ADIABATIC DIFFUSER MODEL

To expand the core of Thermoptim, we add external plug-ins written in the Java language, which define both the equations and the graphical interface. These additional elements are dynamically loaded when launching the software, and appear on its screens transparent to the user, as if they were part of it. The implementation of the Thermoptim extension mechanism by adding external classes led to introduce two semantic distinctions that are important: first, that between the mono and multi-functional components (the first will involve no more than one form of energy (mechanical or thermal)), and the other one related to a new concept in the software package, that of thermocoupler. The thermocoupler are intended to complement conventional heat exchangers allowing components other than "exchange" processes to connect to one or more "exchange" process to represent a thermal coupling.

By adding external components, we can continue to use the whole Thermoptim environment, i.e. all available components and the diagram editor that allows you to very easily describe the internal structure of the system studied. Not only in such a way you significantly simplify the modeling process and facilitate subsequent use and maintenance of the model, but mostly you secure its construction by automating the establishment of linkages between its components and ensuring consistency. This is the more important that the system under study includes a large number of components.

An adiabatic diffuser is a fixed component that serves to convert into pressure a portion of the kinetic energy available in a gas. The initial relative velocity of the outside air can thus achieve a dynamic compression in the inlet diffuser of a jet engine: the kinetic energy of intake air is converted into pressure.

Dans cette note, nous présentons un modèle permettant de représenter un diffuseur adiabatique. Nous commencerons par faire un bref rappel de la thermodynamique du diffuseur, puis nous montrerons l'écran du composant externe, défini dans la classe Diffuser.java.

In this note, we present a model for representing an adiabatic nozzle. After a brief reminder of the thermodynamics of the diffuser, we present the screen of the external component defined in class Diffuser.java[1].

Thermodynamics of adiabatic diffuser

We assume in what follows that the fluid passing through the diffuser at least locally can be considered as a perfect gas, taking a well-chosen value of its specific heat capacity c_p. The notations are those of the book Energy Systems.

The diffuser being adiabatic the stagnation temperature of the fluid is given by:

$$T_{is} = T_a + \frac{C^2}{2\,c_p} \qquad (1)$$

By introducing the Mach number of flow:

$Ma = \frac{C}{\sqrt{\gamma\, rT}}$ and noticing that: $c_p = \frac{\gamma\, r}{\gamma - 1}$

It comes: $\Delta T = T_{is} - T_a = \frac{C^2}{2\,c_p} = \frac{\gamma - 1}{2}\,Ma^2$

Equation (2.6.8) gives the isentropic stagnation pressure:

$PT^{\gamma/(\gamma-1)} = Const$ or $P_{is} = P_a \left(\frac{T_{is}}{T_a}\right)^{\gamma/(\gamma-1)}$

We find:

[1] http://www.thermoptim.org/sections/logiciels/thermoptim/modelotheque/modele-diffuseur

$$P_{is} = P_a \left(1 + \frac{\gamma - 1}{2} Ma^2\right)^{\gamma/(\gamma - 1)} \quad (2)$$

Both relations (1) and (2) can be interpreted as follows: in any isentropic flow of a perfect gas in a tube with fixed walls, the stagnation temperature and pressure are conserved.

If the flow is adiabatic, but not reversible, its law is no longer an isentropic, but a polytropic. With the usual assumptions, the above relations are transformed as shown below.

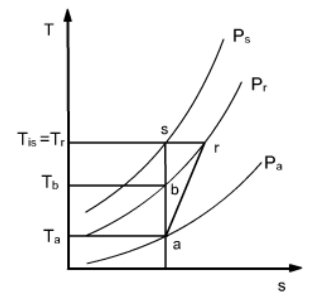

Figure 1 : diagramme entropique diffuseur

$$\Delta h = \frac{C^2}{2}$$

The gas being assumed perfect: $\Delta h = c_p \, \Delta T$

The total enthalpy being conserved, the stagnation polytropic and isentropic temperatures are equal:

$$T_p = T_a + \frac{C^2}{2\, c_p} = T_{is}$$

The polytropic equation gives the stagnation pressure:

$PT^{k/(k-1)} = \text{Const}$ or $P_p = P_a \left(\frac{T_p}{T_a}\right)^{k/(k-1)}$

We find:

$$P_p = P_a \left(1 + \frac{\gamma - 1}{2} Ma^2\right)^{k/(k-1)} \quad (3)$$

The polytropic stagnation pressure is not equal to the isentropic stagnation pressure, the irreversibilities resulting in losses.

The dynamic pressure due to the initial kinetic energy would compress the gas to pressure P_s if there were no irreversibility (Figure 1), and lead to point S at temperature $T_s = T_{is}$ and entropy $s_S = s_A$. Because of irreversibilities, the exit point is R, at the same isentropic stagnation temperature, but at pressure P_r lower than P_s. R can be determined if one knows the isentropic efficiency η_s of the diffuser, B being the corresponding point of the isentropic compression from P_a to P_r:

$$\eta_s = \frac{h_B - h_A}{h_R - h_A}$$

The gas being assumed perfect, $h_R - h_A = h_S - h_A = c_p \frac{\gamma - 1}{2} Ma^2$

Which gives *in fine*:

$$P_r = P_a \left(1 + \eta_s \frac{\gamma - 1}{2} Ma^2\right)^{\gamma/(\gamma - 1)} \quad (4)$$

These relationships allow to fully characterize the process: (4.9.6) provides the stagnation pressure, and therefore the static pressure if we know the residual velocity (generally low and therefore negligible). The temperature of point B can be deduced, its entropy being known. If the isentropic efficiency is given, you can determine point R.

In the model, we have generalized the above expressions to take into account the gas velocity existing at the outlet.

Ratio of stagnation pressures

Let us call ε_p the ratio of the real stagnation pressure to the isentropic stagnation pressure. $\varepsilon_p \leq 1$, called the stagnation pressure ratio, is very commonly used to characterize diffusers, for which the assumption of adiabaticity can often be accepted, but not that of a reversible flow.

If η_p is the polytropic efficiency, equations (4.3.9) and (4.9.1) provide:

$$\varepsilon_p = \left(\frac{P_p}{P_{is}}\right) = \left(1 + \frac{\gamma - 1}{2}\,Ma^2\right)^{(\eta_p - 1)\,\gamma/(\gamma - 1)} \qquad (5)$$

The isentropic efficiency η_s can also be expressed as a function of ε_p:

$$\eta_s = \frac{\left(\frac{P_r}{P_a}\right)^{(\gamma - 1)/\gamma} - 1}{\left(\frac{P_r}{P_a}\right)^{(k - 1)/k} - 1}$$

All calculations done, we find:

$$\eta_s = \frac{\left(1 + \frac{\gamma - 1}{2}\,Ma^2\right)\varepsilon_p^{(\gamma - 1)/\gamma} - 1}{\frac{\gamma - 1}{2}\,Ma^2} \qquad (6)$$

Knowing ε_p, we can find the corresponding isentropic efficiency and thus the stagnation pressure.

Design of the external component

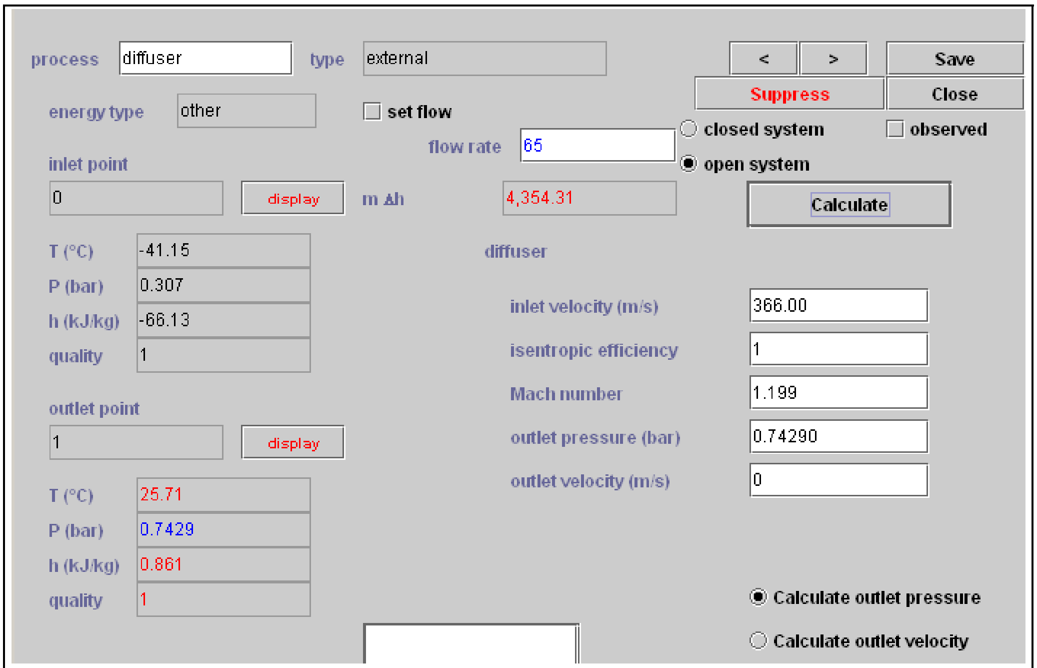

Figure 2: Diffuser screen

General

Two calculation methods are possible: to determine the output pressure knowing the output velocity, or to determine the output velocity knowing the output pressure.

Model parameters are:

- the gas inlet velocity (m/s);

- the isentropic efficiency of the process ;
- either the gas output velocity (m/s), or the gas pressure at the exit of the diffuser, depending on the calculation option chosen.

Model input data are as follows (provided by the inlet component):

- the gas temperature T_a (°C or K) at the diffuser inlet;
- the gas pressure P_a (bar) at the diffuser inlet;
- the gas flow rate $\dot{m}$ (kg/s).

The outputs are:

- either the gas pressure at the exit of the diffuser, or the gas outlet velocity (m/s), depending on the calculation option chosen;
- the gas temperature at the diffuser exit.

Graphical interface

A graphical interface for the component can be deduced (Figure 2). You have to build the bottom left of the screen, the rest being defined as a Thermoptim standard.

The input data are supplied by the inlet process of the system in which the component is inserted: gas flow and inlet point state.

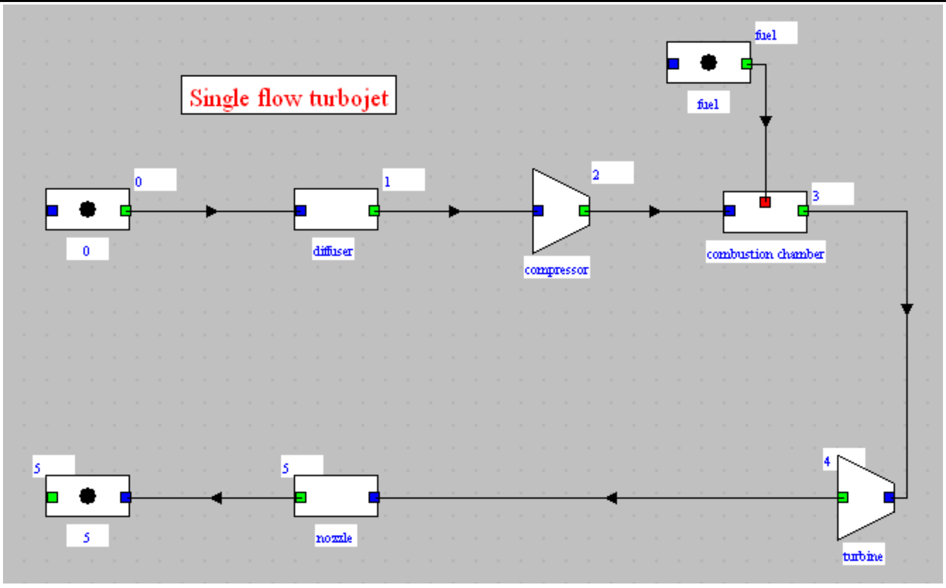

Figure 3: Thermoptim diagram of a single flow turbojet

Sequence of calculations

The sequence of calculations is as follows:

- update of the component before calculation with the values of the inlet process and point;
- update with the settings of the external component screen;
- calculation of the output pressure or velocity and of the outlet point state;
- update of the external component screen.

The problems encountered in practice at each of these steps are quite similar to those presented in the documentation provided in Volume 3 of Thermoptim reference manual. You should refer to it for further explanations.

Figure 3 shows how this component can be used to model a turbojet in Thermoptim.