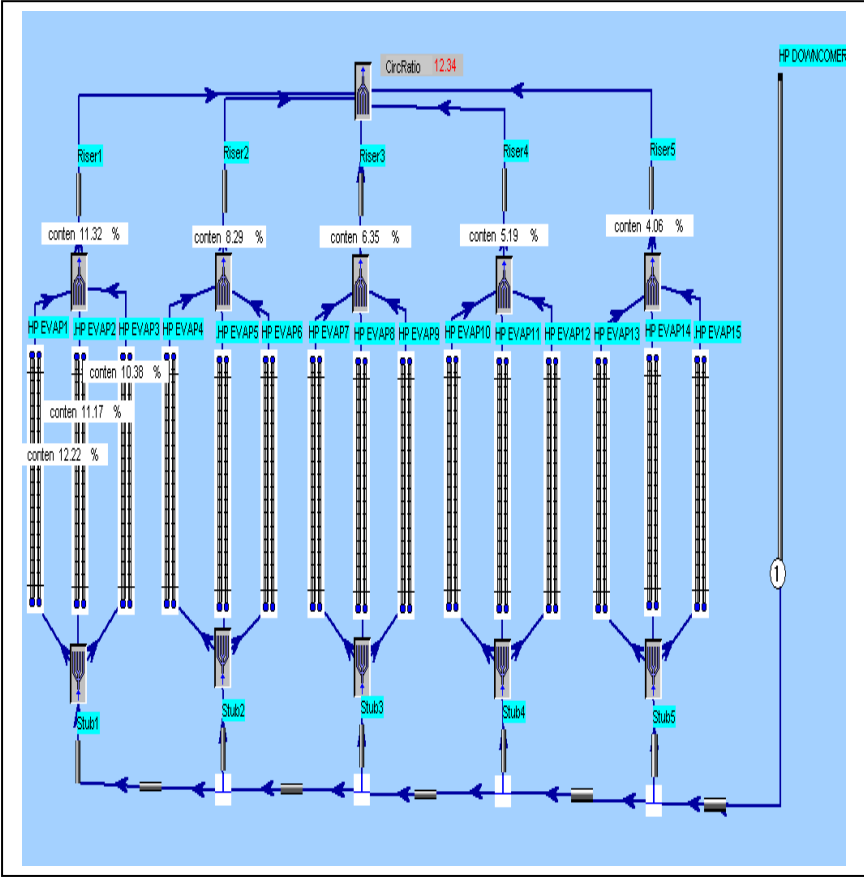


Example of a natural circulation calculation  
 Model with Power Plant Simulator & Designer



# 1. Basic principles natural circulation calculation

The natural circulation calculation is a pressure drop calculation of a pipe mesh system.

At the distribution and mixing points all pressures must be equal.

The mass flow will be determined by the pressure drop, so that the pressures at the mixing points are equal.

The inlet and outlet pressure of the complete circulation system must be also equal, so the mass flow through the complete system will be calculated based on the friction pressure loss and the draft of the evaporators and risers.

This pressure drop will be taken into account:

- Friction in pipes
- Draft gain and losses
- Inlet and outlet pressure drops
- Elbows
- Orifices (if applicable)
- Pressure drop through impact (acceleration through evaporation)
- Manual inserted pressure losses (e.g. valves, test devices etc. if applicable)
- etc.

At the 2 phase flow the pressure drop is much bigger than in one phase flow. This is taken in account with the 2 phase factor, this factor is calculated automatically.

**2 Phase factors are calculated also for bends, orifices etc...**

Additionally the void fraction is considered (phase slip i.e. the steam bubbles rise faster than the water). In consequence the density is higher and the circulation numbers a bit lower.

The natural circulation calculation was evaluated with programs from TU Vienna and Deutsche Babcock.

In the conclusion of the calculation must be checked and verified that the actual steam quality is (much) lower than the critical steam quality.

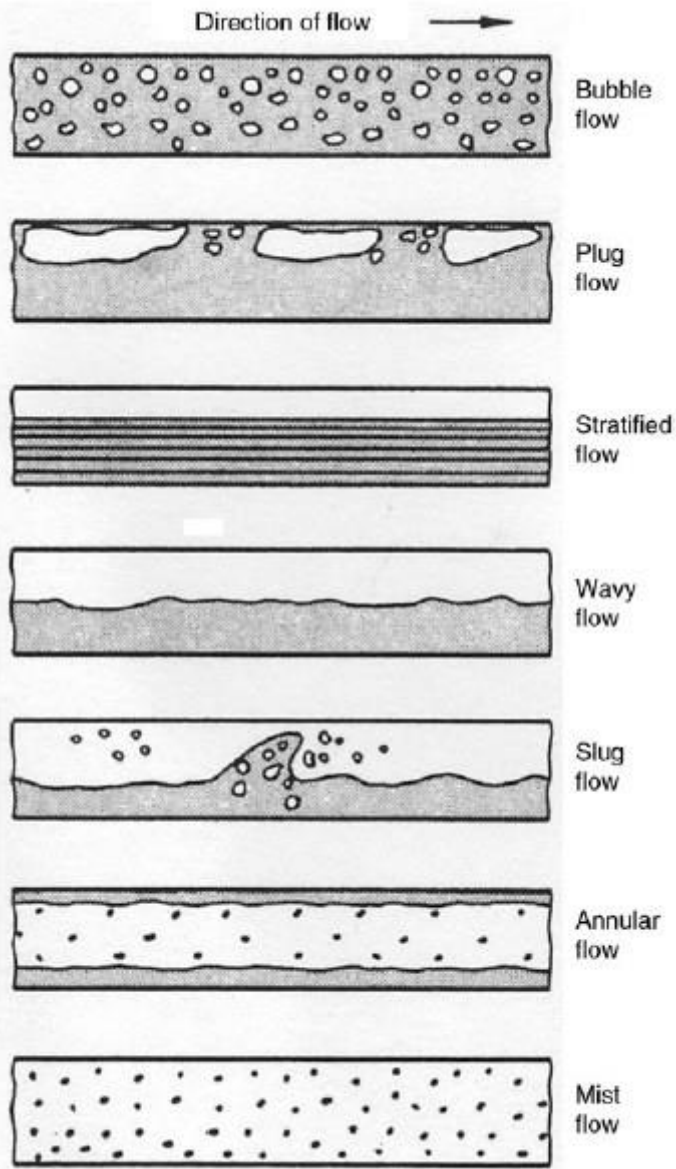
According Benson handbook there is no wetting of the heating surface, if the actual steam quality is higher than the critical steam quality and this can cause a poor cooling of the tubes and this can cause damages.

Also the flow patterns must be checked and verified.

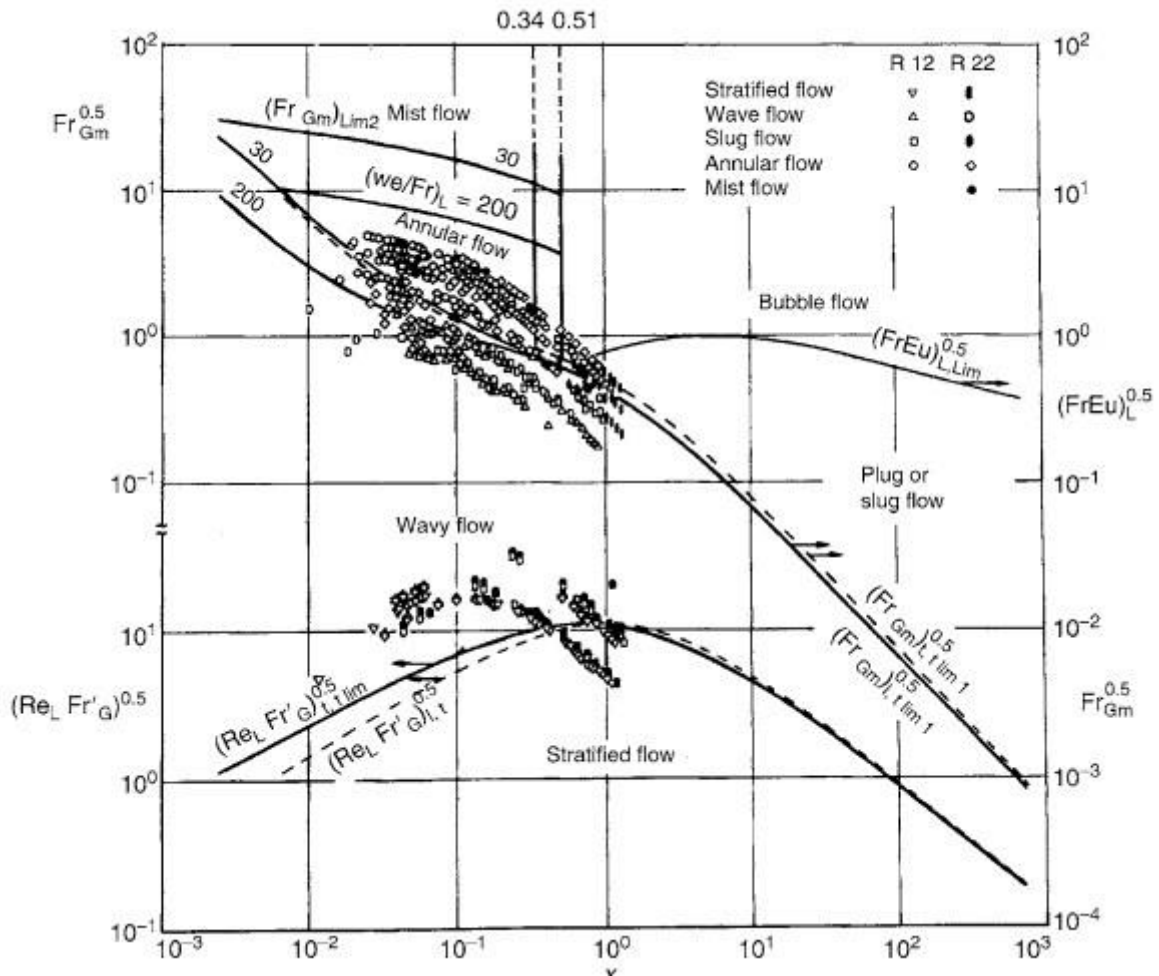
# Flow Patterns horizontal

| Properties  | Value          | Dimension | Description   |
|---|----------------|-----------|---|
| <input type="checkbox"/> Q                          | 0              | KW        | Heat power  |
| <input type="checkbox"/> h inside                   | 0.00           | W/m^2 K   | Heat transfer coefficient (inside tubes)            |
| <input type="checkbox"/> G                          | 0.00           | kg/m^2 s  | Mass flux   |
| <input type="checkbox"/> velocity out               | 0.00           | m/s       | outlet velocity H2O                                 |
| <input type="checkbox"/> velocity in                | 0.00           | m/s       | Inlet velocity H2O                                  |
| <input type="checkbox"/> F_H2O                      | 10.40          | m^2       | Crosssection area (for medium flow)                 |
| <input type="checkbox"/> massMed                    | 0.00           | kg        | Medium mass (weight)                                |
| <input type="checkbox"/> d_i                        | 30.0           | mm        | Inside diameter of tube                             |
| <input type="checkbox"/> dP H2O                     | 0.00           | bar       | Pressure drop of medium                             |
| <input type="checkbox"/> dP Elev_i                  | 0.00           | bar       | Elevation pressure differential in pipes            |
| <input type="checkbox"/> dPfr_i                     | 0.00           | bar       | Friction pressure drop inside pipes                 |
| <input type="checkbox"/> dPacc_i                    | 0.00           | bar       | Acceleration pressure drop in pipes                 |
| <input type="checkbox"/> dP loc_i                   | 0.00           | bar       | Pressure drop on local resistances in pipes (bends) |
| <input type="checkbox"/> dPInout_i                  | 0.00           | bar       | Pressure drop on inlet and outlet in pipes          |
| <input type="checkbox"/> dPressNom                  | 1.00           | bar       | Nominal pressure drop (at 100% load)                |
| <input type="checkbox"/> Ksi_Tube                   | 0.00           | -         | Resistance coefficient of tube                      |
| <input type="checkbox"/> Pnom                       | 42.00          | bar(a)    | Nominal pressure of medium                          |
| <input type="checkbox"/> W nom                      | 108.0          | t/h       | Nominal rate of mass flow of medium                 |
| <input type="checkbox"/> NumTubes                   | 500.000        | -         | Number of parallel tubes                            |
| <input type="checkbox"/> volumeTubes                | 0.00           | m^3       | Volume of tubes                                     |
| <input type="checkbox"/> Tpass                      | 0.00           | s         | Pass time   |
| <input type="checkbox"/> Mass of Steel              | 0.00           | kg        | Mass of steel incl. Fins                            |
| <input type="checkbox"/> Re                         | 0.00           | -         | Reynolds number                                     |
| <input type="checkbox"/> Zeta                       | -1000.00       | -         | Coefficient of resistance                           |
| <input type="checkbox"/> approach point             | void           | K         | approach point                                      |
| <input type="checkbox"/> ffPipesInlet               | 0.00           | -         | Pipe entry hydraulic friction factor (calculated)   |
| <input type="checkbox"/> ffPipesOutlet              | 0.00           | -         | Pipe outlet hydraulic friction factor               |
| <input type="checkbox"/> fouling inside             | 0.0000         | m^2 K/W   | Thermal resistance of fouling inside tubes          |
| <input type="checkbox"/> t outlet H2O               | 20             | C         | Water/Steam temperature outlet                      |
| <input type="checkbox"/> t inlet H2O                | 20             | C         | Water/Steam temperature inlet                       |
| <input type="checkbox"/> p H2O outlet               | 0.00           | bar(a)    | Water/Steam pressure outlet                         |
| <input type="checkbox"/> p H2O inlet                | 0.00           | bar(a)    | Water/Steam pressure inlet                          |
| <input type="checkbox"/> h outlet H2O set           | 0              | kJ/kg     | Water/Steam enthalpy outlet set value               |
| <input type="checkbox"/> h inlet H2O                | 20             | kJ/kg     | Water/Steam enthalpy inlet                          |
| <input type="checkbox"/> w_sat water                | 0.00           | m/s       | Velocity of saturated water                         |
| <input type="checkbox"/> xSteam critical by mass    | Not calculated | %         | Critical steam contents by mass                     |
| <input type="checkbox"/> slip velocity (void fra... | 0.00           | m/s       | slip velocity (void fraction)                       |
| <input type="checkbox"/> A ins                      | 0.00           | m^2       | Area of heating surface inside of pipes             |
| <input type="checkbox"/> Hgeod in                   | 0.00           | mm        | Height from zero mark inlet                         |
| <input type="checkbox"/> Hgeod out                  | 0.00           | mm        | Height from zero mark outlet                        |
| <input type="checkbox"/> Angle to horizontal        | 0.00           | Deg       | Angle to horizontal                                 |
| <input type="checkbox"/> kind of flow horizontal    | Annular flow   | -         | kind of flow horizontal                             |
| <input type="checkbox"/> q_in                       | 0.00           | kW/m^2    | heat flux density inside Pipe                       |
| <input type="checkbox"/> tempMetOut                 | not calculated | C         | Outlet temperature of tube wall                     |
| <input type="checkbox"/> tempMetIn                  | not calculated | C         | Inlet temperature of tube wall                      |
| <input type="checkbox"/> Re_L                       | 0.00           | -         | Re_L  |
| <input type="checkbox"/> Froud number               | 0.00           | -         | Froud number  |

1. Exemption: Input data in output data!
2. Insert here the angle (smaller than 45°)
3. Here the flow pattern
4. Here the critical steam content



13.1. Fig. 2. Flow patterns in horizontal tubes.



|                          |                         |                   |                   |                                 |
|--------------------------|-------------------------|-------------------|-------------------|---------------------------------|
| <input type="checkbox"/> | Angle to horizontal     | 0.00              | Deg               | Angle to horizontal             |
| <input type="checkbox"/> | kind of flow horizontal | swell plug stream | -                 | kind of flow horizontal         |
| <input type="checkbox"/> | q_in                    | 18.92             | kW/m <sup>2</sup> | heat flux density inside Pipe   |
| <input type="checkbox"/> | tempMetOut              | 315               | C                 | Outlet temperature of tube wall |
| <input type="checkbox"/> | tempMetIn               | 311               | C                 | Inlet temperature of tube wall  |
| <input type="checkbox"/> | Re_L_                   | 297714.47         | -                 | Re_L_                           |
| <input type="checkbox"/> | Froud number            | 0.47              | -                 | Froud number                    |
| <input type="checkbox"/> | Fr_05_Gm                | 0.68              | -                 | Fr_05_Gm                        |
| <input type="checkbox"/> | Fr_Eu_05_L_             | 0.12              | -                 | Fr_Eu_05_L_                     |
| <input type="checkbox"/> | Re_L_Fr_G_05_           | 388.59            | -                 | Re_L_Fr_G_05_                   |
| <input type="checkbox"/> | xi_L_                   | 0.01              | -                 | xi_L_                           |
| <input type="checkbox"/> | We_Fr_L_                | 926.54            | -                 | We_Fr_L_                        |
| <input type="checkbox"/> | X_Martinell             | 1.85              | -                 | X_Martinell                     |