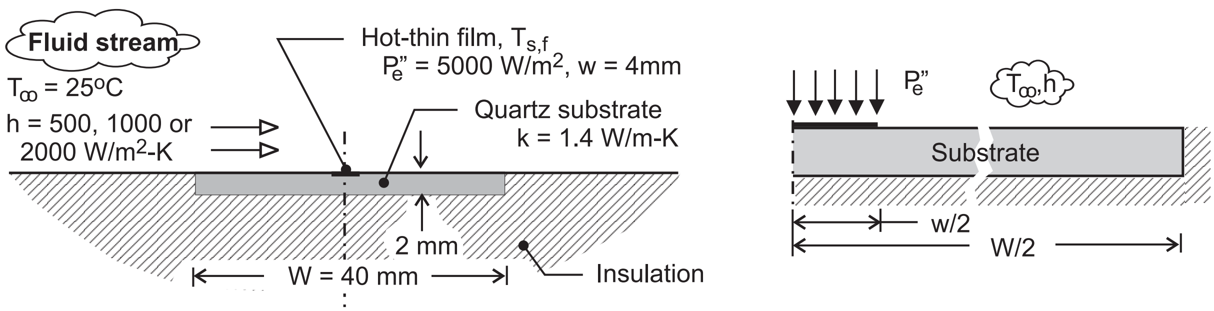
PROBLEM 4.91

KNOWN: Hot-film flux gage for determining the convection coefficient of an adjoining fluid stream by measuring the dissipated electric power, P_e , and the average surface temperature, $T_{s,f}$.

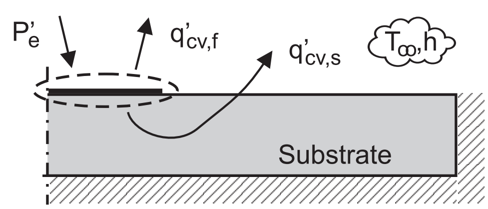
FIND: Using the finite-element method of *FEHT*, determine the fraction of the power dissipation that is conducted into the quartz substrate considering three cases corresponding to convection coefficients of 500, 1000 and 2000 $W/m^2 \cdot K$.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state, two-dimensional conduction, (2) Constant substrate properties, (3) Uniform convection coefficient over the hot-film and substrate surfaces, (4) Uniform power dissipation over hot film.

ANALYSIS: The symmetrical section shown in the schematic above (right) is drawn into *FEHT* specifying the substrate material property. On the upper surface, a convection boundary condition (T_∞,h) is specified over the full width W/2. Additionally, an applied uniform flux $\left(P_e'',\ W/m^2\right)$ boundary condition is specified for the hot-film region (w/2). The remaining surfaces of the two-dimensional system are specified as adiabatic. In the schematic below, the electrical power dissipation P_e' (W/m) in the hot film is transferred by convection from the film surface, $q'_{cv,f}$, and from the adjacent substrate surface, $q'_{cv,s}$.



The analysis evaluates the fraction, F, of the dissipated electrical power that is conducted into the substrate and convected to the fluid stream,

$$F = q'_{cv,s} / P_e' = 1 - q'_{cv,f} / P_e'$$

where $\quad P_e' = P_e''(w/2) = 5000\ W/m^2 \times (0.002\ m) = 10\ W/m.$

After solving for the temperature distribution, the *View|Heat Flow* command is used to evaluate $q'_{cv,f}$ for the three values of the convection coefficient.

Continued …

PROBLEM 4.91 (Cont.)

Case	$h(W/m^2 \cdot K)$	$q'_{cv,f}\ (W/m)$	F(%)	$T_{s,f}$ (°C)
1	500	5.64	43.6	30.9
2	1000	6.74	32.6	28.6
3	2000	7.70	23.3	27.0

COMMENTS: (1) For the ideal hot-film flux gage, there is negligible heat transfer to the substrate, and the convection coefficient of the air stream is calculated from the measured electrical power, P''_e, the average film temperature (by a thin-film thermocouple), $T_{s,f}$, and the fluid stream temperature, T_∞, as $h = P''_e / \left(T_{s,f} - T_\infty\right)$. The purpose in performing the present analysis is to estimate a correction factor to account for heat transfer to the substrate.

(2) As anticipated, the fraction of the dissipated electrical power conducted into the substrate, F, decreases with increasing convection coefficient. For the case of the largest convection coefficient, F amounts to 25%, making it necessary to develop a reliable, accurate heat transfer model to estimate the applied correction. Further, this condition limits the usefulness of this gage design to flows with high convection coefficients.

(3) A reduction in F, and hence the effect of an applied correction, could be achieved with a substrate material having a lower thermal conductivity than quartz. However, quartz is a common substrate material for fabrication of thin-film heat-flux gages and thermocouples. By what other means could you reduce F?

(4) In addition to the tutorial example in the *FEHT* User's Manual, the solved models for Examples 4.3 and 4.4 are useful for developing skills helpful in solving this problem.