Plate Cooling Model (PCM) ver. 1.0

Product Help

Technology Agency
of the Czech Republic

Project TE01020197 "Centre for Applied Cybernetics 3",
Competence Centre Program TA CR

This product was developed within work package WP11 of the project TE01020197 "Centre for Applied Cybernetics 3" supported by the Technology Agency of the Czech Republic under the Competence Centre Program. The development of the software was achieved by the cooperation between Applied Cybernetics Laboratory at Faculty of Mechanical Engineering of Czech Technical University in Prague and PIKE Automation, Ltd.

PCM (ver. 1.0) is the software for the plate temperature calculating after specified cooling time and for the calculating the needed cooling time for cooling of the plates on the desired temperature. The model parameter adaptation can be performed by using this program, if the measurement data are available. Mathematical model of the cooling plate process was developed in cooperation with PIKE Automation, Ltd., and it is implemented in language C++ including the Graphical User Interface (GUI).

Main Dialog Window

Main dialog window of this software consists of five group boxes, see Fig. 1

- ***Plate Definition***
- ***Input Parameters***
- ***Model Validation***
- ***Results***
- ***Adaptation***

The first two items, *Plate Definition* and *Input Parameters*, are used for defining the input values, boundary conditions and model parameters. The third item *Model Validation* is used for model validation, i.e. whether it is possible to use a lumped parameter model in the particular case. The last two items, *Results* and *Adaptation*, give a calculation results and perform the adaptation of the overall heat transfer coefficient. In the following subsections, the mentioned parts of the main window will be introduced in details.

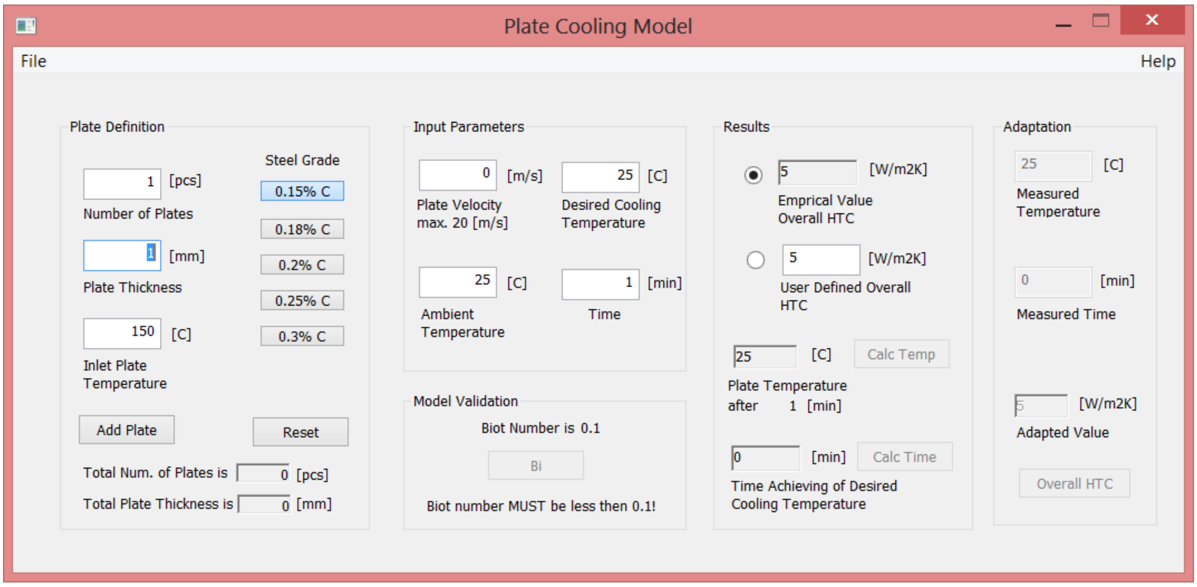

Fig. 1. Main window of the Plate Cooling Model

1.1. Plate Definition

The first group box, *Plate Definition*, is designed to easy defining the quantitative and qualitative properties of the cooling plates, see Fig. 1. The first text box, ***Number of Plates***, defines the number of plates with the same thickness and input temperature. Maximal number of plates is 99. In the case of entering bigger number than 99, the pop up error message window will be appeared, see Fig. 2. However, the total numbers of plates in the stack is not limited.

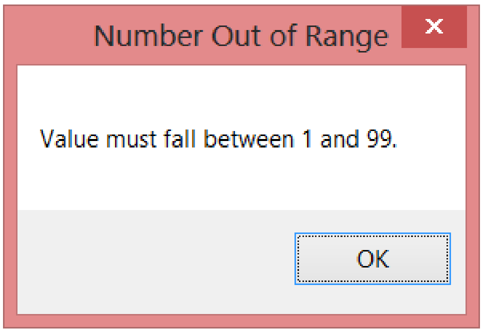

Fig. 2. Error message window

The plate thickness is entered into the ***Plate Thickness*** text box. The entered value must be in the range from 1 mm to 500 mm. Same as in the previous case, if the entered number is out of range, the appropriate error message window will appear.

Inlet Plate Temperature text box is use for entering the inlet plate temperature before the cooling process. Temperature must be in range from 0 °C to 300 °C.

On the right side of this group box five radio buttons are placed. These buttons define five different steel grades, steel with 0.15%, 0.18%, 0.2%, 0.25% and 0.3% of carbon. The contents of this button can be easily changed in accordance with specific requirements.

In the lower part of the *Plate Definition* group box, the button ***Add Plate*** is placed. This button adds a single plate or group of plates in the plate stack, which will be processed in the calculation part of this software. All actual plates in stack can be removed with ***Reset*** button.

In last two lines, the total number of plates in stack and total high of stack are given. Information in these two lines will be automatically updated by clicking on the ***Add Plate*** and ***Reset*** buttons. In this way the process of the entering data can be verified in each step.

1.2. Input Parameters

Input Parameters group box defines the boundary conditions and process parameters. The text box ***Plate Velocity*** in the left up corner of this group box contains a plate velocity value. This velocity must be in range (0 – 20 m/s). Upper limit of the velocity is limited by the accuracy of the empirical equation for the convective heat transfer coefficient calculation. This coefficient will be explained in the appropriate section, where the calculation of the convective heat transfer coefficient is introduced.

Desired Cooling Temperature can be set in the same range as inlet plate temperature. However the ***Ambient Temperature*** text box can accept the values between 0°C and 50 °C.

Cooling time is defined in the ***Time*** text box and this value can have arbitrary values greater then zero.

1.3. Model Validation

The dimensionless Biot number gives the ratio of the heat transfer resistances inside of and at the surface of the body and it is defined with the following formula

$$Bi = \frac{hL_C}{k}, \tag{1}$$

where h is convective heat transfer coefficient, L_C is characteristic length and k is thermal conductivity. In practise, this ratio determines whether or not the temperature inside a body varies significantly. Applied lumped parameter model of the plate cooling process can be used only if the dimensionless Biot number $Bi < 0.1$ and this condition should be verified before each calculation. If the < 0.1 , the temperature distribution in the body can be considered as uniform, and lumped parameter model can be used. This condition can be checked by means of button ***Bi***, which can be found in the *Model Validation* group box.

If this condition is not satisfied, the popup warning window will appears, see Fig. 3.

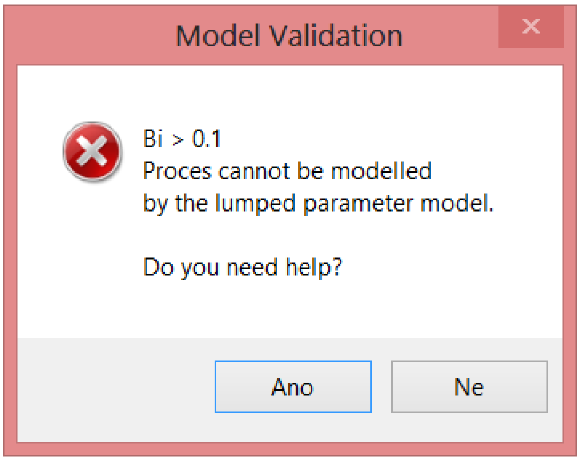

Fig. 3 Model validation warning window

If the button ***ANO*** is clicked, the next window will appear, see Fig. 4.

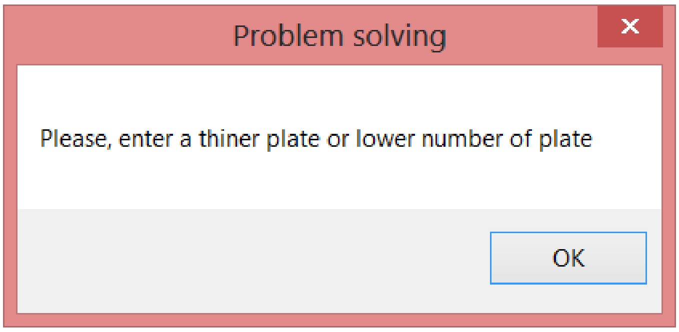

Fig. 4 Problem solving window

In the opposite case, the window given in Fig. 3 will be closed.

1.4. Results

In group box *Results* the calculation results, empirical and user defined overall heat transfer coefficient is given, see Fig. 5. In the ***Empirical Value Overall HTC***, the overall heat coefficient is given. This coefficient is defined by the following formula

$$U = \frac{1}{\frac{1}{h_l} + \frac{\sum x}{k} + \frac{1}{h_u}} \tag{2}$$

where h_l and h_u are convective heat transfer coefficients of the lower and upper surface of the plate or plate stack respectively, x is plate thickness and k is thermal conductivity of the plate. The convective heat transfer coefficient is given as follows

$$h = 10.45 - v + 10\sqrt{v} \tag{3}$$

where v is relative plate velocity through the air. The best accuracy of the empirical formula (3) is in the velocity range between 0 and $20 m/s$.

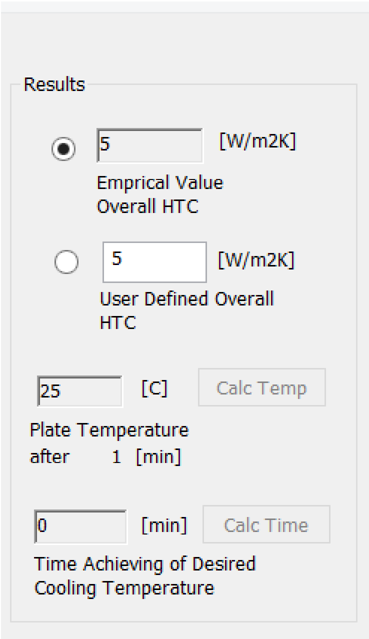

Fig. 5. ***Results*** group box

Beside the calculated empirical values of the overall heat transfer coefficient, the user defined overall heat transfer coefficient can be defined, as well. This value can be specified in the ***User Defined Overall HTC*** text box. However this value can be entered only if the radio button on the left side is activated.

The basic two functions of this software calculate the plate or stack temperature at a particular time and cooling time needed to achieve desired plate temperature. The first function is performed by clicking on the ***Calc Temp*** button. The plate temperature in the desired time is calculated by the following formula

$$T(t) = (T_1 - T_\infty) e^{-\frac{2U}{x\rho c}t} + T_\infty \tag{4}$$

where T_1 is the initial plate temperature, T_∞ is the air bulk temperature, ρ is the steel density, c is specific heat and t is time.

The cooling time is calculated using the following equation

$$t(T_a) = -\frac{x\rho c}{2U} \ln\left(\frac{T_a - T_\infty}{T_1 - T_\infty}\right) \tag{5}$$

where T_a is desired temperature of the plates. This calculation will be performed with ***Calc Time*** button.

1.5. Adaptation

In the framework of this software, the adaptation of the overall heat transfer coefficient can be done, if the measured temperature at time t is known. It is necessary, if the model has an insufficient accuracy or if the verifying of the obtained results is needed. The *Adaptation* group box is given in Fig. 6 and as it can be seen, this box consists of three text boxes and one button.

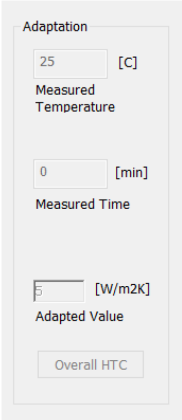

Fig. 6. ***Adaptation*** group box

Measured Temperature and ***Measured Time*** text boxes are used to enter the measured temperature and measured cooling time, respectively. In the third ***Adapted Value*** text box, the adapted value of the overall heat transfer coefficient calculated on the basis of the measured temperature at time t is given.

Adapted value of the overall heat transfer coefficient is calculated by the following formula

$$h_m = -\frac{x\rho c}{2t}\ln\frac{T_m - T_\infty}{T_1 - T_\infty} \tag{6}$$

The part of the code for the adaptation of the overall heat transfer coefficient is running by the ***Overall HTC*** button. It should be note that any part of the calculation code, in this software, cannot be performed before entering at least one plate.