CURRENT STATUS OF APEX HEAT TRANSFER MODELING USING "K-epsilon" MODEL OF MHD TURBULENCE

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CURRENT STATUS OF APEX HEAT TRANSFER MODELING USING "K-epsilon" MODEL OF MHD TURBULENCE

1. Implementation of new features in the model
2. Testing the model against the experimental data
3. Application of the new codes to the APEX tasks

GOVERNING EQUATIONS

$$\frac{\partial U}{\partial t}+U\frac{\partial U}{\partial x}+V\frac{\partial U}{\partial y}=-\frac{1}{\rho}\frac{\partial P}{\partial x}+\frac{\partial}{\partial y}[(\nu+\nu_t)\frac{\partial U}{\partial y}]; \quad \nu_t=C_\nu\frac{k^2}{\varepsilon}; \tag{1), (2}$$

$$\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}=0; \tag{3}$$

$$U_S\frac{dh}{dx}-V_S=0; \tag{4}$$

$$\rho C_p(\frac{\partial T}{\partial x}+U\frac{\partial T}{\partial x}+V\frac{\partial T}{\partial y})=\frac{\partial}{\partial y}[\lambda(1+\frac{\nu_t}{\nu}\frac{Pr}{\sigma_T})\frac{\partial T}{\partial y}]; \tag{5}$$

New !

$$\frac{\partial k}{\partial t}+U\frac{\partial k}{\partial x}+V\frac{\partial k}{\partial y}=\frac{\partial}{\partial y}[(\nu+\frac{\nu_t}{\sigma_k})\frac{\partial k}{\partial y}]+\nu_t(\frac{\partial U}{\partial y})^2-\varepsilon-C_3\frac{\sigma}{\rho}B_0^2k; \tag{6}$$

New !

$$\frac{\partial \varepsilon}{\partial t}+U\frac{\partial \varepsilon}{\partial x}+V\frac{\partial \varepsilon}{\partial y}=\frac{\partial}{\partial y}[(\nu+\frac{\nu_t}{\sigma_\varepsilon})\frac{\partial \varepsilon}{\partial y}]+C_1\nu_t\frac{\varepsilon}{k}(\frac{\partial U}{\partial y})^2-C_2\frac{\varepsilon^2}{k}-C_4\frac{\sigma}{\rho}B_0^2\varepsilon. \tag{7}$$

LOW-REYNOLDS NUMBER MODIFICATION (CHIEN) - New !

$$0=\frac{d}{dy_+}\left[\left(1+\frac{\varepsilon_t}{\sigma_k}\right)\frac{dk_+}{dy_+}\right]+\varepsilon_t\left(\frac{dU_+}{dy_+}\right)^2-\tilde{\varepsilon}_+-\varepsilon_{+0}-C_3\frac{Ha^2}{Re_\tau^2}k_+;$$

$$0=\frac{d}{dy_+}\left[\left(1+\frac{\varepsilon_t}{\sigma_\varepsilon}\right)\frac{d\tilde{\varepsilon}_+}{dy_+}\right]+C_1f_1\varepsilon_t\frac{\tilde{\varepsilon}_+}{k_+}\left(\frac{dU_+}{dy_+}\right)^2-C_2f_2\frac{\tilde{\varepsilon}_+^2}{k_+}+E-C_4\frac{Ha^2}{Re_\tau^2}\tilde{\varepsilon}_+;$$

$$\varepsilon_+=\varepsilon_{+0}+\tilde{\varepsilon}_+;$$

$$\varepsilon_t=C_\nu f_\nu\frac{k_+^2}{\tilde{\varepsilon}_+};$$

$$\left.\begin{array}{l}
f_\nu=1-\exp\{-C_{Ch3}y_+\};\\
f_1=1;\\
f_2=1-0.22\exp\{-(Re_T/6)^2\},\quad Re_T=\dfrac{k_+^2}{\tilde{\varepsilon}_+};\\
\varepsilon_{+0}=2k_+/y_+^2;\\
E=-2\dfrac{\tilde{\varepsilon}_+}{y_+^2}\exp\{-C_{Ch4}y_+\}\\
C_1=1.35,\quad C_2=1.80,\quad C_\nu=0.09,\quad \sigma_k=1.0,\quad \sigma_\varepsilon=1.3
\end{array}\right\}$$

CLOSURE COEFFICIENTS - New !

Spanwise magnetic flux:

$$C_3 = 1.53 - 0.208 \times (\mathrm{Re}/10^4) \quad \text{if} \quad \mathrm{Re} \le 30{,}000$$

$$C_3 = 0.67 \times (1 + 8\exp\{-\mathrm{Re}/10^4\}) \quad \text{if} \quad \mathrm{Re} > 30{,}000$$

$$C_4 = 1$$

Wall-normal magnetic flux:

$$C_3 = 1.53 - 0.208 \times (\mathrm{Re}/10^4) \quad \text{if} \quad \mathrm{Re} \le 30{,}000$$

$$C_3 = 0.67 \times (1 + 8\exp\{-\mathrm{Re}/10^4\}) \quad \text{if} \quad \mathrm{Re} > 30{,}000$$

$$C_4 = 1$$

Streamwise magnetic flux:

$$C_3 = 0.067 \times (1 + 27.7 / \mathrm{Re}^{0.477})$$

$$C_4 = 0.1$$

BOUNDARY CONDITIONS - New

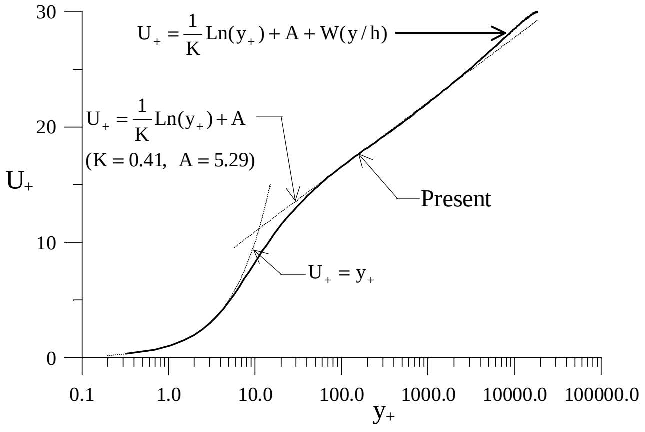
Free surface boundary conditions:

$$(\frac{\partial k}{\partial y})_s \exp\{-C_5 2\frac{Ha^2}{Re}\} + k_s[1-\exp\{-C_5 2\frac{Ha^2}{Re}\}] = 0$$

$$\varepsilon_s = \frac{C_\nu^{3/4} k_s^{3/2}}{0.07hK}$$

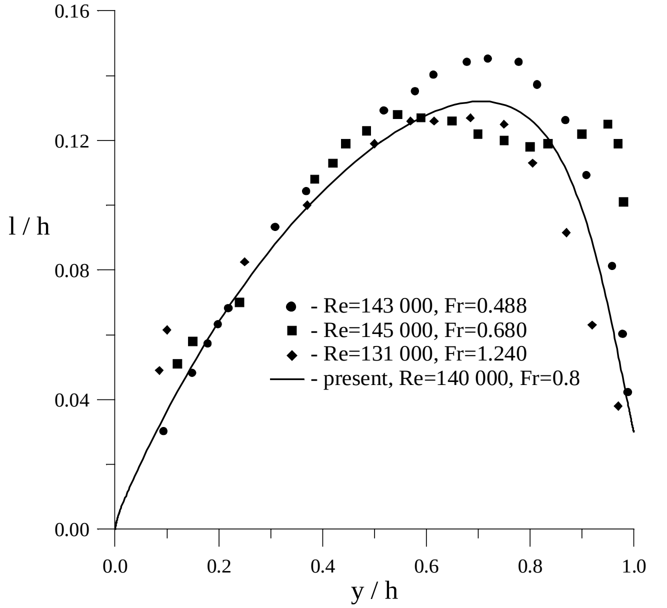
$$C_5 = 5.3 + 26\exp\{-1.32\ 10^{-4}\ Re\}$$

TESTING THE MODEL



Test case:

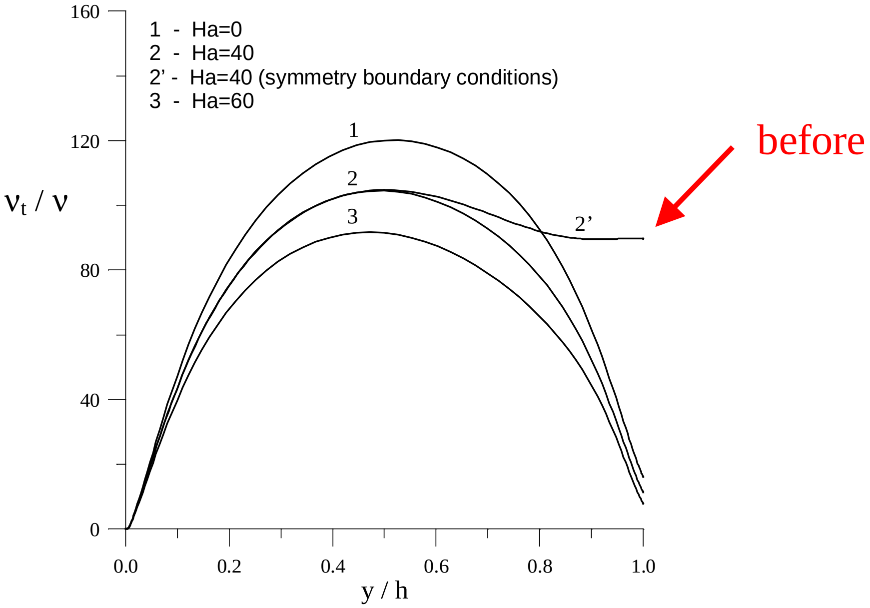
Ha=0. Comparison of the velocity profile for Re=500 000, Fr=0.8.



Test case:

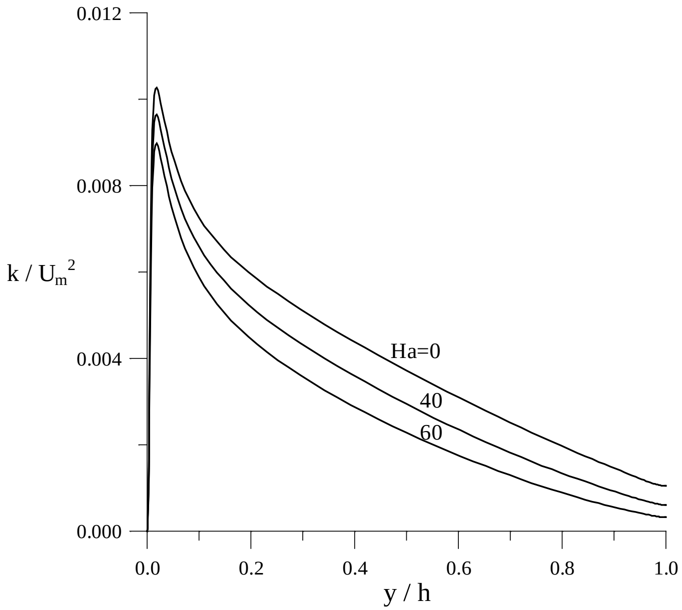
Ha=0. Comparison of the mixing-length against the Nezu experimental data.

SOME NUMERICAL RESULTS (spanwise magnetic flux)



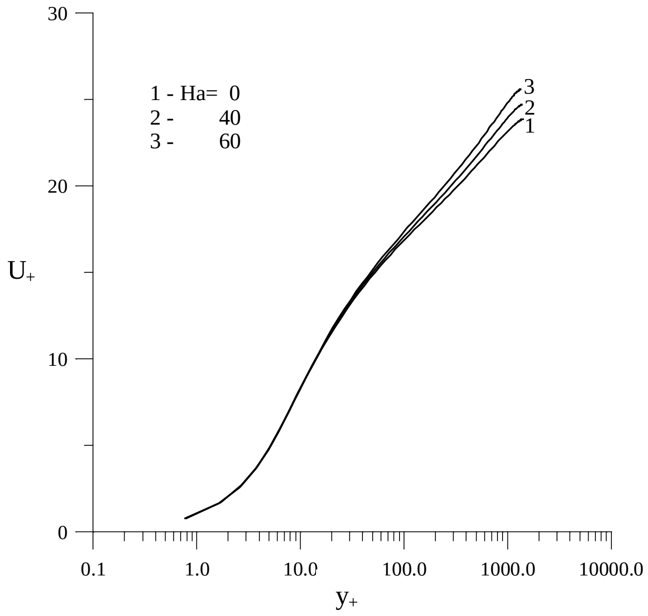
before

Eddy viscosity. Re=30 000, Fr=0.8.

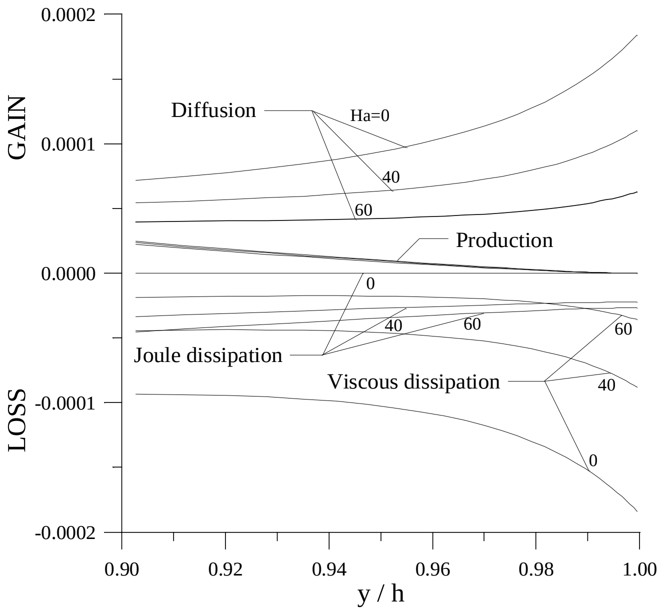


Turbulent kinetic energy. Re=30 000, Fr=0.8.

SOME NUMERICAL RESULTS (spanwise magnetic flux)

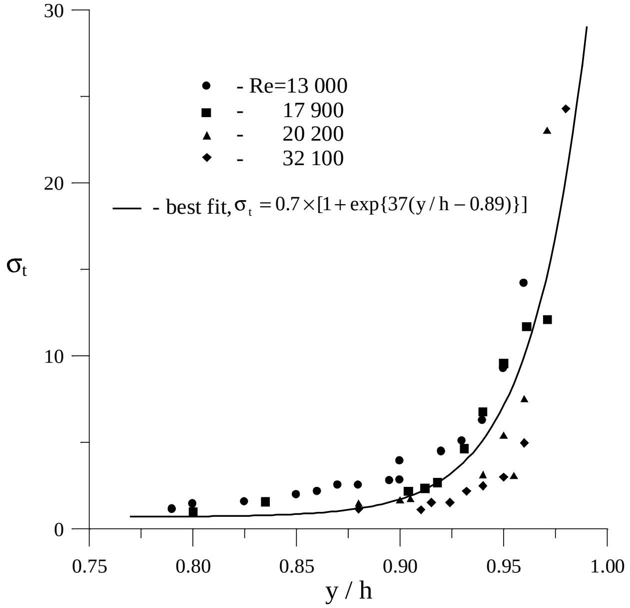


Velocity profile. Re=30 000, Fr=0.8.

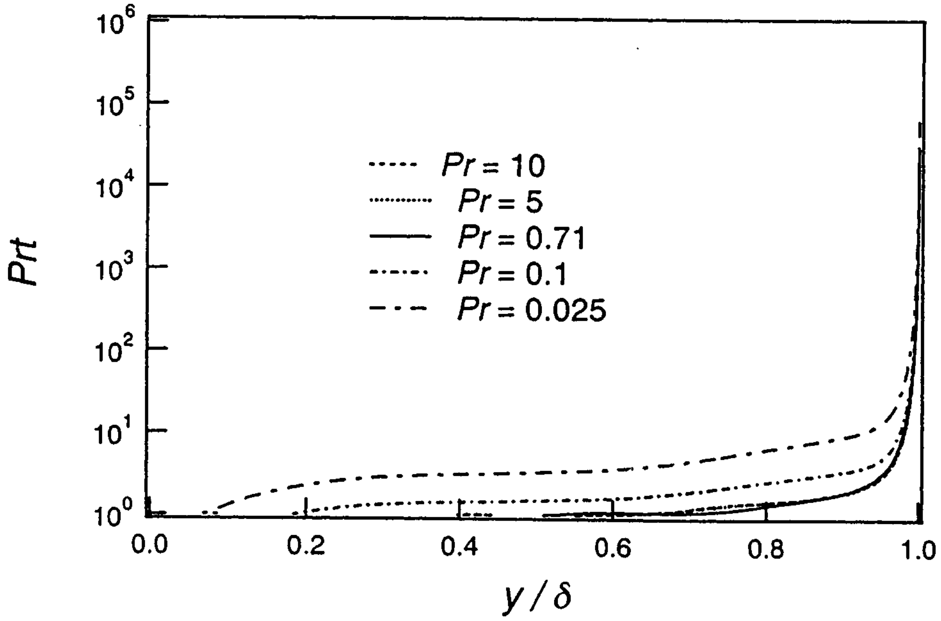


Budget of turbulent kinetic energy near a surface.
Re=30 000, Fr=0.8.

HEAT TRANSFER ANALYSIS



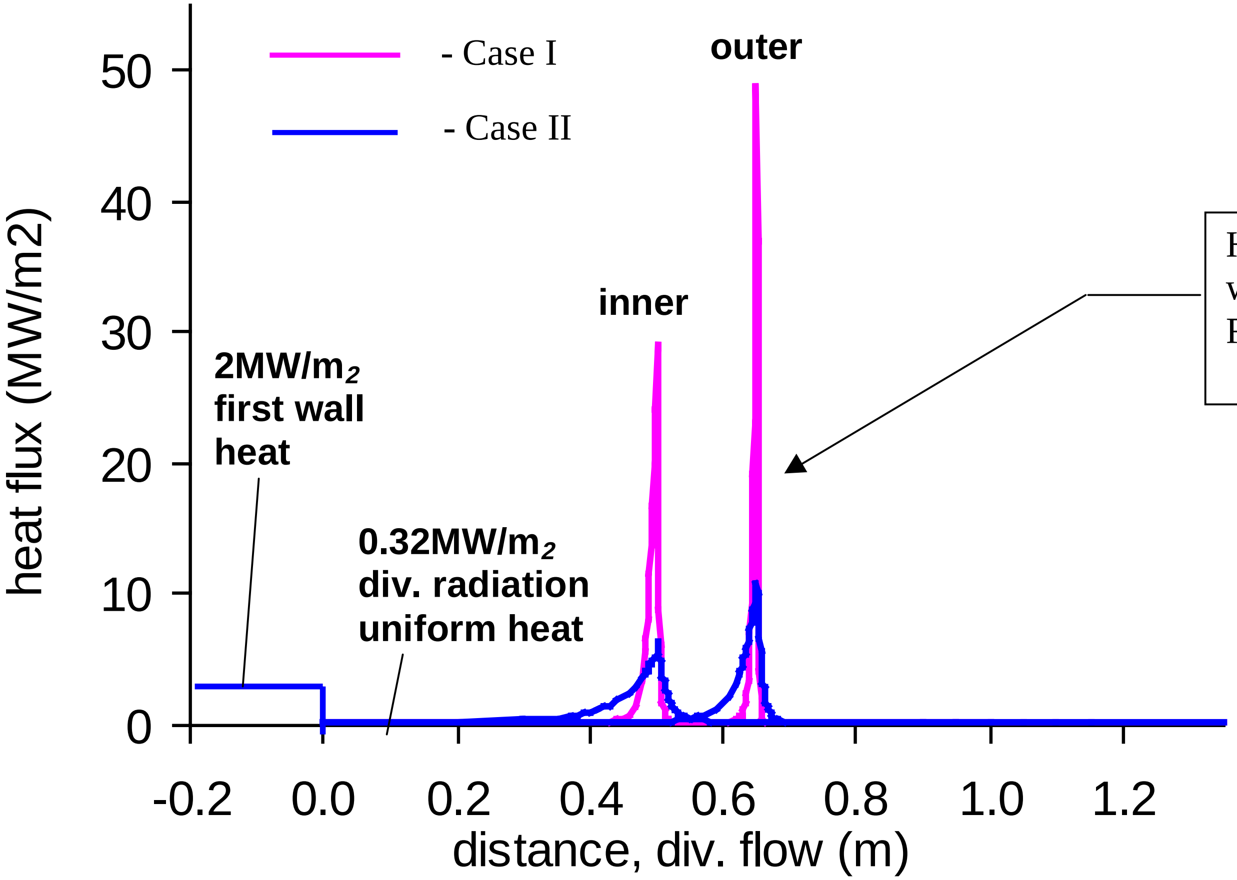
Turbulent Prandtl number near a surface obtained by combining present numerical data with experimental results by Ueda for water free surface flow.



Turbulent Prandtl number near-surface distribution. DNS data by Kunugi et al.

APPLICATION OF THE PRESENT MODEL TO THE INTEGRATED DIVERTOR DESIGN UNDER THE TASK III

(see also R.Nygren’s presentation)



Heat flux distributions were calculated by R.Nygren

APPLICATION OF THE PRESENT MODEL TO THE INTEGRATED DIVERTOR DESIGN UNDER THE TASK III

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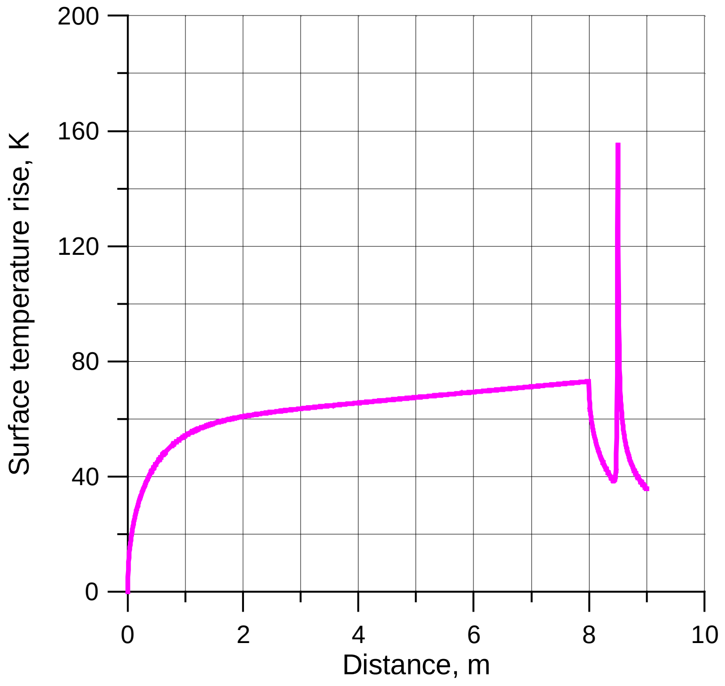
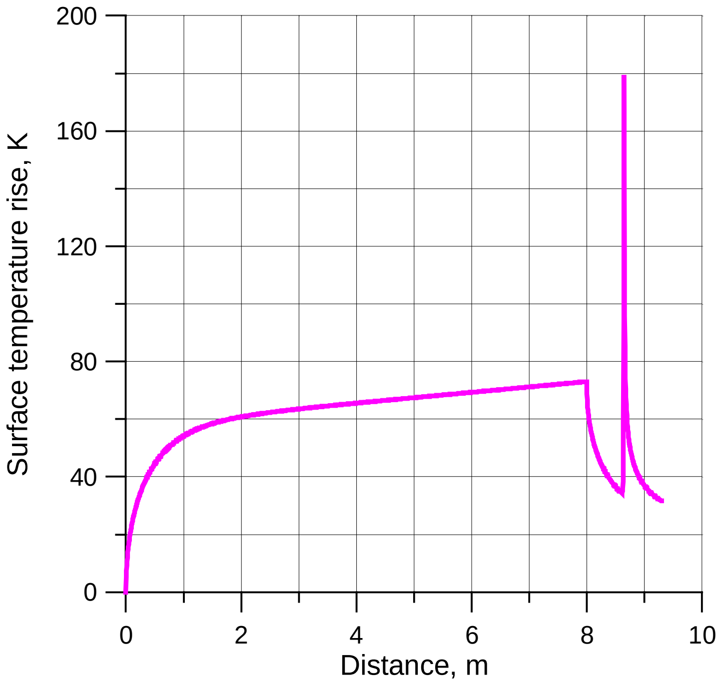
Case I: inner divertor

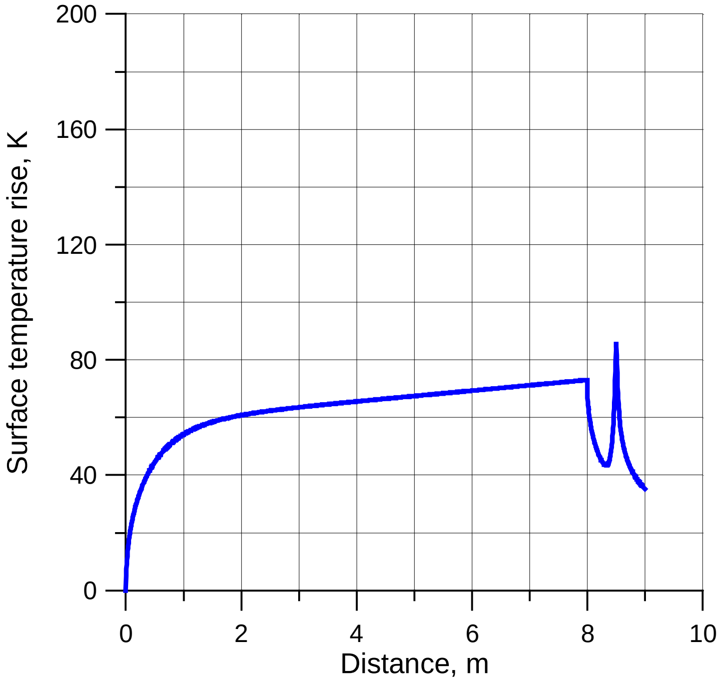


Case I: outer divertor

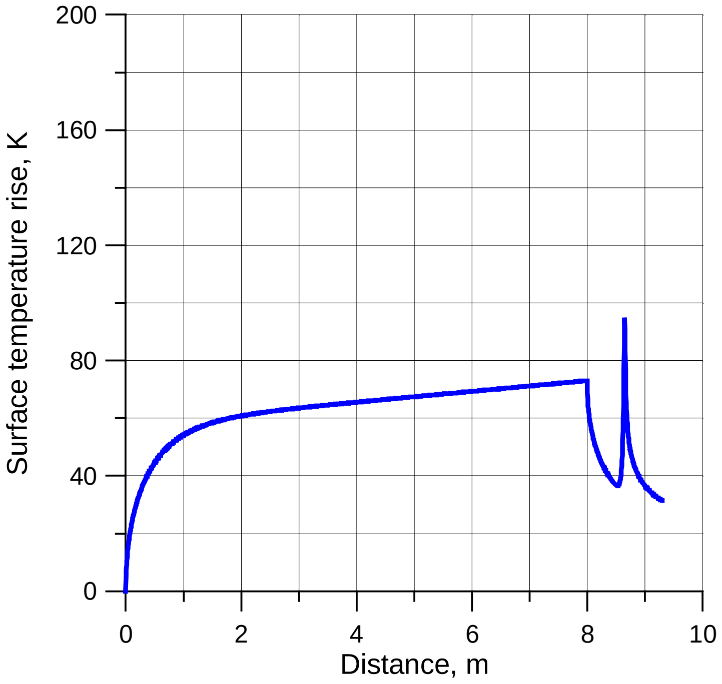


APPLICATION OF THE PRESENT MODEL TO THE INTEGRATED DIVERTOR DESIGN UNDER THE TASK III
(see also R.Nygren’s presentation)

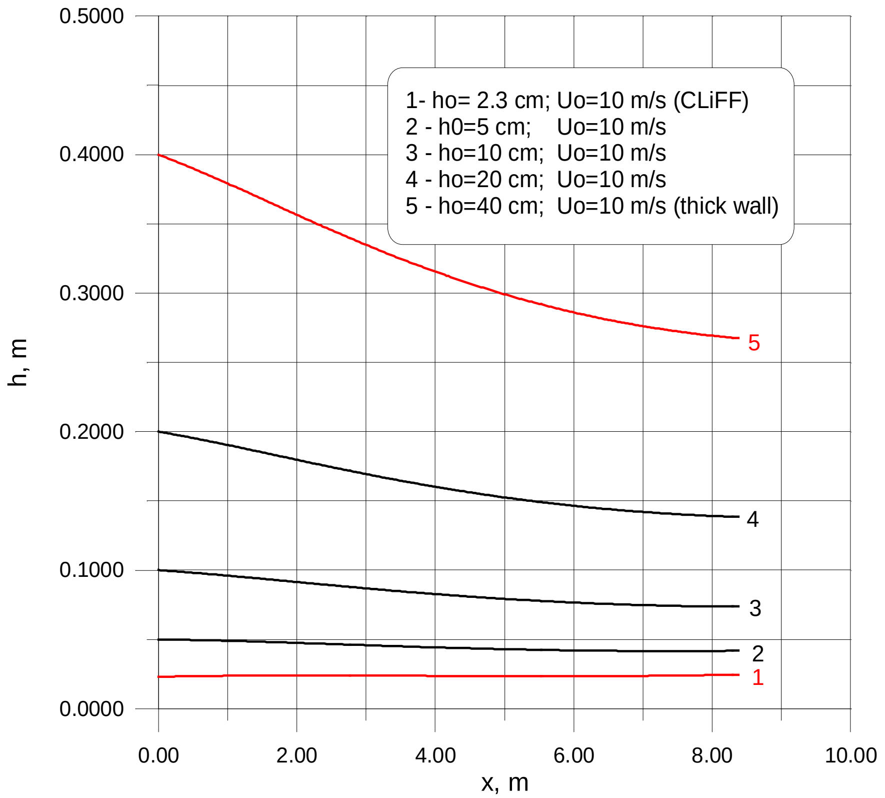
Case II: inner divertor



Case II: outer divertor



APPLICATION OF THE PRESENT MODEL TO THE CALCULATIONS OF THE THICKNESS OF THE FLIBE THIN/THICK LIQUID LAYER



APPLICATION OF THE PRESENT MODEL TO THE CHOICE OF THE TEST SECTION PARAMETERS IN THE FLYHI EXPERIMENT

The test section is an inclined chute. The model will be used to get:

- Test section length
- Nozzle dimensions
- Chute inclination length
- Initial velocity
- Power and location of the heater

Also, the model will be used to choose an optimum scheme of heating (tank heating, surface heating, bulk heating, and bottom heating) and the location of transducers (for example, thermocouples).

Preliminary results show high sensitivity of the flow parameters to small changes of the inclination angle in the case of a near-horizontal chute orientation and to the nozzle height.