat flux sensor), of its location and of the measurement noise on the accuracy and stability of the predicted bank thickness is also investigated. It is shown that the proposed inverse heat transfer procedure becomes increasingly reliable and accurate for predicting the bank thickness as it shrinks. This feature is of the utmost interest for preventing the sudden and accidental loss of the protective banks of industrial furnaces filled with molten material. Recommendations are also made concerning the type and location of sensors.

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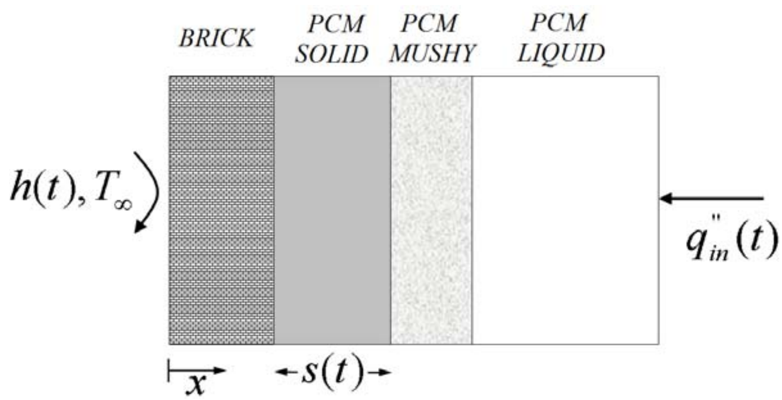
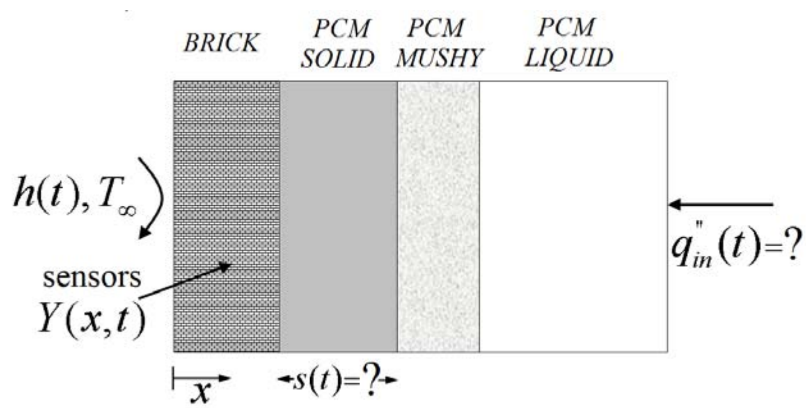


a) The direct problem: $q''_{in}(t)$ and $h(t)$ are known; $T(x,t)$, $q''(x,t)$, and $s(t)$ are calculated from the direct model.



b) The inverse problem: $q''_{in}(t)$ is unknown. It is determined from temperatures and/or heat fluxes $Y(x,t)$ measured inside or at the outer surface of the brick wall.

Fig. 1: Schematic of a melting furnace.

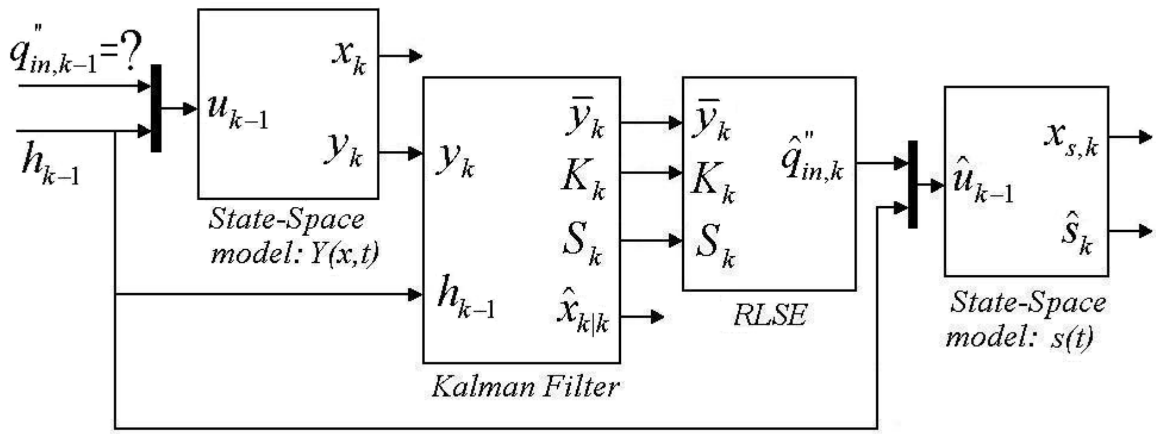


Fig. 2 : The inverse method; a Kalman filter coupled with a recursive least-square estimator.

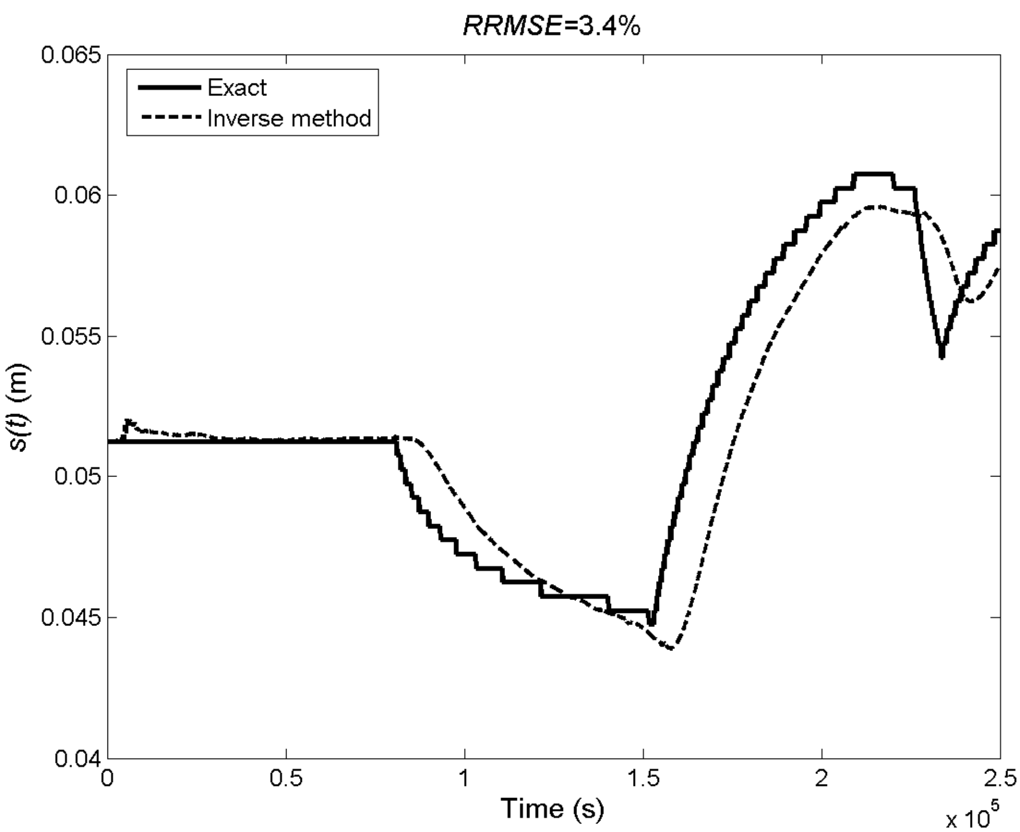


Fig. 3: Predicted (inverse method) and exact bank thickness using a temperature sensor located at the brick outer surface and with a measurement noise standard deviation σ_R =0.5 K.