TechnoSteamGenerator external class

The TechnoEvaporator class is specific to evaporators designed as two- or three-zone exchangers calculated globally.

It makes it possible to calculate the triple exchanger by distinguishing the zones corresponding to the economizer, the vaporizer and the superheater, but has a number of limitations. Although it allows pressure drop to be calculated, it assumes that the pressure is uniform in each of the fluids. It also does not allow to take into account a possible nucleate boiling in the economizer part.

The TechnoSteamGenerator class was developed to address these limitations.

To do this, it implements:

- a specific calculation of pressure drops that makes it possible to modify the pressures inside the steam generator, the calculations of the Nüsselt number being carried out in the usual way, via the FlowConfig
- a generic method taking into account nucleate boiling.

This note introduces the new features specific to this class.

Calculation of pressure drops

The calculation of pressure losses is done in a classic way in the single phase case and for singular losses. In the two-phase case, they are estimated from various correlations. A well-argued synthesis can be found in (Thome and A. Cioncolini, 2015).).

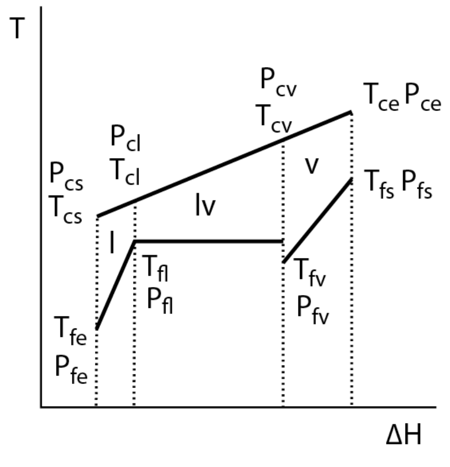

Figure 1 : Évaporateur avec pertes de charge

The correlation of (Lockhart-Martinelli, 1949) is one of the most used, even if it is not among the most precise according to some authors: many publications state that it significantly overestimates them. It would seem that those of (Müller-Steinhagen & Heck, 1986) and (Sun & Mishima, 2009) or that of (Friedel, 1979) are much more precise. All three have been implemented in the TechnoSteamGenerator class.

The notations used in the class are those of Figure 1 which schematically represents the cooling of the hot fluid and the heating of the water to the state of superheated steam.

With the exception of the singular pressure losses at the entrance of the cold fluid, the most important ones take place during vaporization. However, if it is assumed that the pressure decreases during evaporation, the temperature at the end of evaporation is lower than that at the inlet of the exchanger, so that the heat capacity flow becomes negative, which leads to an erroneous calculation of the exchanger by the NTU method. The calculation is therefore made assuming that the pressure drop takes place after the end of the vaporization, as shown in the figure. Sverheat is calculated with the outlet pressure.

Calculation of saturated boiling

The TechnoEvaporator class used the Gungor-Winterton correlation calculated on an average basis, which was criticizable. It is now implemented by discretizing the evaporation zone into 100 elements, which is much more accurate.
Five new correlations for estimating exchange coefficients during boiling were also implemented, those of (Shah, 1982), (Borishanskiy, 1971), (Kim and Mudawar, 2013), (Kandlikar, 2017) and (Saitoh, 2007).

One of the difficulties is that they lead to significant discrepancies in the estimation of hlvf. It is therefore difficult to know which one to choose if data on the GV studied are not available.

Calculation of nucleate boiling

The calculation of nucleate boiling is much more delicate than that of saturated boiling. This is a relatively new area of investigation and many publications exist, without any really relevant summaries being available..

Figure 2 shows the definitions of the different boiling phases. The curves it shows make it possible to visualize the phenomena at stake.

In ordinate is the temperature of the fluid Tb or wall Tw, and on the abscissa the quality x, which is considered to be negative in the nucleated boiling zone.

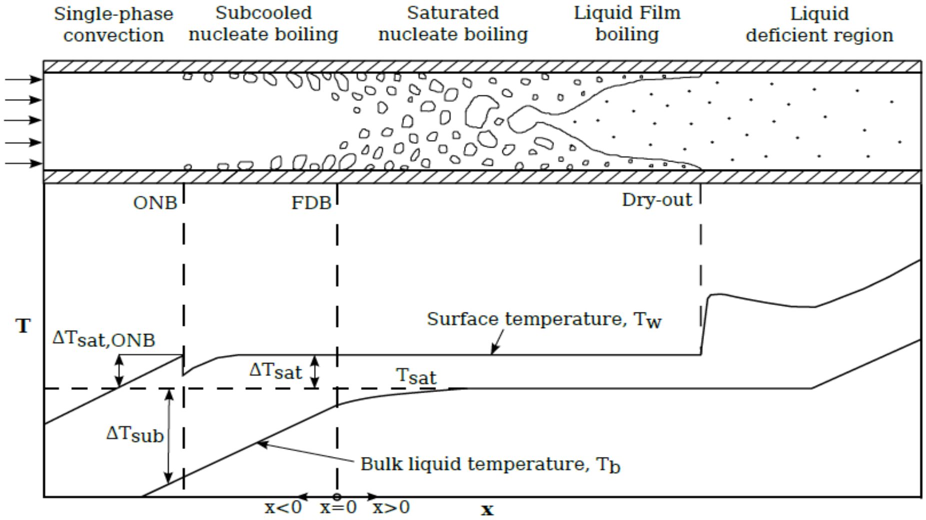

Figure 2: Temperature profiles in an evaporator (Ohrby, 2014)

As the wall temperature Tw increases, three thresholds appear:

- when Tw reaches Tsat, bubbles may begin to appear,
- but they only do so with some delay, when Tw = Tw,onb (Onset of Nucleate Boiling). A complementary flow of the purely convective flow then appears q_fc. It is equal to q_nb for nucleate boiling.
- boiling becomes complete when Tw > Tw, fdb (fully developped boiling), which corresponds to a quality x greater than or equal to 0.

In the TechnoSteamGenerator class, the ONB is detected by a relation such as (Thom, 1965), and the FDB by a relation such as (Bowring, 1962).

It is considered that the exchange coefficient h_fnb is equal to that calculated for saturated boiling, depending on the correlation chosen.

For the transition between the ONB and the FDB, a ramp is made between the local hfl and hlvf reached during the FDB. More sophisticated methods are proposed in the literature, but they are complex to implement and their robustness is not guaranteed.

Calculation process

You will find in the appendix a brief reminder of how the external classes are structured to carry out off-design operating studies of energy systems modelled with Thermoptim.

The general principle of calculations is as follows:

- in sizing mode, once the geometric parameters have been set and the operating conditions of the device have been chosen, a calculation makes it possible to determine the total surface of the exchanger and its possible distribution between different zones if it is a steam generator or a condenser. For example, for a SG, these are the zones corresponding to the economizer, vaporizer and superheater

- in off-design mode, the inlet conditions being known, the driver seeks a solution such that the total area is the same as that determined during the sizing, but the internal distribution of the surfaces can generally be different. The outlet conditions of the hot and cold fluids are then recalculated.

As with other TechnoDesigns, it is the makeDesign() method that coordinates the calculations of the TechnoSteamGenerator class.

After loading the values of the upstream points of the two fluids, it begins by performing the pressure drop calculations using the calcPressureDrops() method. The internal pressures defined in Figure 1 are then updated, as well as the outlet states of the exchanger, which is recalculated several times.

The different zones are then re-evaluated and recalculated, as in the TechnoEvaporator class, with the exception that the pressure is no longer uniform within the exchanger.

The changes then take place in the getUl(techc.amont.X,0) and getUlv(techc.amont.X,0) methods..

Nucleate boiling

The getUl(double xc,double xf) method has been modified to allow nucleate boiling to be taken into account. For cold fluid, it calls the public method void calcNusseltUlf(double T, double P, double x, double Cp, boolean calcDP, TechnoExch te), which refers to calcNuUlf(double P), where all calculations are made.

The exchanger is divided into 100 parts and the different thermal equilibria are calculated. The wall temperature is determined for each interval, assuming that the exchange coefficient on the hot side remains constant.

Different ONB detection correlations have been implemented, and the one that leads to the highest value is retained. Just replace it with another one if you wish.

In the same way, different correlations of OFB detection (or FDB or NVG) have been implemented, and the one that leads to the highest value is retained.

Some examples are given in (Wang, 2011) or (Ghione, 2017).

h_fdb is estimated to be equal to that of saturated boiling.

Figure 3 shows the type of results that are obtained. It gives the Tw-Tsat difference in degrees, and the value of the exchange coefficient in kW/m2/K, as a function of the reduced length of the economizer. The single phase exchange coefficient decreases slowly due to the increase in the temperature of the cold fluid, then the relay is taken to the ONB by the two-phase exchange coefficient, from the abscissa about 0.7. In this case, the FDB is not reached at the time the quality becomes equal to 0.

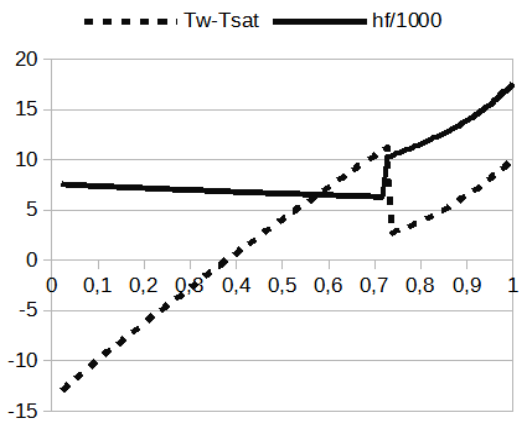

Figure 3 : Évolutions dans l'économiseur

Saturated boiling

The getUlv(double xc,double xf) method passes the baton to the TechnoSteamGeneratorConfigs class to allow saturated boiling to be taken into account. This class behaves analogously to the set of FlowConfig from which it is derived.

The six available correlations are calculated, with the chosen one providing the two-phase Nusselt value.

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Annex : Class structure for heat exchanger off-design calculations

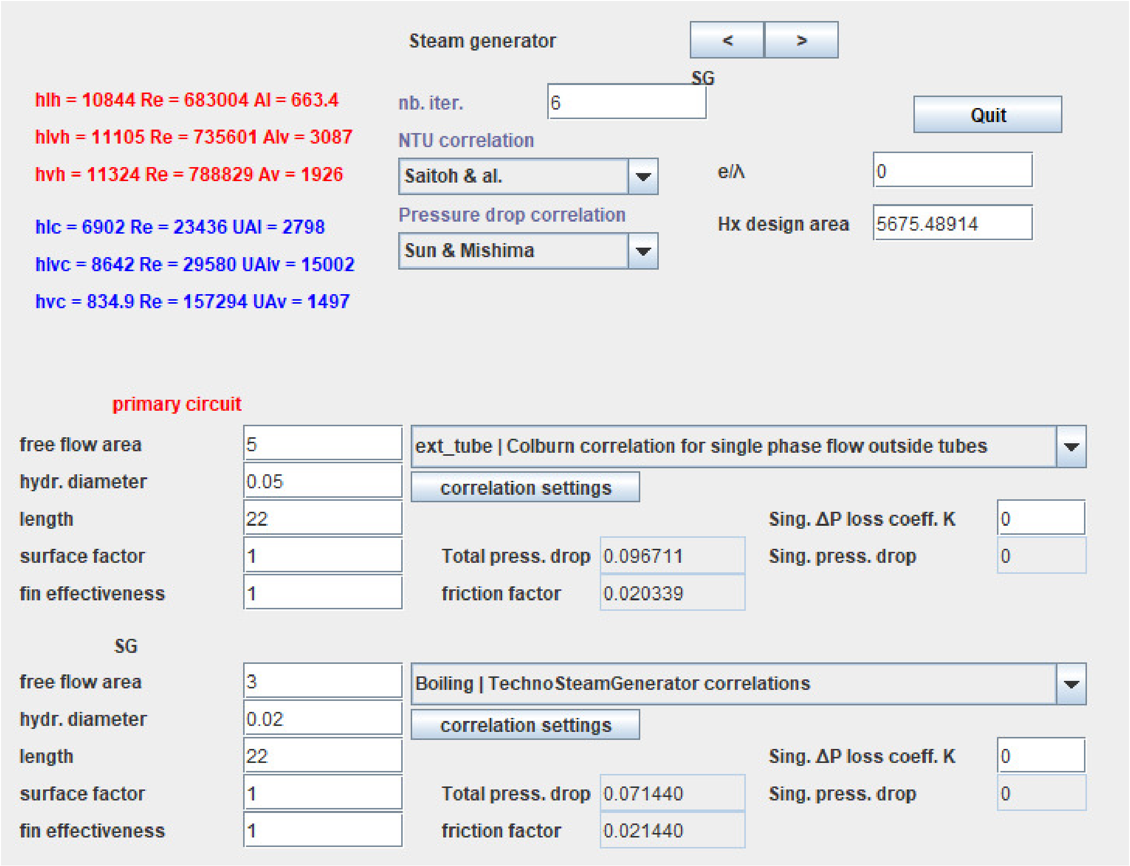
Volumes 3 and 4 of the Thermoptim reference manual present the main lines of the extension mechanism of the software package in the form of so-called external Java classes, the last volume focusing more particularly on control and calculations in off-design conditions..

The overall structure is explained in section 3.2.2 of Volume 4. As noted, the instantiation of these external classes is done through a driver, which can be generic or specific..

Guided exploration (DTNN-1) explains how to set up a simple heat exchanger. It deals with the calculation of the surface of an air-water tube and fin heat exchanger. It is recommended to start by referring to it before going further.

The TechnoSteamGenerator class is of the TechnoDesign type, and more particularly TechnoHx, generic class for heat exchangers. It inherits directly from TechnoEvaporator, specific to evaporators designed as exchangers with two or three zones calculated globally.

Each of the two fluids is represented by a TechnoExch class, and each of these defines a flow configuration defined in a FlowConfig class.



hlh = 10844 Re = 683004 Al = 663.4

hlvh = 11105 Re = 735601 Alv = 3087

hvh = 11324 Re = 788829 Av = 1926

hlc = 6902 Re = 23436 UAl = 2798

hlvc = 8642 Re = 29580 UAlv = 15002

hvc = 834.9 Re = 157294 UAv = 1497

nb. iter. 6

NTU correlation: Saitoh & al.

Pressure drop correlation: Sun & Mishima

e/Λ 0

Hx design area 5675.48914

primary circuit

free flow area 5

hydr. diameter 0.05

length 22

surface factor 1

fin effectiveness 1

ext_tube | Colburn correlation for single phase flow outside tubes

Sing. ΔP loss coeff. K 0

Total press. drop 0.096711

Sing. press. drop 0

friction factor 0.020339

SG

free flow area 3

hydr. diameter 0.02

length 22

surface factor 1

fin effectiveness 1

Boiling | TechnoSteamGenerator correlations

Sing. ΔP loss coeff. K 0

Total press. drop 0.071440

Sing. press. drop 0

friction factor 0.021440

Figure A.1: Technological sizing screen

Figure A.1 shows the TechnoSteamGenerator class screen with a setting adapted to the PWR reactor driver proposed in the Thermoptim-UNIT portal[1].

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[1] https://direns.mines-paristech.fr/Sites/Thopt/en/co/pilote-gv-rep.html

At the top appear the choice of correlations (here Saitoh & al. for the exchange coefficient and Sun and Mishima for the pressure drops), as well as the calculation results.

The number of iterations appearing at the top of the screen is a parameter that allows to refine the accuracy of the nucleate boiling calculations, at the cost of the execution time all the greater the higher it is..

In the central and lower part are located the two screens of the TechnoExch, "primary circuit" for hot fluid and "SG" for cold fluid. The two associated FlowConfig are identified by the names of their correlations, "sp_plate | Single phase... " and "Boiling| TechnoSteam... ». Correlation parameters can be viewed and changed.

In the TechnoExch class we specify the geometric characteristics relating to each fluid, such as the fluid flow area, the hydraulic diameter...

Depending on the case, the calculations are carried out directly in the TechnoHx, in the TechnoExch or in the FlowConfig. You have to refer to the code of each class to see how they are chained.

As we recalled above, it is necessary to use a driver to instantiate a TechnoHx and the classes related to it. It may be a generic driver as explained in Guidted Exploration (DTNN-1), but it is usually preferable to create a specific driver, of the type shown in the examples relating to the off-design operation of a steam plant or refrigerator.[2].

Remarks

The implementation that has been made of the various correlations of the TechnoSteamGenerator class corresponds to turbulent flow regimes. If you want to study laminar flows, they will need to be completed appropriately.

Since some correlations use surface tension, Thermoptim's internal substances have been modified to allow this calculation. If you use certain external substances, you will have to complete them either directly by adding the corresponding methods to them, or by modifying the TechnoExch class by directly incorporating the appropriate methods, coupled with the initLambdaMu() method of the latter.

Also pay attention to the fact that the backups and restores of the parameters are partly from the TechnoHx, and partly from the driver.

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[2] https://direns.mines-paristech.fr/Sites/Thopt/en/co/exempl-dim-techno-non-nominal.html