MATHEMATICAL MODELLING OF AN ADVANCED ONCE-THROUGH SUB- OR SUPERCRITICAL HEAT RECOVERY STEAM GENERATOR

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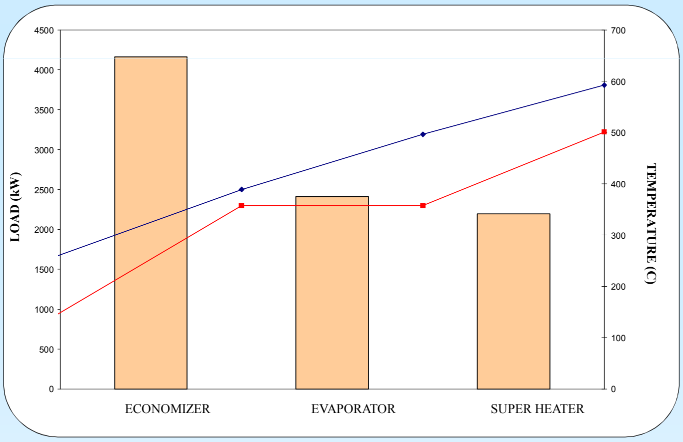
Abstract

The design and the follow-up of a once-through circulation boiler differs from the design and the follow-up of a conventional boiler. A specific thermodynamic model has to suit very high pressure, sub- and supercritical steam properties. General equations have to be used for each tube of the boiler to take into account the fact that the liquid-vapor phase transition can occur in different locations according to the operation conditions. Thus, it is no more possible to develop empirical equations corresponding to each part of the traditional heat recovery steam generator: the economizer, the evaporator and the super heater. The mathematical complexity as well as the number of equations is increased. Furthermore, in the supercritical case, no phase transition is observed and correlation to predict pressure drops and heat transfer must be reliable for any density of the fluid.

Traditional HRSG simulation

Mathematical models for traditional boilers are usually based on empirical equations corresponding to each part of the boiler: the economizer, the boiler and the super heater.

RESULTS. We use VALI-Belsim software to simulate the traditional 180 bar «one pressure steam» boiler. We obtain information on temperature before and after each part of the boiler. We also obtain the different heat transfer coefficients and some additional information as pressure drops, fluid velocity, etc.



Once-through HRSG simulation

THERMODYNAMIC MODEL. «IAPWS-IF97» Industrial formulation for the thermodynamic properties of water and steam has been used.

EQUATIONS.

$$Q=\alpha * A * \Delta T_{sl} \quad ; \quad \Delta T_{sl}=\frac{(T_{mf}-T_{w1})-(T_{mf}-T_{w2})}{\ln\left((T_{mf}-T_{w1})\big/(T_{mf}-T_{w2})\right)} \quad ; \quad T_{mf}=\frac{T_{f1}+T_{f2}}{2}$$

$$\frac{1}{\alpha}=\frac{1}{\alpha_{app}}+\frac{e}{\lambda * \frac{A_w}{A}}+\frac{1}{\alpha_i * \frac{A_i}{A}} \; ; \; \alpha_{app}=\alpha_f *\left[\frac{A_{po}}{A}+\eta_f \frac{A_{fo}}{A}\right] ; \; \alpha_i=\frac{Nu*\lambda}{d}$$

$$\text{single phase} \rightarrow Nu=\frac{(\xi/8)(Re_l-1000)Pr}{1+12{,}7\sqrt{(\xi/8)}(Pr^{2/3}-1)} \quad ; \quad \xi=\frac{1}{\sqrt{(1{,}82\log_{10}Re-1{,}64)}}$$

$$\text{vaporisation} \rightarrow \alpha(z)=\sqrt[3]{\alpha(z)^3_{conv}+\alpha(z)^3_B}$$

$$\Delta P=\frac{f\cdot\rho\cdot\overline{V}^2}{2g}\frac{l}{d_i} \; ; \text{if laminar} \quad f=\frac{64}{Re} \; ; \text{if turbulent} \quad f=\frac{0.3164}{\sqrt[4]{Re}}$$

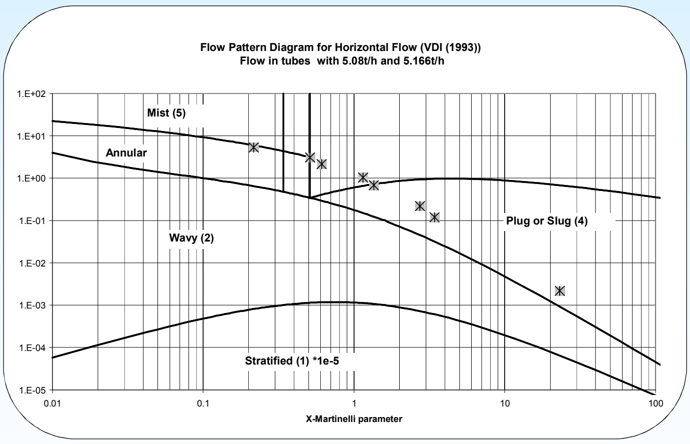
$$\text{vaporisation (Martinelli)} \left[\frac{\Delta P}{L}\right]_{2\,phases}=\left[\frac{\Delta P}{L}\right]_{liquid}\cdot\Phi^2_{ftt}$$

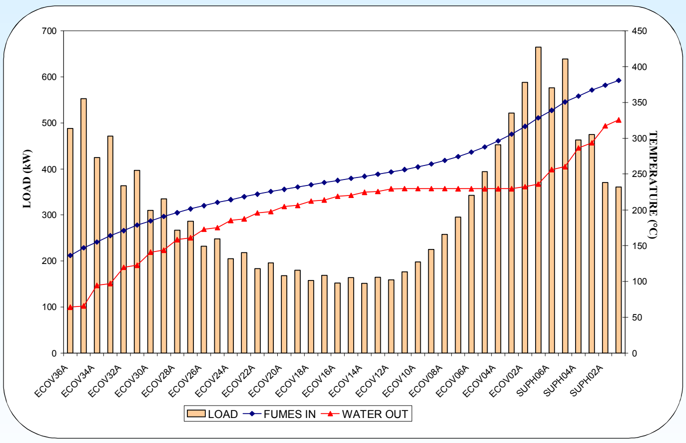
$$\Phi^2_{ftt}=1+\frac{20}{X}+\frac{1}{X^2} \quad ; \quad X=\left(\frac{1-x}{x}\right)^{0,875}\left(\frac{\rho_{go}}{\rho_{lo}}\right)^{0,5}\left(\frac{\eta_{lo}}{\eta_{go}}\right)^{0,125} \quad ; \quad X=\sqrt{\frac{\left[\frac{\Delta P}{L}\right]_{liquid}}{\left[\frac{\Delta P}{L}\right]_{vapor}}}$$

water

fumes

$$\Delta P=\frac{f\cdot\rho\cdot\overline{V}^2}{2}N_R$$





Possibility to use the same mathematical model (with some small improvements) with traditional HRSG