

# VisiMix DI

## User's Guide

Simulation of Mixing in Tanks  
with  
Combined Mixing Devices

Mixing in low viscosity fluids Hydrodynamics  
Turbulence  
Single phase mixing  
Heat transfer

Jerusalem



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## SECTION 1. INTRODUCTION

### 1.1. Welcome to VisiMix DI .

VisiMix DI is a new software product for mathematical modeling and technical calculations of mixing equipment with different impellers on the same shaft.

**The program is used as a complimentary software to the program VisiMix Turbulent.**

The current first version of program includes calculation sections covering mathematical modeling of Hydrodynamics, Turbulence, Single-Phase mixing and Heat transfer in cylindrical tanks with mixing devices consisting of:

- 4 or 5 impellers identical impellers;
- 2 to 5 impellers of different types;
- 2 to 5 impellers of different tip diameter;
- 2 to 5 impellers with different number of blades;
- 2 to 5 impellers with different pitch angles;
- 3 to 5 impellers on different distances;

It allows to perform calculations related to hydrodynamic characteristics of each impeller with regard to interaction of the impellers. In combination with this program, the basic program VisiMix Turbulent become a universal tool for analysis and solving of mixing-related problems in practically any industrial mixing equipment unit.

### 1.2. Compatibility of VisiMix DI with other VisiMix programs.

- In order to allow application of the program VisiMix DI, the basic program VisiMix TURBULENT must be started.
- The projects created and saved with the program VisiMix DI have extension **.vsd**.
- It is possible also to open and work with the projects with extension **.vsm** created and saved by current versions of VisiMix TURBULENT and VisiMix LAMINAR. In this case the program VisiMix DI does not open the Impeller data. All the input data of the **.vsm** project are kept intact.
- The projects with extension **.vsd** or saved with the program VisiMix DI cannot be opened with other VisiMix programs.

### 1.3. Limitations of VisiMix DI.

The current version of VisiMix DI includes calculation sections covering mathematical modeling of Hydrodynamics, Turbulence, Single-Phase mixing, Heat transfer and Mechanical calculations of shafts.

- 1.3.1.** The program handles from 2 to 5 impellers. For mixing tanks with only **ONE impeller** on the shaft it is recommended to use the program VisiMix Turbulent which includes much more calculation options.
- 1.3.2.** If the total number of the impellers is 2, identical impellers cannot be entered. For mixing tanks with **TWO IDENTICAL impellers** on the shaft it is recommended to use the program VisiMix Turbulent which includes much more calculation options.
- 1.3.3.** If the total number of the impellers is 3, identical impellers with same distance between them cannot be entered. For mixing tanks with **THREE IDENTICAL IMPELLERS WITH THE SAME DISTANCE BETWEEN THEM** it is recommended to use the program VisiMix Turbulent which includes much more calculation options.

The message *Application of the main program is recommended* means that one of the conditions 1.3.1. – 1.3.3. is not satisfied.

- 1.3.4. Tip diameter of the smallest impellers cannot be less than 0.5 of tip diameter of the biggest impeller
- 1.3.5. Tip diameter of the biggest impeller cannot be less than 0.2 of the tank diameter;
- 1.3.6. Distance between two impellers cannot be less than half of tip diameter of the largest of the two impellers.
- 1.3.7. Pumping direction of the impellers with pitched blades is always down.
- 1.3.8. The minimum allowed distance from bottom for most impellers is about 0.25 of the impeller diameter.
- 1.2.9. The maximum allowed distance from the lower impeller to the tank bottom is the double tank diameter.
- 1.2.10. The maximum allowed distance from the upper impeller to the level of media is the double tank diameter.
- 1.2.11. The maximum allowed distance between the two neighboring impellers is the double tank diameter.
- 1.2.12. The minimum distance from the upper impeller to the level of media is 0.5 of width of the impeller blades.

## SECTION 2. SCIENTIFIC BACKGROUND.

Algorithms of the program VisiMix DI are based on the fundamentals VisiMix know-how, and also on results of special theoretical and experimental researches that are performed by VisiMix team starting from the year 2000. Purpose of the researches is to expand application of physical models of the main mixing phenomena used in VisiMix and described in THE REVIEW OF MATHEMATICAL MODELS USED IN VISIMIX SOFTWARE. This purpose is achieved:

- by development of more universal mathematical models and calculation algorithms that are not connected to a single impeller data;
- by experimental measurements that are performed in order to confirm or adjust the mathematical models and experimental constants that are used for closure of mathematical description;
- by development of new algorithms that allow entering and simultaneous treatment of initial data for impellers with different key parameters of geometry (with and without disc, with different number of blades, etc).

The current stage of these researches provides sufficient data for expanding of a significant part of VisiMix models. It allows to extend mathematical models of flow characteristics, distribution of turbulence, macro- and micromixing and heat transfer to mixing tanks with practically any combination of different impellers on the shaft.

While modeling in the current program is based essentially on the physical models and systems of equations described in THE REVIEW OF MATHEMATICAL MODELS USED IN VISIMIX SOFTWARE, there are a few different features.

- The main equations of momentum equilibrium take into account presence of impellers with blades of different size and design.
- Meridional circulation is calculated for each impeller with respect to interaction of the flows.
- Local values of turbulent dissipation are calculated for each impeller with respect to its geometry.
- Modeling of macromixing takes into account exchange rates between zones of different impellers, with respect to interaction of flows and as a function of the entire combination and distances between the impellers;
- Characteristic micromixing time is evaluated with respect to difference of circulation flow rate and turbulence parameters of different impellers;

- Simulation of temperature regimes takes into account different levels of turbulence created in zones of different impellers.

### SECTION 3. HOW TO INSTALL VISIMIX DI.

Installation rules for the 'stand alone' and the network version of the program are different. Installation of each program has to be performed accordingly to the Installation instruction that is applied to the program CD.

### SECTION 4. STARTING VISIMIX DI.

After installing VisiMix DI, the main VisiMix menu appears on the screen (Figure 1). It has the following structure:

**Project**  
**Edit input**  
**Calculate**  
**Supplements**  
**Last menu**  
**Last input table**  
**Window**  
**View**  
**Help**



Figure 1.

#### 4.1. Project

VisiMix performs mathematical modeling of processes in relation to a project - a single set of initial data, which includes the types and main dimensions of equipment as well as the physical properties of the media and regime parameters. The project is identified by its name. All output windows corresponding to the same project are displayed in frames of the same color.

To start VisiMix, select **Project**. When the **Project** submenu appears, you have two options: starting a new project or working with one of the projects you have previously stored in the system.

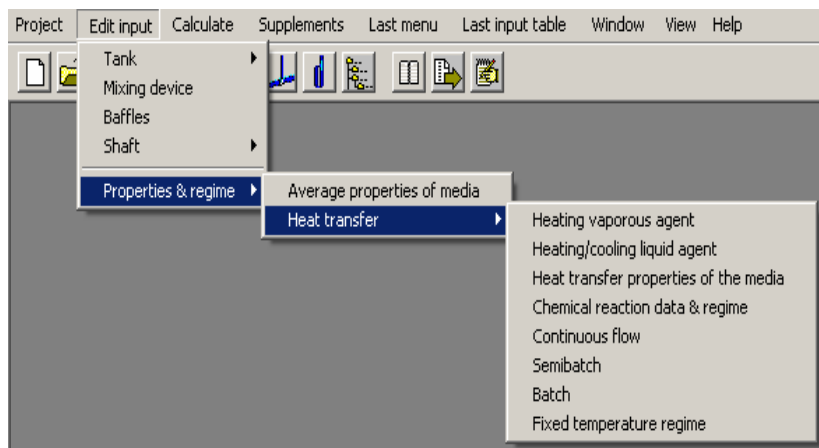
The program enables you to open several projects (up to four) which can be simultaneously displayed on the screen. However, you may modify initial data, create new output windows, or use any other functions only for the current project whose name appears in the text field at the bottom of the screen. To change the current project, use **Project list** option in **View** or the **Project list** button in the upper bar. The names of four projects with which you last worked, and their locations are displayed at the bottom of the **Project** menu, between **Print** and **Exit** options.

If windows related to several projects are displayed on the screen, you can also change the current project by double-clicking on the colored frame of the window related to the project you now want to become the current one.

## 4.2. Edit input

This option gives you access to all input tables related to the Current Project. Use it to selectively modify the initial data, for instance, Volume of media, Average density or any other parameter by choosing the appropriate submenu item.

The **Edit input** option has the following structure (Figure 2) briefly described below.



**Figure 2.**

### **Tank:**

**Tank geometry** - Main inside dimensions of the tank and volume of media

**Tank shell** - Tank shell characteristics for heat transfer calculations

### **Jacket**

**General characteristics** - Main data on various types of jackets, including number of jacket sections, their height, position and connection between the jackets

**Specific characteristics** - Specific data for each jacket type, i.e. width of conventional jacket and parameters of heat transfer enhancing devices, diameter or half-pipe coil, parameters of embossed/dimpled jackets.

**Mixing device** Design and rotation velocity of mixing device, and type, dimensions and position of each impeller.

**Baffles** Type, number, position and dimensions of baffles.

### **Properties & Regime:**

**Average properties of media** - Average density and viscosity, or rheological parameters for non-Newtonian media, used for hydrodynamic calculations.

#### **Heat transfer:**

**Heating vaporous agent** - Heating steam pressure or data for another condensing heating agent.

**Heating/cooling liquid agent** - Liquid heat transfer agent, its flow rate and initial temperature.

**Heat transfer properties of the media** - Physical properties of the media required for heat transfer calculations.

**Chemical reaction data & regime** - Kinetic constants for non-isothermal reaction, heat effect, process temperature range.

**Continuous flow** - Data used for simulation of temperature regime of continuous flow tanks and reactors only - flow rate of media, temperature and concentration of reactants in the inlet flow, etc.

**Semibatch** - Data used for simulation of temperature regime of Semibatch tanks and reactors only - initial temperature and concentration of reactants, feeding duration, etc.

**Batch** -Data used for simulation of temperature regime of Batch tanks and reactors only - initial temperature and concentration of reactants, etc.

**Fixed temperature regime** - Media temperature.

## 4.3. Calculate

Use this option to perform the calculations. The **Calculate** submenu provides access to modeling in relation to all mixing problems and output parameters.



## 4.4. Supplement

This option is used for modeling of tanks with Scraper (sweeping-wall) agitators.

## 4.5. Last Menu

This convenient option enables you to directly invoke the **Calculate** submenu with which you last worked.

### Example:

You have clicked on **Mixing power** in the **Hydrodynamics** submenu and obtained a corresponding output. In order to obtain another output parameter, for instance, **Vortex depth**, you do not need to return to the **Calculate** menu. Simply click on **Last menu - Vortex depth** to obtain your output.

## 4.6. Last Input Table

This is another shortcut, which enables you to directly invoke the input table with which you last worked. For example, if you want to compare heat transfer rates and select the best vaporous heat transfer agent, you can change the input after each calculation by selecting **Last input table** only, without going through the long procedure of addressing **Edit input-Properties & Regime - Heat Transfer**. This option is activated after you have first accessed an input table through the **Edit input** option or the quick access buttons in the upper screen bar.

## 4.7. Window

This option functions the same way it does in Microsoft Windows.

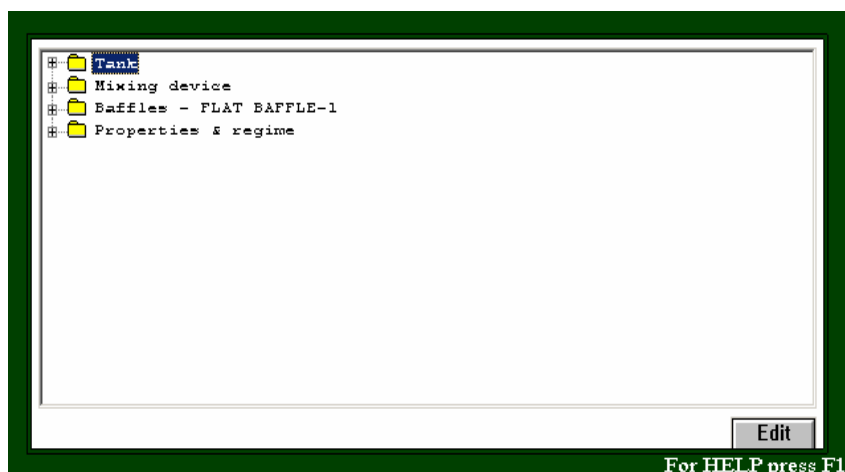
## 4.8. View

This option contains the following functions:

- Initial data explorer**
- Project list**
- Drawing of apparatus**

### 4.8.1. Initial data explorer

This option (Figure 3) shows a list of initial data for the current project, including equipment data (tank, impeller, shaft and baffle), and properties & regime parameters (see the description of the **Edit input** option above). This option is also accessible from a quick access button in the upper screen bar. To modify any of the initial data using the initial data explorer, select the required item, and press the **Edit** button at the bottom of the screen. The appropriate input screen will be invoked.



**Figure 3.**

#### **4.8.2. Project list**

This option invokes the Project list dialogue, which contains a list of opened projects. In this dialogue, you can choose or change the current project. The name of the current project appears in the text field at the bottom of the screen. This option is also accessible from a quick access button in the upper screen bar.

#### **4.8.3. Drawing of apparatus**

This option shows the diagram of the mixing unit for the current project, with main dimensions. This diagram automatically appears on the screen after all basic initial data for a new project has been entered, or when an existing project is opened. It is also accessible from a quick access button in the upper screen bar.

#### **4.9. Help**

This option functions the same way it does in Microsoft Windows. Press **F1** to invoke the **Help** section corresponding to the active window.

## SECTION 5. STARTING A NEW PROJECT OR OPENING AN EXISTING ONE

Select **Project**. The following submenu appears:

- New**
- Open**
- Close**
- Clone**
- Project comments**
- Save**
- Save as**
- Report**
- Print**
- [Recent projects]**
- Exit**

### 5.1. New

To start a new project:

- 1) Select **New** from the **Project** menu.
- 2) When the new project dialogue appears (Figure 4), enter a project name in the name field, then click **Save**.

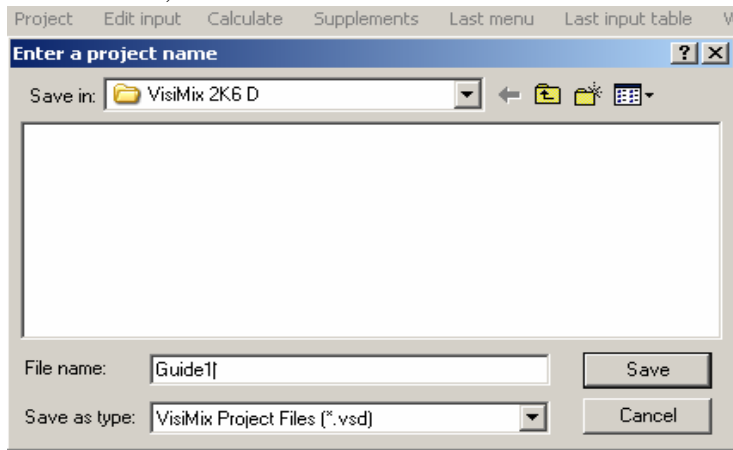


Figure 4.

This option is also accessible from a quick access button in the upper screen bar.

### 5.2. Open

To open an existing project:

1. Select **Open** from the **Project** menu. The **Open** dialogue appears (Figure 5).

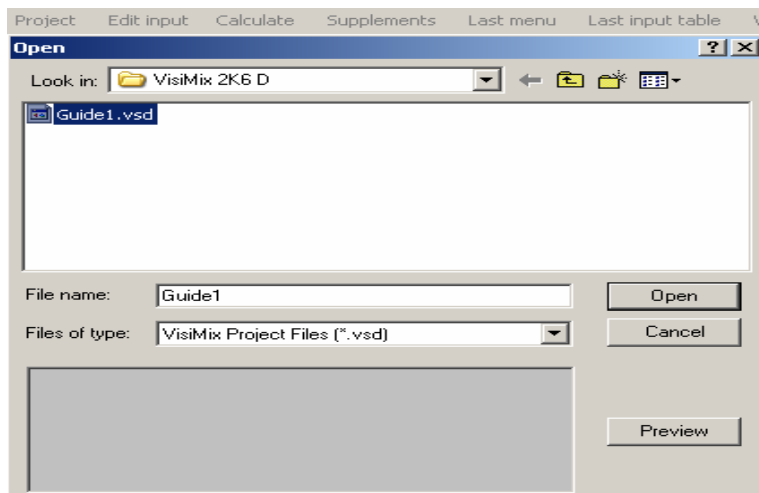
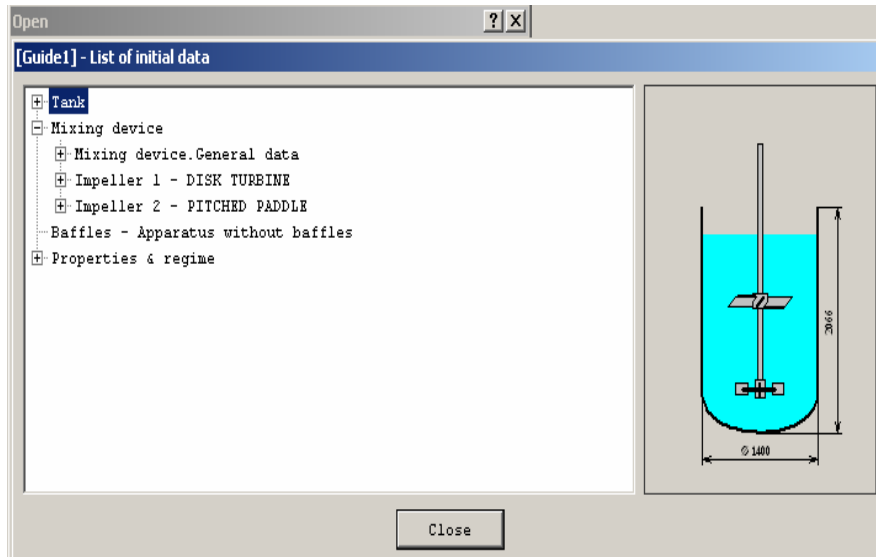


Figure 5.

The text box at the bottom of the screen displays basic information about the project you have selected (tank type, volume of the media), and your comments to the project if any have been made.

Press **Preview** button to display detailed information about the selected project (tank, impeller, baffle, and media properties), and the diagram of the mixing system (Figure 6). Press **Close** button at the bottom to exit the **Preview** dialogue.



**Figure 6.**

2. From the file browser screen select the desired project and click **Open**.

The program displays a diagram of the apparatus and its main dimensions. Use the **Edit input** option, **Initial data explorer** or the quick access buttons in the upper screen bar to check and modify initial data for your equipment (Tank, Baffles and Mixing device). For media properties and regime characteristics, use **Edit input** option or **Initial data explorer** (Properties & Regime).

The **Open** option is also accessible from a quick access button in the upper screen bar.

You can also open any of the four projects with which you last worked from a list of recent projects displayed at the bottom of the **Project** menu above the **Exit** option.

The projects created and saved with the current program have extension **.vsd**. It is possible also to open and work with the projects with extension **.vsm** created and saved by VisiMix TURBULENT and current versions of programs and VisiMix LAMINAR.

**NOTE.** *Projects with extensions .vsd or .vsm can be opened from any directory.*

### 5.3. Close

Use this option to close and save the current project.

### 5.4. Clone

Use this option to create up to four copies of you current project. It serves as a convenient tool for comparing different variants of the same basic project. This option is also accessible from a quick access button in the upper screen bar.

## 5.5. Project comments

Use this option to create or modify your comments to the project. This option is also accessible from a quick access button in the upper screen bar.

## 5.6. Save.

Use this option to save all initial data for the current project. This option is also accessible from a quick access button in the upper screen bar.

The project is saved with the extension **.vsd**. It cannot be opened with other VisiMix programs, including the program VisiMix TURBULENT.

## 5.7. Save as

Use this option to save the current project under a new name. The project is saved with the extension **.vsd**. It cannot be opened with other VisiMix programs, including the program VisiMix TURBULENT.

## 5.8. Report

Use this option to accumulate the initial data and calculated results in a file of standard HTML format.

Selecting **Report** at any stage of working on a current project invokes a submenu, which is identical to the **Calculate** submenu (Figure 7).

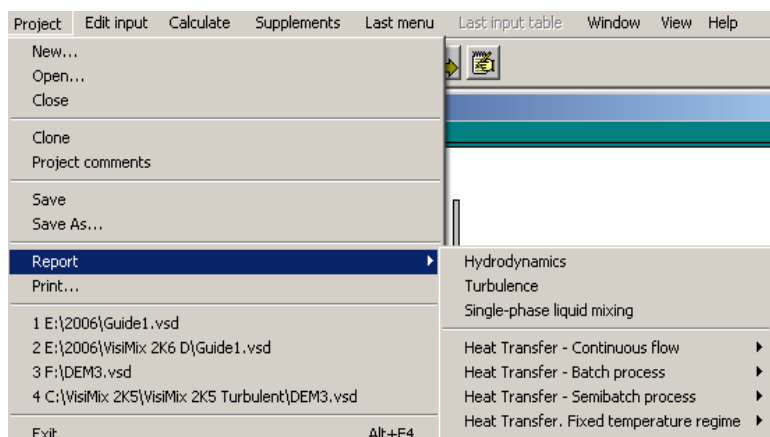


Figure 7.

Choose the Menu option you are interested in, enter a name for the report and a directory for it to be saved (Figure 8.). VisiMix will create a report containing relevant initial data and the results of the calculations.

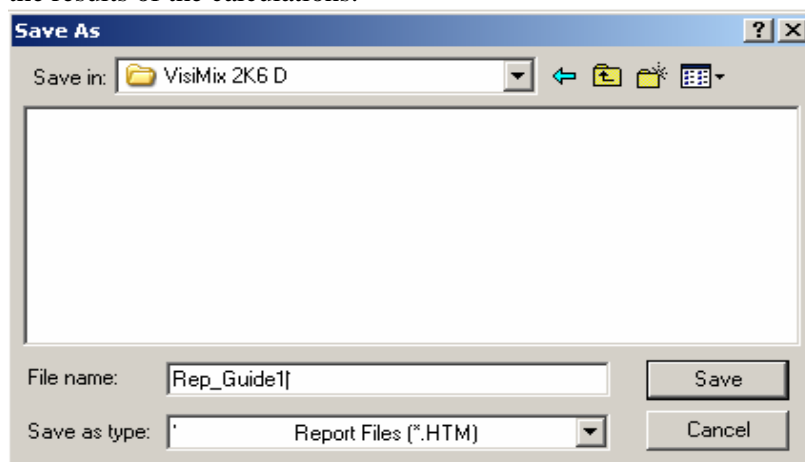
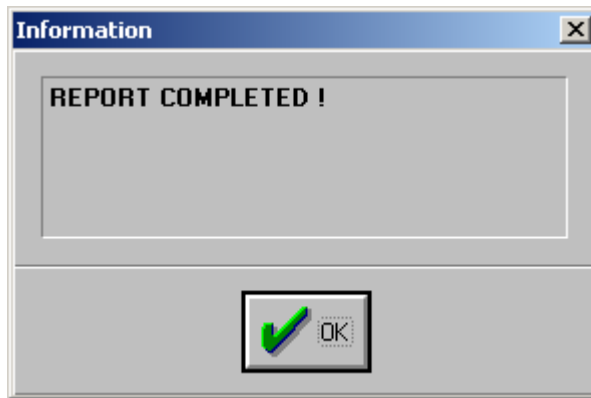


Figure 8.

On completing the report, VisiMix issues an appropriate message (Figure 9).



**Figure 9.**

You may create one or more reports for your project.

The report is formed as a file with a **.htm** extension, and you may open, edit and print this file from Microsoft Internet Explorer or Microsoft Word (Microsoft Office 97 or higher). The **Report** option presents all graphs, in addition to a graph form, in a standard tabular format. This enables you to plot and process your data in any way you wish using other programs, for example, EXCEL.

## **5.9. Print**

Use this option to print the content of the active output window - the output window, which has a blue caption. This option is also accessible through a quick access button in the right part of the screen.

The initial data (tank, mixing device, baffles, average properties of media) are printed directly from the corresponding input data tables.

Each print-out also includes the complete information on the project and directory names.

## **5.10. Exit**

Use this option to close opened projects and quit VisiMix.

## SECTION 6. ENTERING INITIAL DATA .

### 6.1. General information

Entering of initial data for the program is identical to the operations performed with the programs VisiMix **TURBULENT and Laminar**. The only difference is connected with entering of data on **Mixing device**.

After you enter the name of a new project and click OK, VisiMix requests basic initial data required for all calculations by invoking the appropriate input tables. Supplying this data allows the program to start the calculations. You can use the **Calculate** function before all initial data is entered, but VisiMix will ask you to supply all parameter values first. The data you have entered is stored in the system, and when addressing any further parameters of the output submenus, you will be asked to enter only data that is required for modeling the selected parameter and which has not been entered previously.

You may enter any input parameter in SI or US customary and commonly used units.

Use the **Edit input** option, **Initial data explorer**, or **Last input table** option to selectively modify your initial data.

VisiMix verifies the input. If your input contains inapplicable symbols, e.g. characters or punctuation marks instead of numbers, VisiMix issues a message indicating that one of the input values is incorrect. In this case you must click **OK** and correct the error. If your input is outside reasonable limits, contradicts previously entered data, or is beyond VisiMix calculation range, VisiMix modifies the input, offering the nearest acceptable value to the one entered, and issues an appropriate message when necessary. In this case you must check the data before exiting the input table.

### 6.2. Tank

After you enter the name of a new project and click **OK**, the **Tank types** graphic selection of tanks appears. The tanks differ by **bottom type** (flat, conic or elliptical) and **type of a heat transfer device** (Conventional jacket, Half-pipe coil, Embossed / dimpled jacket, or No heat transfer device) (Figure 10).

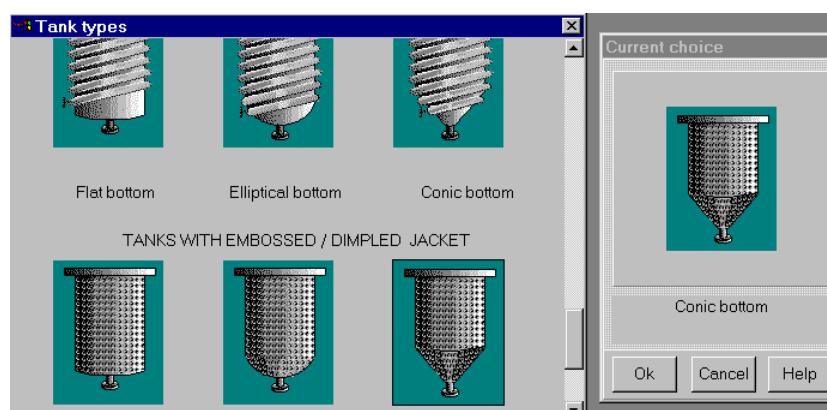


Figure 10.

Choose a tank by clicking anywhere inside the selected drawing. The tank you have selected will appear in the **current choice** window on the right. Click **OK** to confirm your choice.

#### NOTE:

*If you do not plan to perform heat transfer calculations in the current project, do not select a jacketed tank, even if your tank has a heat transfer device. Select an equivalent*

*unjacketed tank instead. If you select a tank with a heat transfer device, you will be asked to supply all its parameters.*

When the scheme of the selected tank appears (Figure 11), supply the requested values of tank parameters by completing the table of dimensions.

**NOTE:**

*The Total tank height is measured from the lowest point of the bottom to the upper edge of the tank, tank head not included.*

### 6.2.1. Tank with flat bottom

Supply the internal dimensions of the selected flat-bottomed tank (Figure 14). Enter the **Inside diameter** and either the **Total tank height**, or **Total volume**, and the second parameter will be entered automatically. The same applies to the **Level of media** and **Volume of media**. After the table has been completed, click anywhere on the field of the window, and the diagram on the screen will change to reflect your input. Click **OK** to confirm your input, and use the **Choose new tank** button at the bottom of the screen to change the tank type. The TANK TYPES screen will then be displayed.

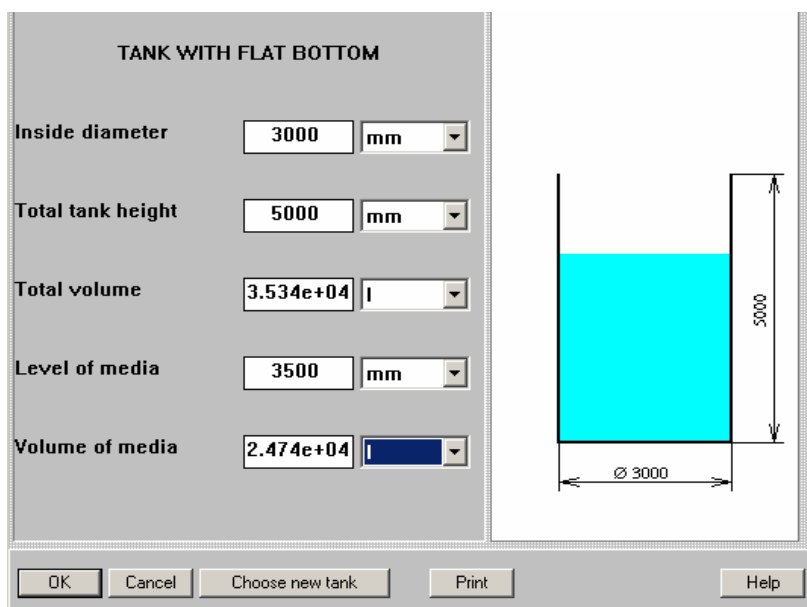


Figure 11.

**NOTE:**

*In modeling Heat transfer Semibatch process, the Volume of media is understood as an initial value.*

### 6.2.2. Tank with elliptical bottom

Supply the internal dimensions of the selected tank with an elliptical bottom. This option may also be used for calculating tanks with a spherical bottom, as the influence of the difference in geometry proves to be insignificant for the process modeling. Enter the **Inside diameter** and either the **Total tank height**, or **Total volume**, and the other parameter will be entered automatically. The same applies to the **Level of media** and **Volume of media**. After the table has been completed, click anywhere on the field of the window, and the diagram on the screen will change to reflect your input. Click **OK** to confirm your input, and use the **Choose New Tank** button at the bottom of the screen to change the tank type. The TANK TYPES screen will then be displayed.



**NOTE:**

*In modeling Heat transfer, Semibatch process, the Volume of media is understood as an initial value*

### 6.2.3. Tank with conical bottom

Supply the internal dimensions of the selected tank with a conical bottom. The **Cone angle** is usually 45-60 degrees. The maximum **Height of cone** is controlled by VisiMix as a function of the **Inside diameter** and the **Cone angle**.

Enter the **Inside diameter**, cone dimensions, and either the **Height of Cylindrical Part**, or **Total volume**, and the other parameter will be entered automatically. The same applies to the **Level of media** and **Volume of media**. After the table has been completed, click anywhere on the field of the window, and the diagram on the screen will change to reflect your input. Click OK to confirm your input, and use the **Choose New Tank** button at the bottom of the screen to change the tank type. The TANK TYPES screen will then be displayed.

**NOTE:**

*In modeling Heat transfer Semibatch process, the Volume of media is understood as an initial value*

### 6.2.4. Tank shell characteristics

If you have selected a tank with a heat transfer device (**HTD**) you will be asked to fill this table (Figure 12) for the current project.

TANK SHELL CHARACTERISTICS

Material: Steel glass lined

Wall thickness: 10 mm

Thermal resistance of fouling: 0.0002 (m²\*K)/W

Tank mass (without drive) If unknown, enter 0 \*: 0 kg

Buttons: OK, Cancel, Print, Help

\* In this case tank mass will be evaluated by VisiMix

**Figure 12.**

**Material.** Select the desired tank material. All the required data for the selected material will be supplied by the program.

**Wall thickness.** This parameter is required for calculating the wall thermal resistance. If you do not know the exact figure, enter an approximate estimate; for steel tanks it is usually 5-9 mm. You may not enter a wall thickness lower than 1.5 mm.

**Thermal resistance of fouling.** Fouling of the heat transfer area may occur both on the jacket and on the media side of the tank wall. Thermal resistance of fouling depends on the

kind of heat transfer agent (HTA) and the properties of the media, and is estimated according to available practical data. Some typical values for deposit layers not exceeding a thickness of 0.5 mm on the surface of stainless steel plates are given in the Table in APPENDIX 2. Enter the estimated value, or zero if there is no fouling. In the case of fouling on both sides of the wall, enter the sum of the estimated values of the corresponding thermal resistance values for each side.

**Tank mass.** Enter the **Tank mass** value, which is necessary for simulation of heating/cooling dynamics. The **Tank mass** must include the mass of the head, HTD, baffles, shaft and impeller, and should not include the mass of the impeller's drive. It is always preferable to enter the mass value, which has been calculated by the tank designer and appears in the tank technical drawings. If this value is not known, enter "0". In this case the program will calculate the tank mass based on the tank dimensions and material. However, this calculation does not take into account any additional parts of the tank device, and is therefore approximate.

### 6.2.5. Tank heat transfer general data

You will be asked to fill in this table (Figure 13) if you have selected a tank with a heat transfer device (HTD) for the current project.

A diagram of a jacketed tank will appear, according to the selected Tank type and dimensions.

**Tank head type.** Enter tank head type (flat, elliptical), or “absent” for an open tank.

**Jacket covers bottom.** If you choose **YES**, the heat transfer area of the bottom will be assumed to equal 2/3 of its total area. In most cases, heat transfer area of the bottom part of the HTD constitutes only a small part of the entire heat transfer area.

**Number of jacket sections.** You may perform calculations for jackets consisting of one or two separate sections. If you choose "1", the program will assume your tank has lower jacket only. In this case, parameters relating to the upper jacket section will appear in inactive script.

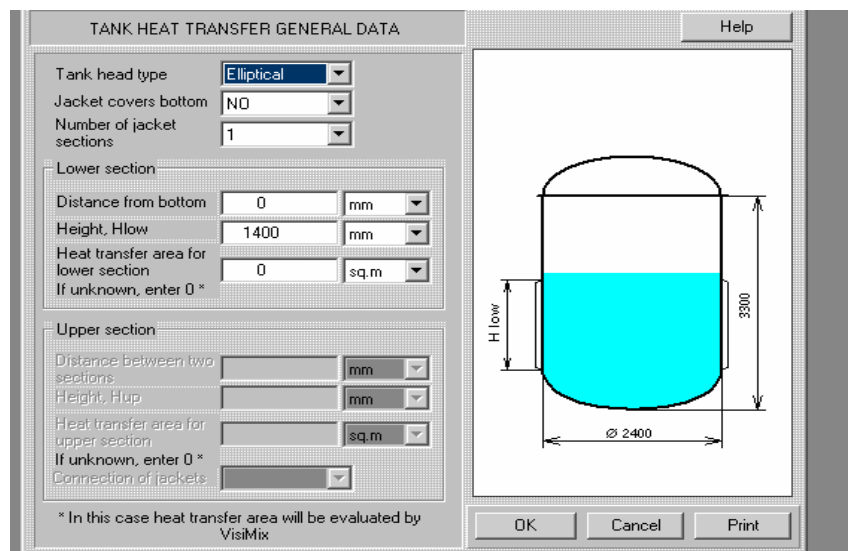


Figure 13.

**Distance from bottom.** For tanks with elliptical or conical bottom, enter the distance from the edge of the shell cylindrical part.

**Heat transfer area.** Enter the exact values of the HT area for each jacket section, if known. If not, enter zero, and the program will calculate the HT area according to your input.

**Connection of jackets.** For a **2-section jacket**, specify if the sections are connected **in series**, or **in parallel**. For liquid heat transfer agents (LA), VisiMix assumes that the inlet tube is located in the lower cross-section, and the outlet - in the upper cross-section of each jacket section. The jacket sections are assumed to be connected **in series**, if the **Lower section** outlet is connected to the **Upper section** inlet. For condensing vaporous heat transfer agents (VA), the inlet tube is supposed to be located in the upper cross-section, and the outlet - in the lower cross-section of each jacket section. The jacket sections are assumed to be connected **in series**, if the **Upper section** outlet is connected to the **Lower section** inlet.

## 6.2.6. Tank jacket - Heat Transfer data

### Half-pipe coil jacket. Specific characteristics.

You will be asked to fill in this table (Figure 14) after you have selected a tank with a Half-pipe coil HTD and completed the TANK HEAT TRANSFER GENERAL DATA input table. The entire table appears in active script if a 2-section jacket has been selected. For a single-section jacket, only the **Lower section** boxes are active.

**Pipe diameter.** Enter the inside diameter of the Half-pipe coil jacket.

**Distance between coils.** Enter the distance between the axes of the adjacent half-pipe turns as shown in the diagram.

**Number of starts.** Enter the number of starts of the Half-pipe coil (1 or more, according to the tank design).

Figure 14.

**NOTE:**

*If you have a 2-section jacket and attempt to exit the table without entering data for both jacket sections, VisiMix issues an appropriate message.*

### Conventional jacket. Specific characteristics.

You will be asked to fill in this table (Figure 15) after you have selected a tank with a conventional jacket and completed the TANK HEAT TRANSFER GENERAL DATA input table.

The entire table appears in active script if a 2-section jacket has been selected. For a single-section jacket, only the **Lower section** boxes are active.

**Figure 15.**

**Width, W.** Enter the width of the channel inside the jacket, i.e. half of the difference between the inside diameter of the jacket and the outside diameter of the tank.

**Wall thickness, t.** Enter the thickness of the jacket wall.

In addition to the jacket dimensions, the parameters of devices used for improving the jacket heat transfer, such as agitation nozzles and spiral baffles, are entered in this table.

**Heat-transfer enhancing device.** Select “agitation nozzles” or “spiral baffle” for an appropriate heat-transfer enhancing device. Select “absent” if your jacket has no heat-transfer enhancing device.

**Agitation nozzles** are mainly used in glass-lined equipment. Their main effect is to impose a spiral flow pattern tangential to the jacket wall by momentum exchange between the high-velocity tangential stream leaving the nozzle and the jacket fluid. This momentum exchange results in “swirl velocities” in the range of 0.3-1.2 m/s, which is high enough to cause turbulent flow [Donald H. Bollinger, *Assessing Heat Transfer in Process Vessel Jackets*, *Chemical Engineering*, September 20, 1982, pp. 95-100]. VisiMix takes into account both agitation nozzles, which create a spiral tangential flow, and additional inlets that may be located on the jacket surface.

**NOTE:**

*The flow rate through all inlets is assumed to have the same value.*

The following parameters are entered for the jackets with agitation nozzles:

**Diameter of nozzle.** Enter the throat diameter of the agitation nozzle.

**Number of inlets.** Enter the total number of inlets for the jacket, including agitation nozzles.

**Number of nozzles.** Enter the number of agitation nozzles in the jacket (2-3 agitation nozzles are recommended).

Agitation nozzles produce jacket heat-transfer coefficients two or three times higher than those in conventional jackets without nozzles, however, more pumping energy is required to overcome nozzle pressure drop.

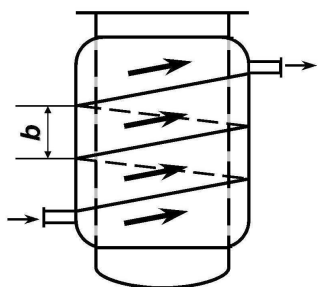
A **spiral baffle** consists of a metal strip spirally wound around a vessel wall from jacket entrance to exit. This strip directs the flow in a spiral path to obtain fluid velocities, typically in the range of 0.3-1.2 m/s. The baffle is manufactured in such a way that a gap is often left between the baffle and the jacket wall. This gap is a second path for the fluid flow from the jacket inlet to outlet, perpendicular to the desired path along the baffle. The fluid that leaks, i. e. bypasses the spiral baffle through this gap, does not contribute directly to heat transfer at the vessel wall. In general, leakage flow amounts to one-third to one-half of the total flow circulated to a spirally baffled jacket.

Compared to agitation nozzles, spiral baffles require a higher flow rate of the heat transfer agent, but result in much less of the pressure drop, to ensure the same heat-transfer rates. Spirally baffled jackets, therefore, require only a part of the energy (typically, not more than about 40%) needed by jackets with agitation nozzles.

The following parameters are entered for the spiral baffle:

**Spiral channel height,  $b$ .** Enter the distance between the adjacent spiral turns for the spiral baffle (see the diagram below).

**Leakage, %.** Enter the estimated part of the heat transfer fluid that bypasses the spiral baffle through the gap between the baffle and the jacket wall.



**Conventional jacket with spiral baffling**

### **Embossed and dimpled jackets. Specific characteristics.**

You will be asked to fill this table (Figure 16) after you have selected a tank with embossed or dimpled jacket and completed TANK HEAT TRANSFER GENERAL DATA input table. Embossed and dimpled jackets ensure better heat exchange and higher efficiency than conventional jackets. Tanks with **embossed** or **dimpled** jackets are manufactured using a special double-layer metal plate, which is preliminarily embossed or dimpled.

**Plate type.** Enter the jacket type – embossed or dimpled.

**Embossed.** This type of plate is made by (1) contact welding of two metal sheets of different thickness so that welded spots are formed at regular spacing from each other and (2) by hydraulic or pneumatic pressure, so that the thicker plate remains flat, and the thinner one is inflated. As a result, a channel of a variable cross-section is formed. The maximum height of the channel is in the range of 3-15 mm. Any material compatible with resistance welding may be used.

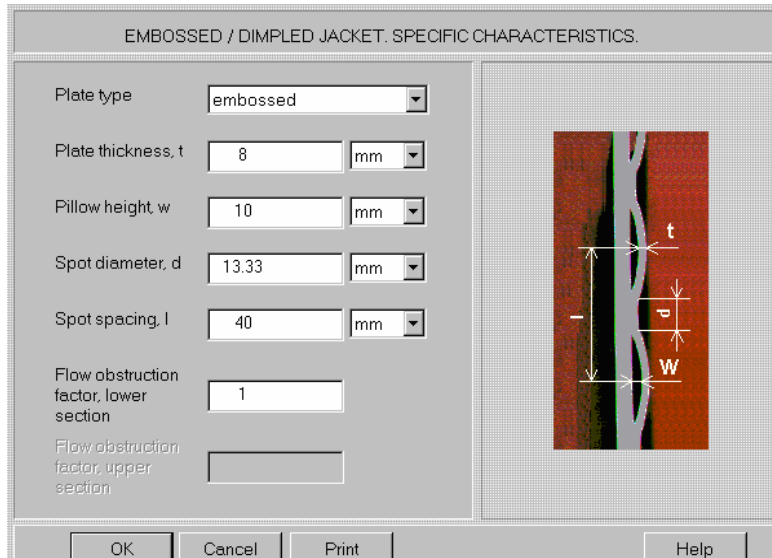
**Dimpled:** fabricated by welding a pre-deformed metal sheet to a flat plate, so as to obtain a channel of a variable cross-section between the plates, the maximum channel height usually varying from 3 to 15 mm, as for embossed plates.

A diagram corresponding to your choice appears on the screen. Enter the dimensions as shown in the diagram:

**Plate thickness,  $t$ .**

**Pillow height, w.**  
**Spot diameter, d.**  
**Spot spacing, l.**

All geometrically possible values are allowed.



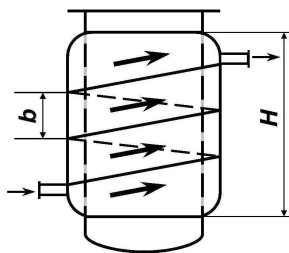
**Figure 16.**

Embossed and dimpled jackets are sometimes equipped with spiral, horizontal, or vertical baffles for further intensification of the heat transfer. In this case, you are requested to enter an additional parameter, **Flow obstruction factor, FOF** which characterizes the decrease in the flow cross-section due to the heat-transfer enhancing device.

If your embossed/dimpled jacket has no heat-transfer enhancing device, enter “1” for the **Flow obstruction factor**.

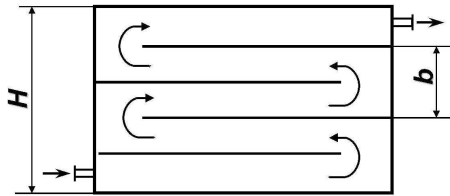
**Flow obstruction factor, FOF.** Enter the ratio of the flow area in the baffled channel to the unbaffled flow area. This coefficient shows the narrowing of the channel and, accordingly, the increase in the flow velocity.

For the spiral baffling of the jacket shown in the diagram below, **FOF = H/b**.



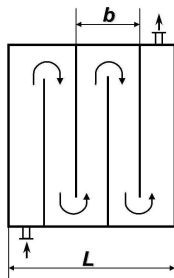
**Embossed/dimpled jacket with spiral baffling**

For the horizontal baffling shown in the diagram below, **FOF = 2H/b**.



**Embossed/dimpled jacket with horizontal baffling**

For the vertical baffling shown in the diagram below, **FOF = 2L/b**.



**Embossed/dimpled jacket with vertical baffling**

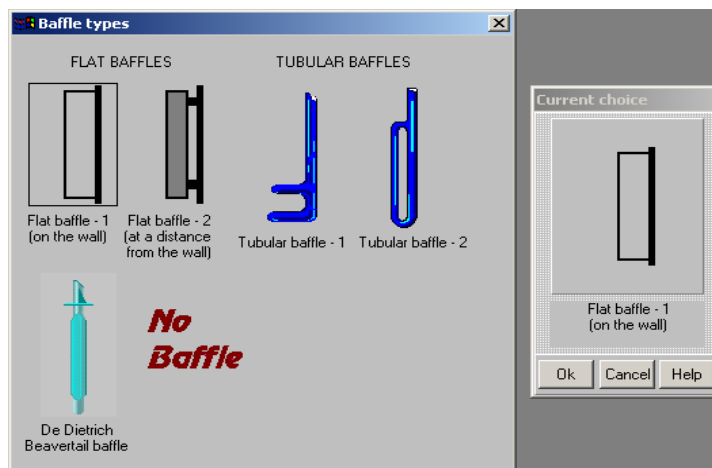
In the case of series connection of the internal heat transfer devices, **FOF = n**, where **n** is number of plates constituting the heat-transfer device.

*In all other cases, the **FOF** value must be selected empirically, based on general engineering considerations.*

### 6.3. Baffles

The procedure for selecting the baffle type and entering baffle data is similar to the one used for tanks.

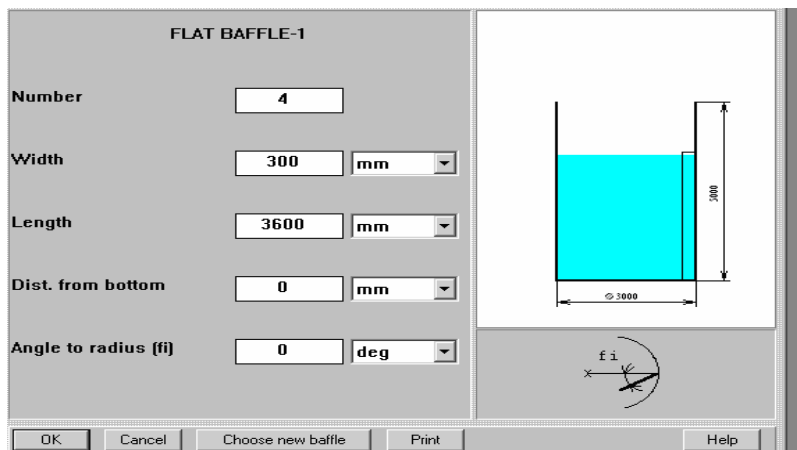
VisiMix selection of baffles is shown in Figure 17.



**Figure 17.**

It includes **flat baffles** used in steel tanks, and **tubular baffles** used mainly in glass-lined equipment. A steel baffled tank has typically a set of 3-4 baffles, the baffle width being 1/10 - 1/12 of the tank diameter. Glass-lined tanks are usually equipped with 1 or 2 tubular or Beavertail baffles fixed to the tank head.

When the scheme of the selected baffle appears (Figure 18), supply the requested baffle parameters.



**Figure 18.**

If baffles of different configurations are installed in the tank, an equivalent baffle should be entered, such that the radial projection of the baffle immersed area equals the average value for all baffles. The number of baffles entered should be the same as the actual number of baffles in the tank. The **Distance from wall** for the equivalent baffle must be equal to the average distance between the wall and the vertical axes of the baffles, and the **Distance from bottom** must equal the average baffle clearance.

**NOTE:**

*Inlet tubes, sensors and other fixed internal devices can be entered using Beavertail baffle of an appropriate size.*

### 6.3.1. Flat baffles

Flat baffle -1 type corresponds to a flat baffle on the wall, Flat baffle-2 corresponds to a flat baffle at a distance from the wall.

**Flat baffle-2** option can also be used for approximate calculations of other types of fixed internal devices, such as discharge tubes. In this case, a product of **Width** and **Length** of a baffle entered in the table should be equal to the radial cross-section of the fixed device. The value of **Distance from wall** must be selected so that the distance between the wall and the vertical axis of the fixed device equals the spacing between the wall and the vertical axis of the baffle.

**NOTE:**

*For radially installed baffles (both flat and tubular), the Angle to radius is zero.*

The distance between **Flat baffle-2** and the tank wall is usually about 1/3 - 1/4 of the baffle width.

### 6.3.2. Tubular baffles

These baffles have a tubular or flattened tubular cross-section. They are used mainly in glass-lined mixing tanks. The **Tube diameter** is usually about 1/7 - 1/11 of the tank radius.



### 6.3.3. De Dietrich Beavertail baffle

These baffles are mainly used in De Dietrich glass-lined equipment. One to three Beavertail baffles are usually installed in the tank; standard ratio of baffle and tank radius is in the range 0.07-0.11.

## 6.4. Mixing device.

The **Mixing device** section of the program serves for entering of characteristics of mixing device. It provides the following options:

- entering the rotation velocity of shaft and power of drive,
- consecutive entering of impellers;
- independent change of characteristics of each impeller, including relative positions of the impellers on the shaft.

### 6.4.1. Mixing device design.

The main input window – **Mixing device** – is displayed automatically (in the case of a New project) or through the **Edit Input>Mixing device** in the main menu bar. For a direct access a button **Mixing device** can also be used.

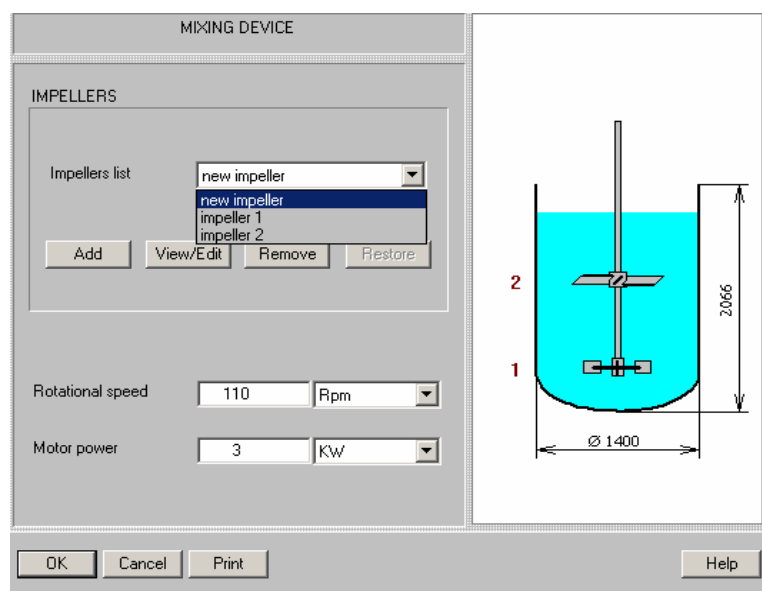


Figure 19.

The **Mixing device** window (Figure 19) shows general design of mixing device that includes 2 or more impellers on the same shaft. It serves for entering of the general characteristics of mixing device: rotational speed and rated (nominal) power of drive. On the stage of hydrodynamic calculations, the rated power of drive is compared with the calculated **Mixing power**. If the expected value mixing power is higher then 70% of the nominal power of drive, a corresponding warning message is returned.

The 30% reservation accepted in VisiMix is based on practical experience. It takes into account usual level of energy losses in electric drives with mechanical speed reducers (gyres). If the speed reduction is performed using electrical or electronic speed control devices, selection of the motor power has to be based on the rated torque moment of the low speed shaft that must be included in the technical characteristic of the drive. The recommended 30% reservation in this case must be related to the calculated **Torque** value.

The **Impellers list** scroll box present in this screen is used for viewing, entering or changing of impellers types, their dimensions and positions on the shaft.

### 6.4.2. Entering of the first impeller.

If the **impellers** are not entered yet, the **Impellers list** scroll box provides only the **New impeller** option. The button **Add** in combination with this option opens the impeller type selection screen. You may choose impellers of most typical designs, both steel and glass-lined. The corresponding diagram occurs in the current window (Figure 20).

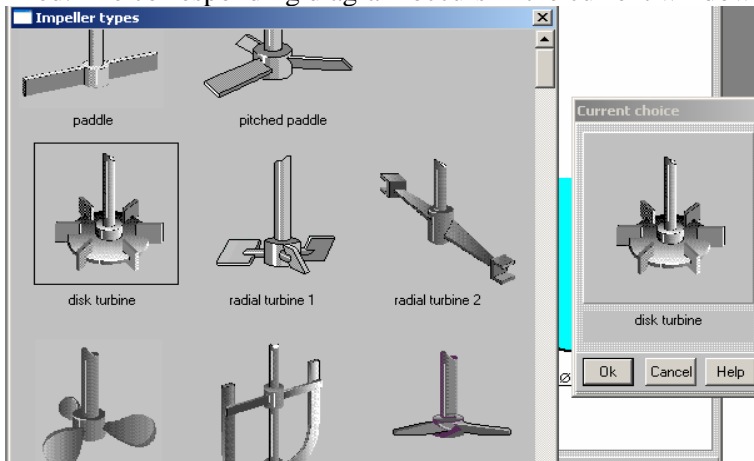


Figure 20.

#### NOTE:

*The program can be applied for practically any existing impeller type, including the types that are not shown in the **Impeller types** screen. If you want to perform calculations for an impeller, which is not shown in the **Impeller types** screen, contact VisiMix technical support.*

When the scheme of the selected impeller appears, supply the requested impeller parameters (Figure 21)

**Width of blade** is understood as actual width and not projected one.

**Distance from bottom** is impeller clearance, which is understood as the distance between the lowest point of the bottom, and the middle of the blade.

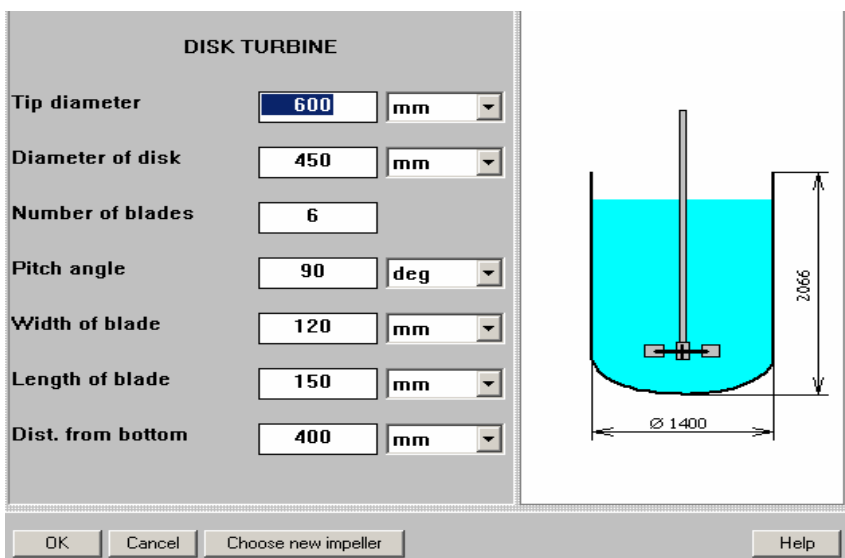


Figure 21.

Use **Help** button in the **Impeller data** input screens in order to get advice with respect to geometry of the impellers. After you finish entering of the impeller dimensions, press OK. You can see the selected impeller and its position with the number 1 in the **Current choice** window.

#### 6.4.3. Entering, replacement and removal of impellers.

In order to enter the additional impeller, select **New impeller** in the window of **Impellers list** scroll box of the **Mixing device** window and use the **Add** button. Select the type and enter dimensions of the impeller as it is described in previous paragraph. After entering of the impeller dimensions, click with the mouse in any point inside the window. A scheme of impeller size and position arrives accordingly to the last input.

After pressing OK, you can see the selected impeller and its position (accordingly to its position number 2, 3, etc., see Figure 19) in the **Current choice** window of the **Mixing device** screen. The impeller numbers are defined accordingly to their positions on the shaft, they are also shown in the mixing device diagram..

*Note. Number attached to each impeller is changing automatically with change of its relative position.*

The **Add** button in combination with the option **Impeller 1** is used if the new impeller has to be identical to the **Impeller 1**. The same – for any other impeller shown in the window of **Impellers list** scroll box .

In order to change dimensions or position of impeller, select the impeller with the corresponding number in the scrolling box and use the **Edit/View** button. To replace the current impeller with an impeller of another type, use **Choose new impeller** in the arriving **Impeller data** window.

The button **Remove** removes the impeller shown in the scrolling box window. To cancel the removal, the button **Restore** is used.

#### 6.4.4. Main limitations for input of mixing device.

1. The maximum number of impellers in the current version – 5;
2. Two identical impellers or three identical impellers with same distance between them cannot be entered.
3. Anchor and Frame impellers can be entered for the tanks with NO BAFFLES.
4. Tip diameter of the smallest impellers cannot be less than 0.5 of tip diameter of the biggest impeller
5. Tip diameter of the biggest impeller cannot be less then 0.2 of the tank diameter;
6. Distance between two impellers cannot be less then half of tip diameter of the big impeller.
7. Pumping direction of the impellers with pitched blades is always down.
8. The minimum allowed distance from bottom for most impellers is about 0.25 of the impeller diameter.
9. The maximum allowed distance from the lower impeller to the tank bottom is the double tank diameter.
10. The maximum allowed distance from the upper impeller to the level of media is the double tank diameter.
11. The maximum allowed distance between the two neighboring impellers is the double tank diameter.
12. The minimum distance from the upper impeller to the level of media is 0.5 of width of the impeller blades.

In the cases 2 and 3 the current version of program **VisiMix TURBULENT** has to be used.

#### 6.4.5. Anchor, frame

Compared to the Anchor impeller, the Frame impeller has an additional horizontal bar. This bar is used to prevent the winding of the impeller vertical arms. Its effect on the power and mixing process in turbulent regime is negligible. The **Tip diameter** of Anchor and Frame impellers is usually about 0.8 to 0.9 of the tank **Inside diameter**, and the **Width of blade** ("arm") is about 0.07 of the impeller **Tip diameter**.

Impellers of these type are entered for tanks without baffles only.

#### 6.4.6. Propeller

The propeller in the current version of VisiMix corresponds to a **marine screw** with a **Pitch = 1.0** (a blade angle of about 26 degrees). The **Tip diameter** is usually 1/4 to 1/3 of the tank diameter.

#### 6.4.7. Disk turbine

The most typical design with vertical blades is a **Rushton turbine** with the following geometry: a pitch angle of 90 degrees; six blades; a disk diameter that is 0.75 of the **Tip diameter**; a blade width that is 0.2 of the **Tip diameter** and a blade length that is 0.25 of the **Tip diameter**. The **Tip diameter** of the Disk turbine impeller is usually less than 0.4 of the tank **Inside diameter**.

#### 6.4.8. Pitch paddle

A common Pitch-paddle impeller, called also Pitch-blade turbine, PBT has 4-6 blades a Pitch angle of 45 degrees, however, pitch angles of 30 and 60 degrees are also used. For this impeller, the **Width of blade** is usually 0.15 – 0.25 of the **Tip diameter**, and the **Pumping direction** is down. The **Tip diameter** is usually 0.5 to 0.7 of the tank diameter. The program allows for choosing arbitrary impeller geometry. However, more than eight blades and a blade width greater than 0.3 of the **Tip diameter** are not recommended. **Pumping direction** for Pitch angle of 90 degrees is of no importance.

#### 6.4.9. Paddle

For paddle impellers with vertical blades, the **Tip diameter** is usually 0.5 to 0.7 of the tank diameter. The number of blades is usually 2 to 6; the width of blades is 0.1 to 0.15 of the **Tip diameter**. The blades of glass-lined impellers are usually made of tubes, and in such a way as to avoid sharp angles.

#### 6.4.10. Lightnin A310

The blades of this impeller have a special hydrofoil configuration developed by the manufacturer in order to reduce energy losses. The pitch angle and geometric proportions of the impeller are fixed by the manufacturer, therefore the only variable parameters are the **Tip diameter** and the **Distance from bottom**.

### 6.4.11. Tooth-disk impellers

These impellers are mainly used for the preparation and homogenization of multi-component mixtures, such as paints, coatings, etc. They are driven by high speed drives with RPM of about 250-500; their tip velocity is usually 8-15 m/s or greater. Typically, the number of blades is 28 to 36.

### 6.4.12. De Dietrich

#### De Dietrich impeller

The blades of this glass-lined impeller are made of slightly flattened and curved tubes. The geometric proportions of the impeller are set by the manufacturer; therefore, the only variables are the **Tip diameter**, and the parameters describing the position of impeller in the tank, i.e. the **Distance from bottom**, and the **Distance between stages** for multistage systems. For the mixing of viscous media, the **Tip diameter** is usually 0.5 to 0.7 of the tank diameter.

#### De Dietrich GlasLock with Variable Flat Blades

De Dietrich glass-lined GlasLock impellers are used for various unit operations, including blending, mixing, homogenization, gas dispersion, suspension, heat transfer, crystallization, etc. They are designed with individually adjustable and removable blades, and can be used in both single and multistage applications.

#### De Dietrich GlasLock with Flat Blades

The typical pitch angles of GlasLock impellers with flat blades are:

|            |  |
|------------|--|
| 30 degrees | recommended for suspension and crystallization                         |
| 45 degrees | recommended for homogenization   |
| 60 degrees | general use for multipurpose reactors: blending, mixing, heat transfer |
| 90 degrees | recommended for dispersion, gas absorption, gas-liquid reaction        |

The width of the blades is usually about 0.1 to 0.2 of the **Tip diameter**, the length of the blades is 0.1 to 0.25 of the **Tip diameter**. The standard number of blades is three.

#### De Dietrich GlasLock with Hydrofoil Blades

GlasLock impellers with hydrofoil blades ensure low power consumption and a high pumping capacity. They are used for suspension processes, heat transfer, and chemical reactions. The standard number of blades is three. The geometric proportions of the impeller are fixed by the manufacturer; therefore, the only variables are **Pitch angle**, **Tip diameter** and the parameters describing the position of the impeller in the tank, i.e. the **Distance from bottom**, and the **Distance between stages** for multistage systems.

#### De Dietrich GlasLock with Breaker Bar Blades

GlasLock impellers with Breaker Bar Blades are mainly used for viscous products. The standard pitch angles are 45 and 90 degrees, the standard number of blades is two. For the mixing of viscous media, the **Tip diameter** is usually 0.5 to 0.8 of the tank diameter.

### 6.4.13. Glass-lined paddle impellers

This option can be used for glass lined impellers of different design and dimensions, including those manufactured by Pfaudler, Tycoon, etc. It may also be used for polymer-lined impellers. Glass lining technology requires a streamlined configuration for all the elements of the impellers; therefore, the impeller blades are usually manufactured of flattened tubes.

#### 6.4.14. Radial turbine

This option can be used for the calculations for a number of impellers produced by different manufacturers. For instance, for approximate simulation of a **INTERMIG** impeller, select **Radial turbine 2** and enter:

Pitch angle,  $\phi = 26$  degrees,  
Width of blades,  $W = 0.1$  Tip diameter;  
Length of blades,  $L = 0.1$  Tip diameter.

#### 6.4.15. Scraper agitator.

Scraper agitators are used in tanks and reactors that require intensive heat transfer to a jacket. Their application is typical the cases when it is necessary to prevent adhesion of solid particles (for instance, in crystallizers, in reactors for precipitation processes, for suspension polymerization, etc.) or formation of a high viscosity film on the heat transfer surface of the tank

Some kind of plastic, in the most cases -Teflon, is used as a material for the scrapers. The close contact of the scrapers to the tank wall is ensured due to flexibility of the plastic. For input of scraper agitator you have to use **Supplement** option of the main menu.

### 6.5. Mechanical calculations of shafts.

Data in this part of the program are used for checking the suitability of the shaft based on the calculation of the critical frequency of shaft vibrations and maximum torsion stresses in dangerous cross-sections.

Calculations are based on the shaft sizes as preliminarily estimated and entered (see below). If the results of the calculations do not confirm the shaft reliability, the program issues appropriate messages. In this case, you should modify your input, e.g., increase the cross-section of the shaft section mentioned in the message, reduce the number of revolutions, etc.

The maximum torque of the selected impellers drive is used as initial data for Torsion stress calculation. For this reason, the mechanical calculations are always performed after the calculations of the hydrodynamics. The program automatically performs a preliminary check-up of the selected drive. If the drive does not correspond to the requirements described above, the program issues appropriate messages.

The program allows for two shafts schemes that differ by position of bearings with respect to the impellers:

**Console shafts** – bearings are placed on the end of shaft opposite to the impellers. Usually the bearings are fixed on the tank cover (head) or on a special construction over the level of media. Impellers are fixed on the ‘console’ end of the shaft that is submerged in liquid media. However, the program can be applied for ‘bottom entering’ or ‘side entering’ shafts.

**Beam shafts** – bearings are placed on both ends of the shaft, and impellers are fixed between the bearings. Such shafts are described also as ‘shafts with end bearing’ or ‘shafts with submerged bearing’.

All shaft sections are assumed to be made of the same metal with identical mechanical properties. Calculations can also be performed for glass-lined shafts and shafts with other

coatings. However, applicability of the VisiMix suitability criteria is not guaranteed for these cases.

Calculations are performed for shafts with two to five impellers fixed on different distances from the bearings.

### 6.5.1. Shaft design

Four types of shafts are considered:

- A solid stiff console shaft with a constant diameter (**console regular**);
  - A stiff console shaft consisting of two parts of different diameters (**console combined**);
  - A solid stiff beam shaft with a constant diameter (**beam regular**);
  - A stiff beam shaft consisting of two parts of different diameters (**beam combined**);
- A built-up shaft with stiff couplings is regarded as a single item.

The term “stiff shaft” means that the rotational frequency of the shaft is less than the shaft’s critical (resonance) frequency of vibrations.

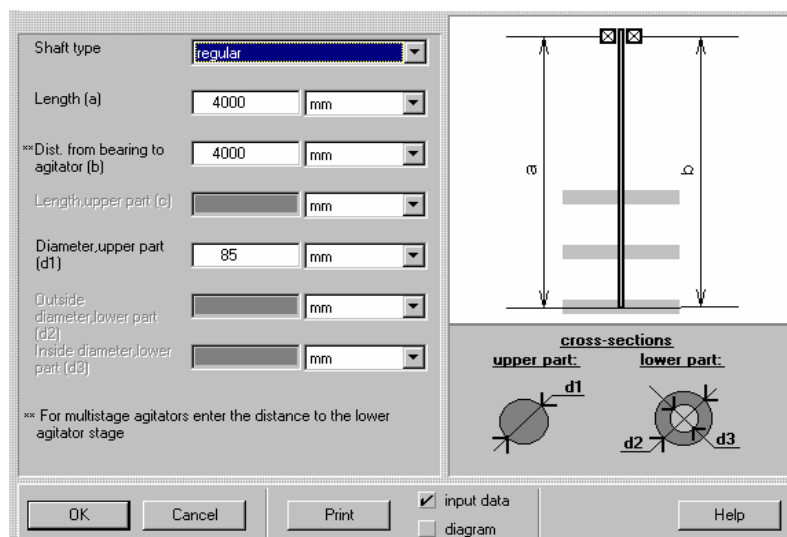


Figure 22.

**Length (a).** This parameter is related to the ‘loaded’ part of the shaft. For console shafts you enter length of the console, i.e. distance between the cross-section of the lower bearing and the end of the shaft. For beam shafts distance between bearings is entered.

A built-up shaft with stiff couplings is regarded as a single item.

**Distance between bearings (b)** is entered for console shafts only. Influence of this parameters for the regular shafts is not significant. If the distance is unknown, enter 0. In this case the program performs calculations for  $b = a/4$ , that corresponds in the most cases to the maximum reservation.

**Upper part (length, diameter).** For a combined shaft, the upper section is the section between the cross-section of the bearing and the cross-section corresponding to the change of the shaft diameter. For a regular shaft, the whole shaft is considered as the upper section.

**Diameter between bearings (d0)** is required for combined console shafts only. If this diameter is unknown, you are asked to enter 0 for approximate calculation. In this case the  $d0$  is assumed to be equal to diameter of the upper shaft section ( $d0 = d$ ).

**Lower part (outside and inside diameters).** For a shaft with a solid lower section, enter “0” as an inside diameter.

### 6.5.2. Shaft material.

Enter the properties of the shaft material: **Density, Yield strength, Young’s modulus of elasticity** (Figure 24).

Some typical values of Yield strength and Young’s modulus of elasticity for a number of commonly used materials is presented in the Table 3 (given according to Mechanics of Materials, SI Metric Edition, F. P. Beer, E. R. Johnston, Jr., McGraw-Hill, 1985, and Mixing in the Process Industries, Second Edition, N. Harnby, M. F. Edwards, A. W. Nienow, Butterworth - Heinemann, 1992).

The image shows a software dialog box titled "SHAFT MATERIAL". It has a light gray background and a thin border. At the top, the title "SHAFT MATERIAL" is centered. Below the title, there are four rows of input fields. Each row consists of a label on the left, a text input box in the middle, and a dropdown menu on the right. The first row is for "Density" with the value "7850" and units "kg/cub.m". The second row is for "Yield strength in tension" with the value "3e+08" and units "N/sq.m". The third row is for "Young's modulus of elasticity" with the value "1.93e+11" and units "N/sq.m". The fourth row is for "Pull-out factor" with the value "2". At the bottom of the dialog, there are four buttons: "OK", "Cancel", "Print", and "Help", arranged horizontally from left to right.

**Figure 23.**

The actual values of these properties depend on shaft shape and dimensions, heat treatment and composition of the material.

**Density** for different steels lies in the range 7700 - 8000 kg/m<sup>3</sup>  
For Titanium, the density is 4500 kg/m<sup>3</sup>.

**Table 1. Yield strength and Young’s modulus of elasticity**

| Material                            | Properties     |             |                             |         |
|-------------------------------------|----------------|-------------|-----------------------------|---------|
|                                     | Yield strength |             | Young modulus of elasticity |         |
|                                     | N/sq. m        | psi         | N/sq. m                     | psi     |
| Structural steel                    | 2.6 E+8        | 3.77 E+4    | 2 E+11                      | 2.9 E+7 |
| High strength low alloyed steel     | 3.5 E+8        | 5.08 E+4    | 2 E+11                      | 2.9 E+7 |
| Quenched and tempered alloyed steel | 7 E+8          | 1.02 E+5    | 2 E+11                      | 2.9 E+7 |
| Stainless cold-rolled               | 5÷11 E+8       | 7.25÷16 E+4 | 1.93 E+11                   | 2.8 E+7 |



|                          |               |               |           |          |
|--------------------------|---------------|---------------|-----------|----------|
| steel                    |               |               |           |          |
| Stainless annealed steel | 2.05÷2.75 E+8 | 2.97÷3.99 E+4 | 1.93 E+11 | 2.8 E+7  |
| Titanium                 | 5.15 E+8      | 7.47 E+4      | 1.03 E+11 | 1.49 E+7 |

### 6.5.3. Impellers data for mechanical calculations.

**Mass of impellers.** The mass of each impeller has to be entered accordingly to its position on the shaft. The numbers of impellers in this table corresponds to their numbers in the **Mixing device** input table (see par.6.4 , Figure 19).

Figure 24.

**Distance from bearing to impeller .** For console shafts enter the distance from the central cross-section of the impeller placed close to the lower end of the shaft (Impeller 1 in the Mixing device table, Figure 19) to the cross-section of the lower bearing. For beam shafts the distance from this impeller to the upper bearing is entered. Positions of other impellers are defined by the program accordingly to the previous inputs.

## 6.6. Properties & Regime

### 6.6.1. Average properties of media

Select media type - Newtonian or Non-Newtonian (Figure 25) - and provide the data based on measurements or reference data..

For the Newtonian option, enter the available viscosity value (either dynamic or kinematic), and the program will calculate the other viscosity value.

For the non-Newtonian option, calculations are based on a universal rheological model shown in this input table. If you describe the behavior of your media with a different model, we recommend approximating the rheological function with the equations adduced here.

**NOTE:**

*Contact VisiMix technical department for more information about this function.*

AVERAGE PROPERTIES OF MEDIA

Type of media  
 Newtonian  Non-Newtonian

Average density:  kg/cub.m

Dynamic viscosity:  Pa\*s

Kinematic viscosity:  sq.m/s

Constant K:  Pa\*(sec)<sup>n</sup>

Exponent n:

Yield stress:  N/sq.m

Behavior of Non-Newtonian media is approximated with the functions:

$$\tau = \tau_0 + K * \gamma^n$$

$$\mu = \tau_0 * \gamma^{-1} + K * \gamma^{n-1}$$

where  $\mu$  - dynamic viscosity, Pa\*sec;  
 $\gamma$  - shear rate, 1/sec;  
 $\tau$  - shear stress, Pa;  
 $\tau_0$  - yield stress, Pa.

OK Cancel Print Help

**Figure 25.**

Data entered in this table are used for calculation of **Hydrodynamics, Turbulence and Single-phase liquid mixing.**

**NOTE:**

*If you do not know the exact values, enter approximate ones. For turbulent regimes, small errors in estimation of viscosity are usually not important. For density, accuracy is more important because mixing power is proportional to the density value.*

**6.6.2. Heat transfer**

**Heat transfer properties of the media**

Heat transfer calculations and modeling of heating/cooling dynamics is performed with respect to the change in the physical properties of the media as a function of the temperature. Calculations are based on approximate empirical correlations and on the values of properties available for any single temperature value. These correlations differ for water solutions and organic substances. Specify the **Media (Water solution or Organic substance)** and enter the values of the media properties and the corresponding temperatures (Figure 26). See APPENDIX 3 for reference data on the properties.

**Chemical reaction data and regime**

The program performs simulation of temperature regime for chemical reaction with heat release or consumption based on the kinetic and thermodynamic data entered in this table (Figure 27).

HEAT TRANSFER PROPERTIES OF THE MEDIA

Media Organic substance

| PARAMETER         |  | TEMPERATURE                        |  |
|-------------------|--|------------------------------------|--|
| Average density   | <input type="text" value="1100"/> kg/cub.m | <input type="text" value="20"/> °C |  |
| Dynamic viscosity | <input type="text" value="0.015"/> Pa*s    | <input type="text" value="20"/> °C |  |
| Specific heat     | <input type="text" value="3200"/> J/(kg*K) | <input type="text" value="20"/> °C |  |
| Heat conductivity | <input type="text" value="0.36"/> W/(m*K)  | <input type="text" value="20"/> °C |  |

**Figure 26.**

HEAT TRANSFER. CHEMICAL REACTION DATA AND TEMPERATURE LIMITS

Will you enter reaction kinetics? NO

Arrhenius constant  J/(mol\*sec)

Energy of activation  J/mol

Lower limit of temperature  °C

Upper limit of temperature  °C

Heat effect of reaction  J/mol

Reaction velocity constant K is described by Arrhenius equation :

$$K = A \exp(-E / RT) ,$$

where

A is Arrhenius constant ,  
 E is energy of activation ,  
 $R = 8.314 \text{ J} / (\text{mol}^{\circ}\text{K}) = 1.986 \text{ Btu} / (\text{lb}^{\circ}\text{mol}) / ^{\circ}\text{F}$   
 is universal gas constant ,  
 T is absolute temperature .

**Figure 27.**

Choose **YES** if you want to enter the data on chemical reaction, and the corresponding boxes in the table will be activated. Choose **NO** if the exact kinetic data or the **Heat effect of reaction** is not known. In this case you will be asked to enter the available approximate data on the **Average rate of heat release (consumption)** or **Heat release (consumption) for a batch** in the input tables that follow. In all cases, specify the range of the process temperatures by entering the **Lower** and **Upper limit of temperature** for the media.

#### **Heating/cooling agent. Convection in jacket**

The program performs heat transfer calculations and modeling for tanks with all commonly used heating/cooling agents. Choose the heating/cooling agent (Figure 28) and enter the **Inlet temperature** and **Inlet flow rate** for the lower jacket section. Enter the **Inlet flow rate** for the upper jacket section if you have selected a 2-section jacket with the sections connected **in parallel** for the current project.

HEATING / COOLING LIQUID AGENT IN JACKET.

Heating/cooling agent:

Inlet temperature:  °C

Flow rate of heat transfer agent in lower jacket:  cub.m/h

Flow rate of heat transfer agent in upper jacket:  cub.m/s

OK Cancel Print Help

---

Operating temperature range: 5 - 204°C [41 - 400°F]  
 Properties of the agent  
 density...1000 kg/m<sup>3</sup> [62.4 lbm/ft<sup>3</sup>]  
 specific heat...4190 J/(kg\*K) [1.01 Btu/(lbm\*°F)]  
 thermal conductivity...0.603 W/m\*K [0.348 (Btu\*ft)/(h\*°F)]  
 dynamic viscosity at 100°C(212°F)...0.000284 Pa\*sec [0.284 cP]

**Figure 28.**

The practical range of operating temperatures and properties of the selected agent are shown in the lower part of the table. If the range of the process temperatures you have previously entered in HEAT TRANSFER. CHEMICAL REACTION DATA AND TEMPERATURE LIMITS input table falls partly or entirely outside the range of operating temperatures for the selected liquid agent, VisiMix issues a message indicating that the selected agent does not correspond to the indicated range of the process temperatures. In this case, select another heating agent or modify the process temperature range.

**NOTE:**

*The liquid agent velocity in inlet/outlet pipes of the jacket does not usually exceed 5 m/s.*

**Heating agent. Condensation in jacket**

The program allows for modeling heat transfer for tanks with a number of widely used vaporous heating agents (VA). Choose the required **Heating agent** and the pressure (Figure 29).

VAPOROUS AGENT IN JACKET - CONDENSATION

Heating agent:

Inlet temperature:  °C

OK Cancel Print Help

---

Boiling temperature : 133°C [271°F]  
 Heat of vaporization : 2166000 J/kg [931 Btu/lbm]

**Figure 29.**

The values of **Boiling temperature** and **Heat of vaporization** for the selected agent are shown at the bottom of the table. Enter the **Inlet temperature** of the selected agent in accordance with this data. If the **Lower limit of temperature** of the media you have previously entered in HEAT TRANSFER. CHEMICAL REACTION DATA AND TEMPERATURE LIMITS input table is so low as to cause freezing of the agent, VisiMix issues a message indicating that the selected agent does not correspond to the indicated range

of process temperatures. In this case, select another heating agent or modify the process temperature range.

### **Continuous flow process. Heat transfer specific data**

The program allows for following the change in the temperature and concentrations of reactants starting from any set of initial conditions according to your input (Figure 30). All characteristics of the inlet flow, i.e. the flow rate, temperature, concentrations of reactants, and the properties are assumed to remain constant within the simulation period.

| CONTINUOUS FLOW PROCESS. HEAT TRANSFER SPECIFIC DATA. |               |
|---|---------------|
| Initial temperature in the tank                       | 30 °C         |
| Temperature of inlet flow                             | 20 °C         |
| Inlet flow rate                                       | 3 cub.m/h     |
| Initial concentration of reactant A in the tank       | 3.6 mol/liter |
| Density of inlet flow                                 | 1100 kg/cub.m |
| Initial concentration of reactant B in the tank       | 0 mol/liter   |
| Specific heat of inlet flow                           | 4100 J/(kg*K) |
| Concentration of reactant A in the inlet flow         | 3.6 mol/liter |
| Average rate of heat release (consumption)            | W             |
| Concentration of reactant B in the inlet flow         | 3.2 mol/liter |
| Simulation time                                       | 4 h           |

**Figure 30.**

**Simulation time.** Enter the real time for the process stage you wish to simulate. It is recommended to start with the time equal to the mean residence time of the media in the tank determined as the quotient of the **Volume of media** by **Inlet flow rate**. The program does not perform simulation for the **Simulation time** values greater than the tenfold value of the mean residence time. If you need to perform simulation for longer processes, use step-by-step procedure. If there are two or more inlet flows, estimate and enter average values for the sum of the flows – the total inlet flow rate, the average density and specific heat conductivity, temperature, concentrations of reactants - with respect to the parameters of each flow.

**Average rate of heat release (consumption).** Enter a positive number for heat release and a negative number for heat consumption.

#### **NOTE:**

*You must enter this parameter if you chose not to enter the data on reaction kinetics in **HEAT TRANSFER. CHEMICAL REACTION AND REGIME** input table.*

### **Semibatch process. Heat transfer specific data**

The data entered in this input table (Figure 31) is used for following the change in temperature and concentrations of reactants starting from any set of initial conditions. All characteristics of the inlet flow – the flow rate, temperature, concentrations of reactants, and the properties are assumed to remain constant during the time of the reactants inlet (**Duration of reactants inlet**).

SEMIBATCH PROCESS. HEAT TRANSFER SPECIFIC DATA.

|   |  |  |  |
|---|--|--|--|
| Initial temperature in the tank                 | <input type="text" value="60"/> °C       | Final volume of media                  | <input type="text" value="1.2e+04"/> l     |
| Temperature of inlet flow                       | <input type="text" value="20"/> °C       | Duration of reactants inlet            | <input type="text" value="1200"/> s        |
| Initial concentration of reactant A in the tank | <input type="text" value="0"/> mol/liter | Density of inlet flow                  | <input type="text" value="1150"/> kg/cub.m |
| Initial concentration of reactant B in the tank | <input type="text" value="0"/> mol/liter | Specific heat of inlet flow            | <input type="text" value="3100"/> J/(kg*K) |
| Concentration of reactant A in the inlet flow   | <input type="text" value="0"/> mol/liter | Heat release (consumption) for a batch | <input type="text"/> J                     |
| Concentration of reactant B in the inlet flow   | <input type="text" value="0"/> mol/liter | Simulation time                        | <input type="text" value="3000"/> s        |

**Figure 31.**

**Simulation time.** Enter the real time for the process stage you wish to simulate. The program does not perform simulation for **Simulation time** longer than fivefold value of **Duration of reactants inlet** (i.e., for cases when the **Simulation time** value is more than 5 times greater than the **Duration of reactants inlet**). If you need to perform simulation for longer processes, use step-by-step procedure.

If there are two or more inlet flows, estimate and enter average values for the sum of the flows – the total inlet flow rate, average density and specific heat conductivity, temperature, concentrations of reactants - with respect to the parameters of each flow.

**Final volume of media.** Enter the maximum volume of the media in the tank after the reagents have been injected. The **Volume of media** entered in one of the TANK input tables is regarded as the initial volume of media. The flow rate of the inlet flow is estimated by VisiMix as a ratio of the difference between the **Final volume of media** and the **Volume of media** to the **Duration of reactants inlet**.

**Heat release (consumption) for a batch.** This is the total heat release or consumption for a batch. The entire heat is assumed to be released (or consumed) during the reactants inlet. Enter a positive number for the heat release and a negative number for the heat consumption.

**NOTE:**

*You must enter this parameter if you chose not to enter the data on reaction kinetics in HEAT TRANSFER. CHEMICAL REACTION AND REGIME input table.*

**Batch process. Heat transfer specific data**

The program allows for following the change in the temperature and reactants concentrations starting from any set of initial conditions according to your input (Figure 32).

BATCH PROCESS. HEAT TRANSFER SPECIFIC DATA.

Initial temperature in the tank  °C

Initial concentration of reactant A in the tank  mol/liter

Initial concentration of reactant B in the tank  mol/liter

Simulation time  h

OK Cancel Print Help

**Figure 32.**

**Simulation time.** Enter the real time for the process stage you wish to simulate.

**Fixed temperature regime**

Enter the **Media temperature** (Figure 33) which is the only additional parameter needed for heat transfer calculations in the **Fixed temperature regime** option.

HEAT TRANSFER  
MEDIA TEMPERATURE  
FOR FIXED TEMPERATURE REGIME

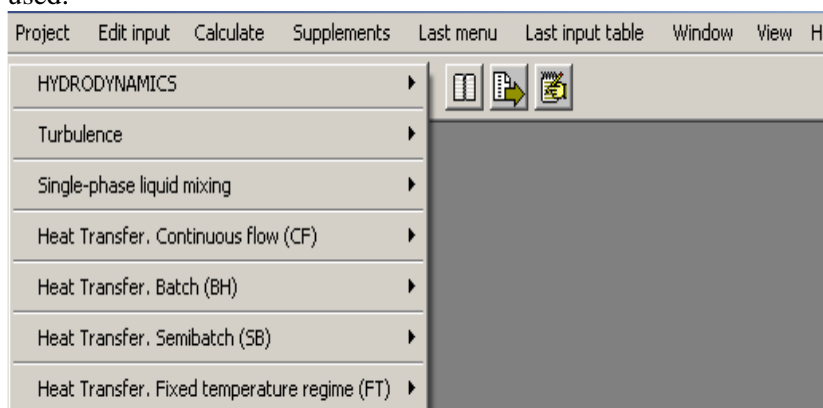
Temperature  °C

OK Cancel Print Help

**Figure 33.**

## SECTION 7. CALCULATION SECTIONS.

The **Calculate** menu opens access to calculation and modeling options of the program (Figure 34). It opens a few sub-menus related to the main sections of the program. Each of these sub-menus opens access to a group of flow- or process-related parameters defined as a result of modeling. For a short-cut access to parameters of the same group the **Last menu** option of the main menu is used.

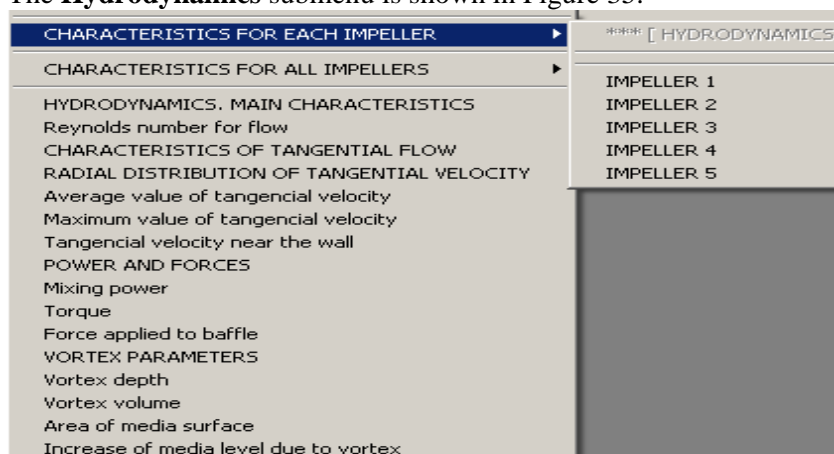


**Figure 34**

Description of the calculated parameters is presented in the Section 8 of the Guide and in the **Help** section of the program.

### 7.1. Hydrodynamics

The **Hydrodynamics** submenu is shown in Figure 35.



**Figure 35.**

This option activates the mathematical simulation of hydrodynamics with respect to the design of the mixing unit and average media properties. Simulation is based on the solutions of the Reynolds equation for a turbulent flow approximated with polynomial expressions.

The conditions of unambiguity (including boundary conditions) are estimated using the equations for energy and momentum equilibrium, and practical data on mixing. In particular, experimental data on the hydraulic resistance of tank walls and bottom, baffles and blades of different impellers installed in the tank are used. The system of equations takes into account also interaction of flows created by different impellers as a function of impeller geometry and distance between them. An extensive experimental material on circulation flow in tanks with different combinations and relative positions of impellers has been accumulated and used for adjusting the equations used in this section.

The **Hydrodynamics** menu includes general flow and mixing parameters such as power, torque, vortex characteristics, etc.



It includes also the additional sub-menus that provide parameters for each of the impellers. The sub-menu **CHARACTERISTICS OF EACH IMPELLER** (Figures 32) provides a complete set of hydrodynamic data for each impeller. Selection of an impeller in this sub-menu opens a table (Figure 33) that includes data on geometry and tip velocity, and also the main calculated parameters such as impeller power number or circulation flow created by the impeller.

HYDRODYNAMICS. CHARACTERISTICS FOR EACH IMPELLER : IMPELLER 1

| Parameter name                  | Units | Value        |
|---------------------------------|-------|--------------|
| Impeller type                   |       | disk turbine |
| Tip diameter                    | m     | 0.600        |
| Pitch angle of blades           | rad   | 1.57         |
| Tip velocity                    | m/s   | 3.46         |
| Impeller Re number              |       | 6.93e+05     |
| Mixing power                    | W     | 109          |
| Power number                    |       | 0.216        |
| Torque                          | N*m   | 9.43         |
| Force applied to impeller blade | N     | 5.93         |

Figure 33.

The sub-menu **CHARACTERISTICS OF ALL IMPELLERS** (Figure 34) is used in order to compare individual parameters of all the impellers installed in the tank.

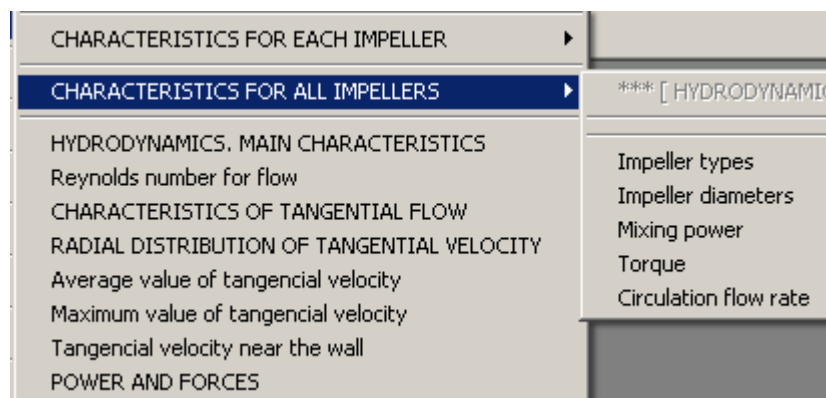


Figure 34.

Selection of a parameter in this sub-menu opens a table (Figure 35) that includes the corresponding values for each impeller.

The screenshot shows a window titled "[Guide1] - Torque" with the following table:

| TORQUE         |       |       |
|----------------|-------|-------|
| Parameter name | Units | Value |
| Impeller 1     | N*m   | 13.9  |
| Impeller 2     | N*m   | 9.02  |

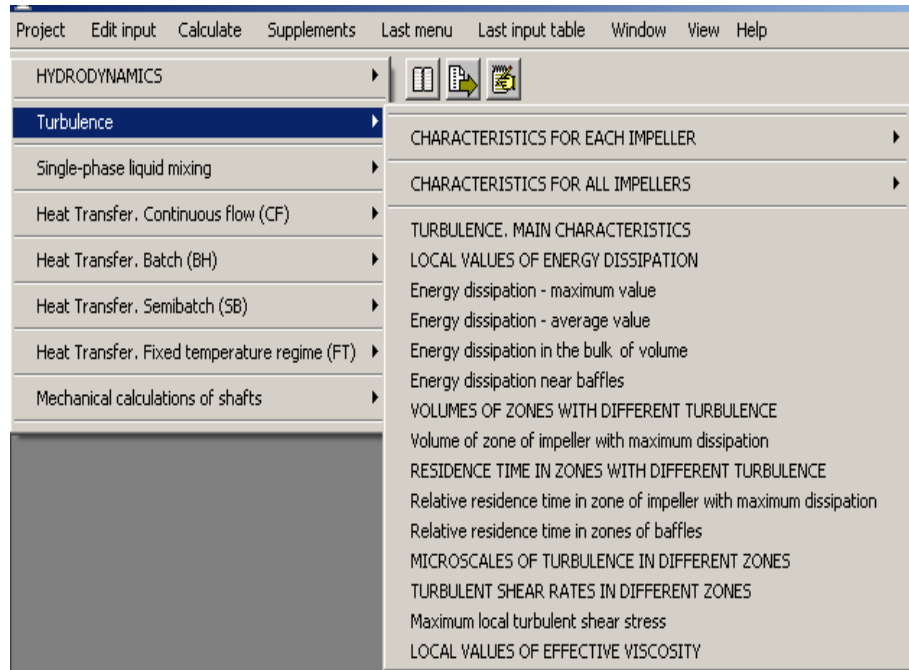
At the bottom right of the window, it says "For HELP press F1".

Figure 35

This menu serves for evaluation of relative input of each impeller into mixing and provides data for improvement of the mixing device.

## 7.2. Turbulence

The **Turbulence** menu is shown in Figure 36.



**Figure 36.**

The intensity of turbulence is evaluated in terms of rates of the turbulent dissipation of energy, which is equivalent to the local specific power per 1 kg of media.

The entire mixing volume is assumed to consist of a few zones with different source and level of local micro-scale turbulence – zones of vortices behind the blades of each impeller, jets formed by each impeller, the bulk volume and vortex areas behind baffles. This section of the program provides estimates for the energy dissipation values for these zones. Evaluations of turbulent energy dissipation rates are based on the Kolmogoroff model of turbulence and on the distribution of the flow velocities defined in the stage of hydrodynamic modeling..

Non-uniformity of distribution of energy dissipation is important for micro-mixing, emulsification, and crystallization. A high degree of non-uniformity has a positive effect on emulsification and a negative effect on crystallization. For single-phase mixing and suspension processes, a more uniform distribution of energy is preferable.

### **NOTE:**

*Turbulence parameters for Anchor and Frame impellers have never been determined experimentally.*

The menu **Turbulence** includes additional sub-menus that provide parameters of local turbulence and shear around each of the impellers. The sub-menu **CHARACTERISTICS OF EACH IMPELLER** opens a list of the impellers. Selection of an impeller in this sub-menu opens an additional sub-menu with two options. By selection of the first option – **General data** – you will get a table (Figure 37) that includes main calculated parameters such as maximum local values of turbulent dissipation, microscales of turbulence and shear rates for the vortex zones around the blades of the selected impeller. The second option - DISSIPATION OF ENERGY

AROUND THE IMPELLER - provides a graph obtained as a result of modeling of transfer and extinguishing of turbulence in the jet created by the impeller (Figure 38).

TURBULENCE. CHARACTERISTICS FOR EACH IMPELLER : IMPELLER 1

| Parameter name                                      | Units | Value    |
|---|-------|----------|
| Maximum energy dissipation near the impeller blades | W/kg  | 80.6     |
| Volume of zone of maximum dissipation               | cub.m | 0.0300   |
| Microscale of turbulence near the impeller blades   | m     | 0.000111 |

For HELP press F1

Figure 37

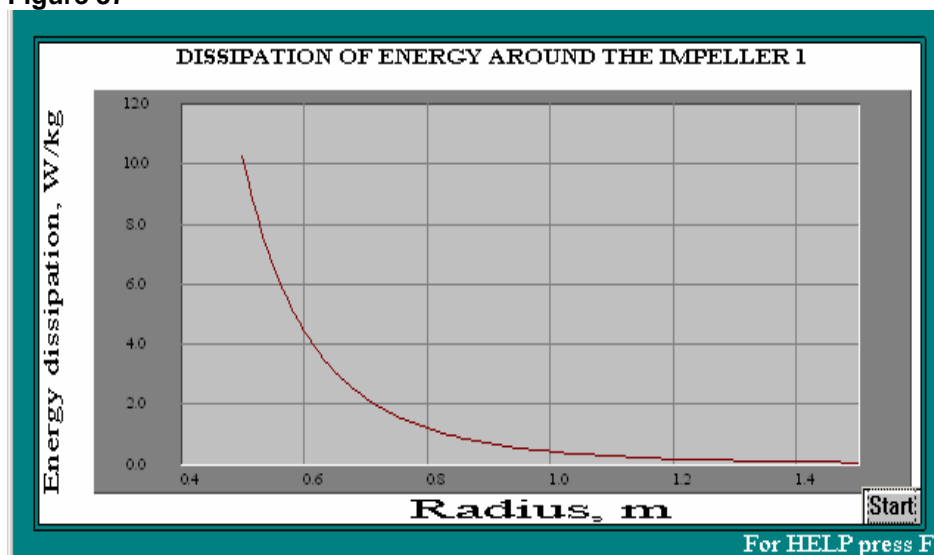


Figure 38

The sub-menu **CHARACTERISTICS OF ALL IMPELLERS** (Figure 39) allows to compare individual parameters of all the impellers installed in the tank.

MAXIMUM ENERGY DISSIPATION NEAR THE IMPELLER BLADES  
 VOLUME OF ZONE OF MAXIMUM DISSIPATION  
 MICROSCALE OF TUBULENCE NEAR THE IMPELLER BLADES  
 TURBULENT SHEAR RATE NEAR THE IMPELLER BLADES  
 EFFECTIVE VISCOSITY

Figure 39

The output table of **TURBULENT SHEAR RATE NEAR THE IMPELLER BLADES** is presented as an example in the Figure 40.

| MAXIMUM ENERGY DISSIPATION NEAR THE IMPELLER BLADES |       |       |
|---|-------|-------|
| Parameter name                                      | Units | Value |
| Impeller 1  | W/kg  | 80.6  |
| Impeller 2  | W/kg  | 34.3  |

For HELP press F1

**Figure 40**

The main menu of Turbulence (**Figure 36**) and the output tables related to impellers include also Effective viscosity. For non-Newtonian liquids the Effective viscosity is based on rheological constants that are entered into input table Average properties of media (**Figure 25**). It is a function of turbulent shear rate and is defined separately for zones with different turbulence. For Newtonian liquids the Effective viscosity is equal to Dynamic viscosity.

### 7.3. Single-phase liquid mixing

This menu option (**Figure 41**) is used for mathematical simulation of mixing of two liquids that are soluble in each other.

| SINGLE-PHASE MIXING. MAIN CHARACTERISTICS |
|---|
| Macromixing time                          |
| Mean period of circulation                |
| Characteristic time of micromixing        |

**Figure 41.**

**Note.** *In the current version this option can be used for the baffled tanks only.*

This option provides a set of data for estimation of the minimum mixing time required for the preparation of a uniform mixture. The mathematical modeling of macro-mixing is based on a numerical solution for a non-stable state convective transport of a solute (tracer). The system of differential equations is simplified in accordance with experimental data on the general flow pattern in mixing tanks and takes into account number, designs and positions of the impellers. The simulation is performed for liquids with no significant difference in density and viscosity.

Micromixing phenomena are analyzed separately (See **Characteristic time of micromixing**), the final evaluation takes into account distribution of circulation and local turbulence around each impeller.

### 7.4. Heat transfer

#### 7.4.1. General

VisiMix DI performs two kinds of heat transfer calculations:

1. Simple calculation of heat flux and heat transfer coefficients for a fixed temperature of the media;

2. Simulation of dynamic temperature regimes of mixing tanks and reactors with respect to reaction kinetics and heat effect.

The modeling of the heat transfer includes calculating media-side heat transfer coefficients, jacket-side heat transfer coefficients and the thermal resistance of the tank wall.

Calculations of the media side heat transfer in tanks with various impellers are based on a physical model which takes into account heat transport in turbulent boundary layer and energy distribution in the flow (see **Review of Mathematical Models**).

VisiMix DI has been developed for the turbulent regime of mixing in the tank. However, for the user's convenience, Heat transfer calculations are performed also for lower Reynolds number values.

Heat transfer in jackets is calculated using known empirical correlations, which are also referred to in the **Review of Mathematical Models**. The program calculates also the thermal resistance of the tank wall.

### **Heat transfer devices (HTD)**

Calculations are performed for tanks with outside heat transfer devices - **conventional jackets**, **half-pipe coil jackets**, and **embossed/dimpled jackets**. The jacket may consist of **one** section (if there is one section only, the program regards it as "Lower") or **two** separate sections ("Lower" and "Upper").

The position of the sections, their dimensions and heat transfer areas may vary. **Lower section** may cover the tank bottom.

### **Connection of two jacket sections**

The sections may be connected "**in series**" and "**in parallel**".

#### **Connection in parallel:**

Liquid heat transfer agent (**LA**) inlets are placed in the lower cross-section of each section, the outlets - in the upper cross-section of each section; the inlet temperature of **LA** is the same for both sections; you should estimate and enter the flow rates for **LA**.

Condensing (vaporous) heat transfer agent (**VA**) - steam, Dowtherm vapor, etc. - inlets are placed in the upper cross-section of each section, the outlets of condensate - in the lower cross-section of each section; the inlet temperature and pressure of **VA** are the same for both sections.

#### **Connection in series:**

Liquid heat transfer agent (**LA**) inlet is placed in the lower cross-section of the lower section; **LA** outlet is placed in the upper cross-section of the lower section; the inlet of the upper section placed in its lower cross-section is connected to the outlet of the lower section; the outlet of the **LA** is placed in the upper cross-section of the upper jacket section. The flow rate of **LA** is the same in both jacket sections. Enter the inlet temperature of **LA** for the lower section; the inlet temperature for the upper section is assumed to be equal to the temperature of **LA** at the outlet of the lower section.

Condensing (vaporous) heat transfer agent (**VA**) - steam, Dowtherm vapor, etc. - inlets are placed in the upper cross-section of the upper section, the outlet of condensate and steam (vapor) of the upper section is placed in its lower cross-section and connected to the inlet pipe placed in the upper cross-section of the lower section. The outlet of condensate is placed in the lower cross-section of the lower section. The steam (vapor) pressure in both sections is assumed to be the same, the inlet temperature for the lower section is assumed to be equal to the saturation temperature.

### **Heat transfer agents (HTA)**

The program performs calculations of heat transfer in heat transfer devices for two kinds of HTA - liquid agents (**LA**) and condensing steam or organic vapors (**VA**). There is no need to enter the physical properties of heat transfer agents: you must only select an appropriate agent and enter the inlet conditions: the inlet temperature for **LA**, the inlet temperature and pressure for **VA**. The required properties of heat transfer agents are retrieved by the program from its database. The program includes also subprograms for approximate calculations of temperature-dependent physical properties of heat transfer agents.

### Properties

Simulation of temperature regimes is performed with respect to the change in physical properties of liquids (the media and **HTA**) as a function of the temperature. For this purpose, the program includes algorithms and sub-programs for approximate calculations of temperature functions of the density, viscosity, specific heat and heat conductivity of liquids, which are based on a single value of the property and the corresponding temperature. The calculation methods for the viscosity and specific heat capacity are similar to the graphical method proposed by Lewis, W. K. and L. Squires for viscosity (see J. Perry, Chemical Engineering Handbook, pp. 3-281,282, Fig. 3-50). Different functions are used for water solutions and organic substances. You will therefore be asked to specify the media in addition to the values of the properties.

#### **NOTE:**

*The methods for calculating physical properties are approximate. Their accuracy is sufficient for heat transfer calculations, but they are not recommended for general use. The table of properties of the most frequently used water solutions and organic solvents is accessible through HEAT TRANSFER PROPERTIES OF THE MEDIA input table. It will help you to approximately estimate the initial data for heat transfer calculations.*

### Simulation of temperature regime. General information

The main menu includes three Heat Transfer options related to the main process regimes - Continuous flow (**CF**), Batch (**BH**) and Semibatch (**SB**). Each of them includes two submenus according to the type of the heat-transfer agent and the process in the heating/cooling device (HTD). The **Liquid agent (LA)** option is used to calculate heating or cooling in the tank with a liquid heating agent (LA). The heat transfer mechanism may correspond to free convection or forced convection in laminar or turbulent flow conditions. In the course of the simulation, the program estimates the flow and heat transfer regime and selects the appropriate correlation.

Before starting the simulation by selecting a parameter in the corresponding submenu of Heat Transfer options of **Calculate**, you will be asked to fill in the appropriate input tables of initial data according to a particular mixing case. However, for all process regimes it is necessary to enter the **Lower and Upper limits of temperature** of the media in the tank in order to define the range for the simulation. It is also necessary to enter the **Simulation time**.

If the calculated temperature (**Media temperature**) falls outside the prescribed temperature limits, the program stops calculation and issues an appropriate message, indicating the time when this occurs. To obtain more information about the process, enter a new value for the **Simulation time**, which must be lower than the one indicated in the message in the corresponding HEAT TRANSFER. SPECIFIC DATA input table for CF, BH and SB processes.

The results obtained with heat transfer calculation options are displayed mainly as graphs; the parameter you selected is presented as a function of time within the simulation period. To present graphs as tables, use the **Report** option (see par. 5.8 above).

The simulation is based on the common equations of heat equilibrium with respect to heat capacity of the media and the tank. You select the tank material in TANK SHELL CHARACTERISTICS input table, and the properties of the material will be retrieved from the VisiMix database. You may enter the tank mass according to the tank drawings. If the exact mass is not known, VisiMix calculates it.

## Chemical reaction with heat release or consumption

The program simulates simple heating or cooling in tanks, and also temperature regimes of chemical reactors. Calculations are performed with respect to a second-order single-phase chemical reaction:



where  $Q_r$  is the specific heat release/consumption of the process.

You may enter kinetic data and heat effect of the reaction in the HEAT TRANSFER. CHEMICAL REACTION DATA AND TEMPERATURE LIMITS input table. The heat release is calculated as a function of the current concentrations and temperature according to the Arrhenius equation. If the kinetic and thermodynamic constants for the reaction are not available, the program may perform calculations based on the average heat release/consumption value you entered. This option may also be useful for simulating temperature regimes of heterogeneous reactions with total heat release value based on experimental data.

### 7.4.2. Modeling of temperature regimes

VisiMix allows you to perform heat transfer calculations for the following types of processes: Continuous Flow (CF), Batch (BH), Semibatch (SB), and for Fixed temperature regime (FT). For each of these processes you may perform simulation for the case of liquid heat transfer agent (LA) in jacket, and for the case of vaporous heat transfer agent (VA) in jacket. The menu of one of the **Heat Transfer** options in **Calculate** is shown in Figure 42.

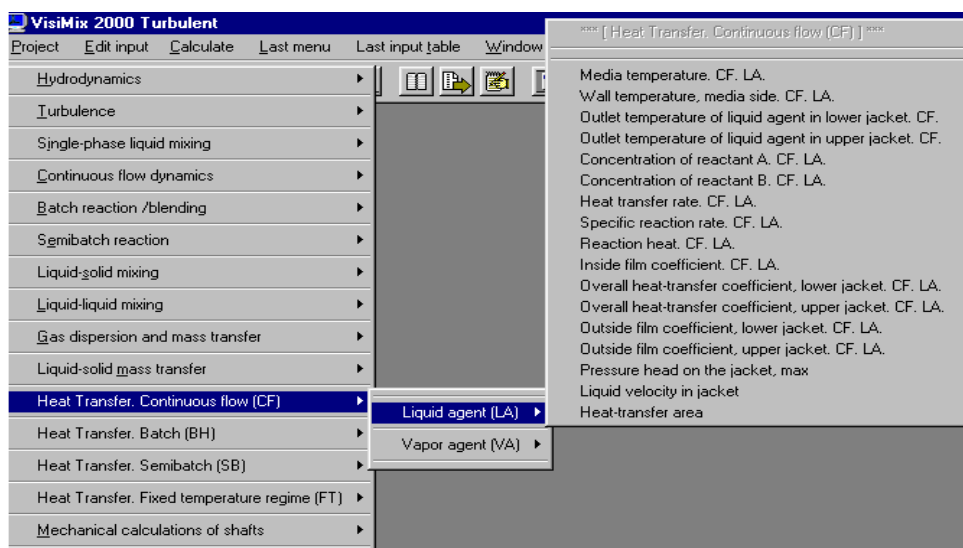


Figure 42.

### Continuous flow process - CF

This option provides mathematical modeling of the dynamics of a continuous flow mixing tank with a heat transfer device. The process eventually reaches a steady-state regime. Granted the sufficient simulation time, the final results obtained in the simulation will represent the steady-state parameters.

In this case, the **Heat transfer area** in the tank is assumed to be constant and is calculated according to the **Volume** or **Level of media** in the tank.

You select a starting point of the simulation, i.e. the media temperature and the concentrations of the reactants. The simulation, including the simulation of transition regimes, can be started from any reactor state.

### **Batch process - BH**

This option provides mathematical modeling for Batch heating/cooling of the tank or Batch chemical reactor with a heat transfer device. In this case, the **Heat transfer area** in the tank is assumed to be constant and is calculated according to the **Volume** or **Level of media** in the tank.

In the case of a chemical reaction, both reactants are supposed to be loaded and distributed in the reactor before the simulation starts.

### **Semibatch process - SB**

This option provides mathematical modeling of Semibatch reactors with heat transfer devices. It is assumed that the solution of reactants A and B is loaded into the tank in the beginning of the process. The volume of the solution is the minimum volume of the media in the tank and corresponds to the value of **Volume of media** you entered in the TANK input table. At moment "0", the loading of the solution of reactants A and B into the tank begins. The solution is loaded at a constant flow rate until the volume of the media becomes equal to the **Final volume of media** you entered in the SEMIBATCH PROCESS. HEAT TRANSFER SPECIFIC DATA input table. You must also specify the **Duration of reactants inlet**, **Density**, **Specific heat capacity** and **Temperature of inlet flow**. The volume flow rate of the inlet flow during the inlet period is calculated as

**(Final volume of media - Volume of media) / Duration of reactants inlet**

The current values of the **Volume of media** in the tank and of the **Heat-transfer area** of heat transfer devices are calculated as functions of time and with respect to the flow rate of the inlet flow.

If kinetic data and **Heat effect of reaction** have been previously entered, VisiMix calculates heat release with respect to the current concentrations of the reactants and temperature. If the **Heat release/consumption for a batch** was entered instead of the **Heat effect of reaction**, the reaction heat release (consumption) is assumed to be constant during the reactants inlet, and to become **zero** after the end of the inlet period.

### **Fixed temperature regime - FT**

This option allows for performing common heat transfer calculations of the tank for a given single set of conditions, i.e. the volume and temperature of the media. No additional data on the process, such as reaction kinetics or heat release, are necessary. All program output in this case is given in the form of tables.

Fixed temperature calculations are the most simple and fast of all VisiMix Heat Transfer modeling options. You may use this option not only for calculating steady-state heat transfer rates for fixed conditions, but also in combination with one of the simulation options as the first stage for a preliminary selection of the equipment, the heat transfer agent, its inlet temperature and flow rate, etc. Another possible application is obtaining output parameters for any desired point on the process simulation curves by reading the **Media temperature** at this time coordinate from the graph **Media temperature vs. time**, and entering it in the FIXED TEMPERATURE. HEAT TRANSFER SPECIFIC DATA input table.

All output parameters are accessed via the **Calculate** option in the main VisiMix menu. To invoke the **Help** section corresponding to the active output window, press **F1**.



## SECTION 8. OUTPUT PARAMETERS.

### 8.1. Hydrodynamics

#### 8.1.1. Reynolds numbers.

Visimix DI provides two values of Reynolds number.

The **Impeller Re number** is defined for each impeller accordingly to the accepted practice, i.e. as a function of number of revolutions of the shaft and tip diameter of the corresponding impeller:

$$Re = D^2 N / \nu$$

Here D – tip diameter of the selected impeller, m,

N - number of revolutions of the shaft, 1/s,

$\nu$  - kinematical viscosity of media, sq.m/s.

The Reynolds number for flow is defined as a hydrodynamic characteristic of flow in the mixing tank, by its physical meaning it is the same as the Re numbers for flows in pipes, channels, etc. This value is based on the average velocity of the flow and radius of the tank.

The lower limit of a turbulent regime corresponds to the Reynolds number value of about 1500. Significant changes in hydrodynamics are observed when the Reynolds number value is lower than 1000. The current version of VisiMix does not perform calculations for Reynolds number values lower than 1500.

#### 8.1.2. Radial distribution of tangential velocity

This graph represents the average radial profile of tangential velocity. Numerous measurements have shown that in a well developed turbulent flow, local profiles of tangential velocity in mixing tanks are close to the average one at almost any height, except for the impeller area.

#### 8.1.3. Average value of tangential velocity

This parameter represents the volume average value for tangential velocity defined by integration.

#### 8.1.4. Maximum value of tangential velocity.

This parameter represents the highest point of tangential velocity profile shown in the graph of RADIAL DISTRIBUTION OF TANGENTIAL VELOCITY.

#### 8.1.5. Tangential velocity near the wall

This is the height average tangential velocity near the wall outside the boundary layer. Velocity degradation in the boundary layer is beyond the scope of VisiMix modeling.

#### 8.1.6. Mixing power

This parameter is calculated as a sum of calculated power consumption values of all impellers. The calculation of power value for each impeller is based on the results of mathematical modeling of velocity distribution and on experimental resistance factor values for blades of different configurations. The data on average density and viscosity, which have been previously entered into the system, are used. If the calculated mixing power exceeds 70% of the motor power rating you have previously entered into the system, the warning “*Mixing power is too high for your drive*” is issued.

The 30% reservation accepted in VisiMix is based on practical experience. It takes into account usual level of energy losses in electric drives with *mechanical speed reducers (gyres)*. If the speed reduction is performed using electrical or electronic speed control devices, selection of the drive has to be based on the rated torque moment of the low speed shaft that must be included in the technical characteristic of the drive. The recommended 30% reservation in this case must be related to the calculated **Torque value**

#### **8.1.7. Torque**

This parameter represents the value for the torque imparted by the mixing device to the media, and applied by flow to the drive and to the mixing tank supporting detail. It is defined as a sum of torque moments applied by each impeller on the shaft. The value does not include additional resistance or friction moments in bearing, sealings and gearboxes.

#### **8.1.8. Force applied to baffle**

This parameter represents the force that is applied to the baffle as a result of flowing it over by the tangential flow. Direction of the force – normal to tank radius, radius of application - the baffle axis.

#### **8.1.9. Vortex depth**

The phenomenon of vortex formation is mainly significant for tanks without baffles. In baffled tanks, the vortex is usually small and can be disregarded. However, at high RPM values, the vortex may be quite large. It is often unstable, and its depth and shape may change considerably. In these cases, calculated vortex parameters should be regarded as estimates only.

If the vortex is too deep and reaches the impeller, unstable gas caverns may form around the impeller blades. The resulting shaft vibrations may reduce the reliability of the equipment. Gas insertion into the media may also occur. VisiMix lets you know if such conditions are expected. If influence of the vortex is significant, the program displays the corresponding message.

#### **8.1.10. Vortex volume**

Volume of the vortex is defined by integration.

This value must be taken into account in the continuous flow processes for calculating mean residence time of media. In particular, it is important for small scale continuous flow equipment.

#### **8.1.11. Area of media surface**

This is the area of the media surface, calculated with respect to deformation of surface due to vortex formation.

#### **8.1.12. Media level increase due to vortex formation**

Due to vortex, there is an increase in the level of media near the tank wall. In some cases, this may cause media overflow.

#### **8.1.13. CHARACTERISTICS FOR EACH IMPELLER.**

##### **Tip velocity.**

It is defined by multiplying angular velocity(in radian per second) by radius of the impeller. It is different for impellers of different diameter.

## Power

The Power for each impeller is defined by multiplying of Torque of the impeller by angular velocity of the mixing device (in radian per second).

## Power number

This parameter is calculated for each impeller. It represents the  $N_p$  coefficient in the equation

$$P = N_p \rho n^3 d^5$$

where

$P$  is the mixing power of the impeller, W;

$\rho$  is average density of the media, kg/cub. m;

$n$  is rotational speed of mixing device, 1/s;

$d$  is the impeller diameter, m.

VisiMix first calculates the mixing power for each impeller, and then  $N_p$  values are calculated using the formula given above.

## Torque.

Torque, or driving moment of each impeller is defined as a result of solving the main equation system describing momentum equilibrium. Calculation is based on experimental values of flow resistance factors for blades of different geometry. The torque value strongly depends on pitch angle of the impeller and radial distribution of tangential velocity.

## Force applied to impeller blade.

This parameter is used for mechanical calculations of impellers. It is defined by dividing the torque by number of blades and equivalent radius of application, usually about 0.8 – 0.9 of the tip radius of the impeller.

## Circulation flow rate.

This parameter defines total volume flow rate of media through each impeller. The method of calculation takes into account local velocity distribution of media, flow resistance of the tank and interaction of flows created by different impellers.

## 8.2. Turbulence. See also 7.2.

### 8.2.1. Energy dissipation - maximum value

This parameter is defined as the maximum value of local turbulent dissipation rate calculated for each impeller (see 8.2.11).

### 8.2.2. Energy dissipation - average value

This parameter represents the volume average specific power, and is calculated as the total mixing power (see 8.1.6) per kg of media.

### 8.2.3. Energy dissipation in the bulk volume.

This value takes into account the total mixing power and the part of energy that is dissipated in zones of vortices behind the blades of each impeller, jets formed by impellers and areas behind baffles.

### 8.2.4. Energy dissipation near baffles

This parameter represents a value of energy dissipation behind baffles calculated using velocity of the flow past the baffles. If this value is lower than energy dissipation in the bulk volume, the value for the bulk volume is given.

### 8.2.5. Volume of zone of maximum dissipation

This parameter represents an estimate of the volume around the impeller in which the energy dissipation is defined as the Maximum value (see 8.2.1). If difference between this value and the energy dissipation values around other impellers is significant, the most important micro-scale phenomena, such as drop break-up, destruction of crystals, nucleation and efficient micro mixing, take place in these zone.

### 8.2.6. Volume of zone surrounding baffles

This parameter represents estimated volume of the zones behind the baffles (see 8.2.4).

### 8.2.7. Residence Time in zones with Different Turbulence

This table provides the relative residence time values for the zone of maximum energy dissipation (8.2.1), behind the baffles, and in bulk volume. These values are calculated as the ratio of the volume of the respective zone to the total volume of media.

### 8.2.8. Microscales of Turbulence in Different zones

This table provides the micro-scales of turbulence for the zone of maximum energy dissipation (8.2.1), behind the baffles, and in bulk volume.

Estimation of micro-scales of turbulence is based on Kolmogoroff hypothesis. The minimum value of a microscale corresponds to the maximum energy dissipation.

### 8.2.9. Turbulent Shear rates in Different zones

This table provides values of the turbulent shear rate in the zone of maximum energy dissipation (8.2.1), behind the baffles, and in bulk volume.

The following formula is used by VisiMix for calculation of the local shear rates :

$$\Gamma_{turb} = (\varepsilon/\nu)^{1/4},$$

where:

$\Gamma_{turb}$  is the turbulent shear rate, 1/s

$\varepsilon$  is the local turbulent dissipation rate (in zone of maximum dissipation, behind the baffles, or in the tank bulk volume, respectively), W/kg or  $\text{m}^2/\text{s}^3$ , and

$\nu$  is the kinematic viscosity of liquid media,  $\text{m}^2/\text{s}$ .

The physical meaning of  $\Gamma_{turb}$  variable is the ratio of turbulent fluctuation velocity  $V_0'$  at the Kolmogoroff scale,  $\delta_0$ , (internal scale of turbulence) to the value of  $\delta_0$ :

$$\Gamma_{turb} = V_0' / \delta_0$$

This parameter must not be confused with average velocity gradient, and its value is typically one or two orders of magnitude greater than the latter. The turbulent shear rate,  $\Gamma_{turb}$  is the characteristic shear rate at the microscale level that governs such processes as mass transport to growing and from dissolving solid particles.

#### **8.2.10. Maximum local turbulent shear**

This parameter defines maximum force of internal friction in the media caused with mixing. It is connected with the turbulent shear rate,  $\Gamma_{turb}$ , by the equation

$$\tau_{turb} = \mu \Gamma_{turb},$$

where  $\mu$  is the dynamic viscosity of the media.

#### **8.2.11. CHARACTERISTICS FOR EACH IMPELLER. General data.**

##### **Maximum energy dissipation near the impeller blades.**

This parameter is calculated as an average value of the turbulent dissipation rate in vortices that are formed around the blades of each impeller. Energy dissipation in this area depends on the difference between the impeller velocity and the tangential velocity of the media. It changes also as a function of the blade sizes and pitch angle close to the blade edge.

##### **NOTE:**

*For Anchor and Frame impellers, this value has never been determined experimentally.*

##### **Volume of zone of maximum dissipation.**

This parameter is defined for each impeller as a function of number and size of the blades.

##### **Microscales of turbulence near the impeller blades**

This parameter is defined for each impeller as a function of local turbulent dissipation. The method of calculation is described in 8.2.8.

##### **Turbulent shear rate near the impeller blades**

This parameter is defined for each impeller as a function of local turbulent dissipation. The method of calculation is described in 8.2.9.

#### **8.2.12. CHARACTERISTICS FOR EACH IMPELLER.**

##### **Dissipation Of Energy Around The Impeller.**

A jet forms around each impeller. Turbulent dissipation in this jet, at least near the impeller, is relatively high. It depends on circulation flow created by the impeller and on its geometry. The energy dissipated in the jet sometimes is significant and has to be taken into account for modeling of some mixing phenomena, for example – coalescence of droplets.

## 8.3. Single-phase liquid mixing

### 8.3.1. Macromixing time

This parameter characterizes the time required for the distribution of solute (admixture, tracer, paint, etc.) throughout the entire volume of the tank. It is calculated as the time required to reduce the maximum difference of local concentrations of the admixture to about 1% of its final average value (in batch mixing conditions). The admixture is assumed to be injected instantly. Selection of the real duration of blending has to be based on the sum of **Macromixing time** and the **Characteristic time of micromixing**.

### 8.3.2. Mean period of circulation

The average time of a single cycle of media circulation is calculated by dividing of Volume of media by sum of the of Circulation flow rates created by all impellers.

### 8.3.3. Characteristic time of micromixing

This parameter represents an estimate of the time required to achieve uniform distribution of the dissolved substances down to the molecular level. It is assumed to depend on the molecular diffusion of solute, while the scale of mixing due to molecular diffusion only is supposed to correspond to the microscale of turbulence. Micromixing time is estimated both as the diffusion time, and as the maximum lifetime of a volume element, which has elapsed before the element enters the zones of high dissipation rates around the blades of impellers. The final value of this parameter is calculated with respect to both estimates. Characteristic size of the volume element is assumed equal to the microscale of turbulence in the tank bulk volume.

## 8.4. Heat Transfer

VisiMix calculates all main parameters of the process for several operating regimes - Continuous Flow (CF), Batch (BH), Semibatch (SB) and Fixed temperature regime (FT) for the cases of liquid agent in jacket (LA) and condensing vaporous agent in jacket (VA).

### 8.4.1. Heat transfer area

This output table contains two parameters – the **Heat transfer area** and the **Active heat transfer area**. Both are calculated for the lower and the upper jacket sections. The **Heat transfer area** is the jacketed part of the tank wall surface, including the jacketed part of the bottom for the lower section. For a single-jacket device, the **Heat transfer area** for the upper section is zero. The **Heat transfer area** values in this table are those you entered in the TANK HEAT TRANSFER GENERAL DATA input table or those values calculated by VisiMix if no such data was entered.

Heat transfer calculations are based on the **Active heat transfer area**, which is the area of the submerged part of the **Heat transfer area**. VisiMix calculates this parameter based on the media volume in the tank. For Continuous Flow (CF), Batch (BH) and Fixed temperature regime (FT), the **Active heat transfer area** is constant and corresponds to the user's input of the **Volume of media** in the TANK input table. If the **Level of media** is higher than the upper edge of the jacket, the **Active heat transfer area** is calculated according to the **Level of media**, and the increase in the media level due to vortex formation is taken into account (see **Vortex parameters**). If in Semibatch (SB) process **Active heat transfer area** increases with the increase in the media level, VisiMix takes this into account.

### 8.4.2. Media temperature

This parameter represents the average temperature of the media in the tank and is the final result of heat transfer simulation. It is displayed as **Temperature vs. time** graphs. The simulation is

performed in the range of temperatures entered by the user in the input table HEAT TRANSFER. CHEMICAL REACTION DATA AND TEMPERATURE LIMITS. If in the course of the simulation the temperature falls outside the prescribed limits, the program stops calculation and issues an appropriate message, indicating the time when this occurs. To obtain more information, a new value for the **Simulation time**, which is lower than the one indicated in the message, must be entered in the corresponding input table of HEAT TRANSFER SPECIFIC DATA for **CF**, **BH** and **SB** processes.

#### 8.4.3. Wall temperature, media side

This parameter is calculated as the average value of temperature of the tank wall on the media side. In the case of fouling, the **Wall temperature** should be understood as the temperature of the media-side surface of the fouling layer. For **CF**, **BH** and **SB** processes, this parameter is displayed as a graph of **Temperature vs. time**, for **Fixed temperature regime (FT)** it is displayed as a single numerical value.

The program does not compare the **Wall temperature** with the permitted **Lower** and **Upper limits of temperature** of the media (see **Media temperature**); in cases when the media is sensitive to super-heating or super-cooling, check the **Wall temperature**.

#### 8.4.4. Outlet temperature of liquid agent in jacket

This parameter represents the temperature of the liquid heat transfer agent at the outlet of the lower and upper jacket sections and is calculated for tanks with liquid heating/cooling agents (**LA**). For **CF**, **BH** and **SB** processes this parameter is displayed as a graph of **Temperature vs. time**, for **Fixed temperature regime (FT)** - as a single numerical value.

#### 8.4.5. Inside film coefficient

This parameter represents heat-transfer coefficient on the media side. It is calculated based on a physical model of heat transfer in a turbulent flow (see 7.11.1.). For **CF**, **BH** and **SB** processes the results of the calculations are displayed as graphs, and the change in the physical properties as a function of the current temperature is taken into account; for semibatch processes, the increase in the media volume is also taken into account. For **Fixed temperature regime**, a single numerical value of heat-transfer coefficient is displayed.

#### 8.4.6. Outside film coefficient

This parameter represents heat-transfer coefficient on the jacket side. It is calculated separately for each jacket section with respect to the current temperatures of the heat transfer agent and the temperature of the wall on the jacket side. Calculation is based on well-known and tested empirical correlations (see 7.11.1.). For **CF**, **BH** and **SB** processes, the results of calculations are displayed as graphs; for **Fixed temperature regime**, a single numerical value of heat transfer coefficient for each jacket section is displayed.

#### 8.4.7. Overall heat transfer coefficient

This parameter is calculated for each jacket section separately. The calculation is based on the values of the **Inside film coefficient**, **Outside film coefficient** and the thermal resistance of the tank wall. The wall thermal resistance is based on your input of the tank **Material** and **Wall thickness** (see TANK SHELL input table). Thermal resistance of fouling is added according to your input in the TANK SHELL table. For **CF**, **BH** and **SB** processes, the results of calculations are displayed as graphs; for **Fixed temperature regime**, a single numerical value of heat transfer coefficient for each jacket section is displayed.

#### 8.4.8. Heat transfer rate

This parameter represents the total heat transfer rate between the media and the heat transfer agent including both jacket sections. For **CF**, **BH** and **SB** processes, the results of calculations are displayed as graphs; for **Fixed temperature regime**, a single numerical value of heat transfer coefficient is displayed.

Positive values for the **Heat transfer rate** correspond to the heat flow from the media to the heat transfer agent (HTA); negative values for the **Heat transfer rate** correspond to the heat flow from the HTA to the media.

#### 8.4.9. Specific reaction rate

This parameter is calculated in the course of simulation according to the values of the **Arrhenius constant** and **Activation energy** entered by the user in HEAT TRANSFER. CHEMICAL REACTION AND TEMPERATURE LIMITS input table with respect to a current media temperature. The results of calculation are displayed as a graph **Specific reaction rate vs. Time**.

#### 8.4.10. Reaction heat

The total heat release or consumption in the tank is calculated in the course of simulation according to the user's input in HEAT TRANSFER. CHEMICAL REACTION DATA AND TEMPERATURE LIMITS input table and with respect to current values of **Concentration of reactants A and B** and **Media temperature**. The results of calculations are displayed as a graph of **Reaction heat vs. time**. Positive values correspond to heat release (exothermic reactions), negative values - to heat consumption (endothermic reactions).

#### 8.4.11. Concentrations of reactants A and B

Calculations are based on common equations of bimolecular second-order reaction, and use the kinetic data entered in the HEAT TRANSFER. CHEMICAL REACTION DATA AND TEMPERATURE LIMITS input table. The results of calculations are displayed as a graph of **Concentration of reactants vs. time**.

#### 8.4.12. Pressure head on the jacket

This parameter is calculated for tanks with liquid heating/cooling agents (**LA**). The output table contains the calculated value for the maximum possible pressure difference between the outlet and the inlet for each jacket section (the local resistance values for the inlet and outlet are not taken into account). For **CF**, **BH** and **SB** processes, **Pressure head on the jacket, max.** is calculated, which corresponds to the maximum flow resistance, i.e. to the lowest possible temperature of the heat-transfer agent in the jacket. For **FT** regime, the **Pressure head on the jacket** is calculated, for a calculated temperature of heat-transfer agent in jacket, corresponding to the **Media temperature for FT regime**.

Height of the jacket is taken into account.

#### 8.4.13. Upper limit of heat transfer rate for half-pipe coil

This parameter is calculated for tanks with half-pipe coil jackets heated by condensing vaporous agent (**VA**) only. It is generally known that high condensation rates result in the high volume flow rate of the condensate and may cause "flooding" of the half-pipe coil jacket. The program estimates the maximum value of the heat transfer rate, which will not cause flooding. Calculations are based on empirical correlations verified during a long period of practical use.



The **Upper limit of heat transfer rate** for a given tank can be increased by connecting the two half-pipe coil sections in-parallel and increasing the **Number of starts** of the half-pipe coil (see HALF-PIPE COIL JACKET. SPECIFIC CHARACTERISTICS input table).

#### 8.4.14. Mass flow rate of condensate

This parameter is calculated for tanks heated with condensing vaporous agent (**VA**). It appears in **Heat Transfer. Fixed temperature regime** submenu of the **Calculate** option only. The result of the calculations is presented as a single numerical value.

To calculate this parameter for **CF**, **BH** and **SB** processes, do the following:

1. Address **Mass flow rate of condensate. VA. FT.** in **HT FT** submenu after performing simulation;
2. Enter the lowest temperature of your process in the table MEDIA TEMPERATURE FOR FIXED TEMPERATURE REGIME accessible through **Edit input----- Properties and regime----Heat transfer----Fixed temperature regime.**
3. For **SB** simulation, enter the maximum **Volume of media** for your process in the TANK input table.

#### 8.4.15. Liquid velocity in jacket

This parameter is calculated as the flow rate of the liquid heat transfer agent divided by the area of the jacket cross-section in the direction of the flow.

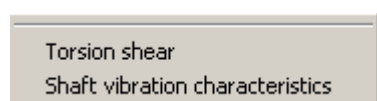
### 8.5. MECHANICAL CALCULATIONS OF SHAFTS

#### Calculated parameters and suitability criteria

The program performs two sets of calculations:

- **Maximum torsional shear stress.** The torque applied to the shaft is assumed to correspond to the maximum value of the driving momentum due to motor acceleration, i.e. 2.5 times higher than the motor rated torque. These calculations are performed for the upper cross-sections of the upper and lower stages of the shaft. A single-stage shaft (**regular**) is regarded as the upper stage of a 2-stage shaft with a zero length for the lower stage. The shaft is considered to be strong enough if the calculated stress value is equal or higher than 0.577 of the yield strength of the shaft material.
- **Critical frequency of vibrations.** The shaft is considered to be stiff and reliable if the rotational frequency is less than 70% of the calculated critical (resonance) velocity. According to many years' practical experience, this condition is fully reliable for mixing in homogeneous liquids, as well as in liquid-liquid and liquid-solid systems. For gas-liquid systems, the impeller rotational frequency must be about 60% of the critical frequency. To avoid additional sources of vibrations, two more conditions are recommended:
  - \* the product of the rotational frequency of the shaft and the number of blades must not equal the critical frequency of the shaft, and
  - \* the number of baffles in the tank must not be equal to the number of impeller's blades. In tanks with an even number of baffles, it is advisable to use impellers with an odd number of blades.

The menu of **Mechanical calculations of shafts** is shown in Figure 43.



**Figure 43.**

*The following output parameters are provided in Torsion shear table.*

### 8.5.1. Allowable shear stress

**Allowable shear stress** is equal to 0.577 of the yield strength of the material you entered .

### 8.5.2. Maximum shear stress in upper shaft section

This parameter is the maximum torsion shear stress in the upper cross-section of the shaft (cross-section of the lower bearing for single- and two-stage shafts) resulting from the maximum driving momentum due to the motor acceleration. The shaft is considered to be strong enough if the calculated stress value is equal or higher than 0.577 of the yield strength of the material (see Shaft design, par. 6.5.1).

### 8.5.3. Maximum shear stress in lower shaft section

This value is calculated as a torsion shear stress in the upper cross-section of the lower section of two-stage shafts (see above). For single-stage shafts, this parameter is not taken into account.

### 8.5.4. Maximum shear stress in the shaft section between bearings.

This value is calculated for console shafts only. It is related to the Diameter of shaft between bearings (d0).

The following output parameters are found in *Shaft vibration characteristics* table.

### 8.5.5. Critical frequency of vibrations

The critical frequency of vibrations is the main calculated parameter in the **SHAFT VIBRATIONS CHARACTERISTICS** output table. It is the critical (resonance) frequency of the shaft vibrations. This value must not be close to the rotational frequency of the shaft.

The shaft is considered as **stiff** if the rotational frequency is less than 70% of the calculated critical (resonance) velocity. Based on many years' practical experience, this condition is fully reliable for mixing in homogeneous liquids, as well as in liquid-liquid and liquid-solid systems. For gas-liquid systems, the impeller rotational frequency must be about 60% of the critical frequency. To avoid additional sources of vibrations, two more conditions are recommended:

- the product of the shaft rotational frequency and the number of blades must not equal the critical frequency of the shaft, and
- the number of baffles in the tank must not be equal to the number of impeller's blades. In tanks with an even number of baffles, it is advisable to use impellers with an odd number of blades.

### 8.5.6. Rotational frequency

Rotational frequency is the rotational velocity of the shaft, rps.

### 8.5.7. Rotational to critical frequency ratio

This parameter is calculated as a ratio of the shaft's rotational velocity and its critical frequency, and is included for your convenience.

The shaft is considered as **stiff** if the ratio is lower then 0.7. For mixing in gas-liquid systems the ratios lower then 0.6 are recommended.

## APPENDIX 1. CONVERSION TABLES

### Conversion of US customary and commonly used units to SI units

| Parameter                         | Value in US customary or commonly used units | Corresponding value in SI or technical metric units |
|-----------------------------------|--|---|
| <b>Linear sizes, Area, Volume</b> |  |   |
| Linear size                       | X in   | 25.4*X mm   |
|                                   | X ft   | 0.3048*X m  |
| Area                              | X sq. ft                                     | 0.0929*X sq.m                                       |
| Volume                            | X gal US                                     | 3.785*X liter, 0.003785*X cub. m                    |
|                                   | X cub. ft                                    | 28.3*X liter  |
|                                   |  | 0.0283*X cub. m                                     |
| <b>Specific area</b>              |  |   |
| Specific area                     | X sq. ft/cub. ft                             | 3.2808*X sq. m/cub. m                               |
| <b>Mass, density</b>              |  |   |
| Mass                              | X lbm  | 0.4536*X kg   |
|                                   | X lb. mol                                    | 0.4536*X kmol, 453.6*X mol                          |
| Density                           | X lbm/cub. ft                                | 16.02*X kg/cub. m                                   |
|                                   | X lbm/gal US                                 | 119.8*X kg/cub. m                                   |
| <b>Viscosity</b>                  |  |   |
| Dynamic viscosity                 | X cP   | 0.001*X Pa*s  |
|                                   | X lbf*s/sq. ft                               | 47.88*X Pa*s  |
| Kinematic viscosity               | X cSt  | 1E-6*X sq.m/s                                       |
|                                   | X sq. ft/s                                   | 0.0929*X sq. m/s                                    |
| <b>Surface tension</b>            |  |   |
| Surface tension                   | X lbf/ft                                     | 14.59*X N/m   |
|                                   | X dyn/cm                                     | 0.001*X N/m   |
| <b>Concentration</b>              |  |   |
| Concentration (mass/volume)       | X lbm/1000 gal US                            | 0.1198*X kg/cub. m                                  |
|                                   | X lbm/cub. ft                                | 16.02*X kg/cub. m                                   |
| Concentration (molar/volume)      | X lb. mol/cub. ft                            | 16.02*X kmol/cub. m                                 |
|                                   | X lb. mol/gal US                             | 119.8*X kmol/cub. m                                 |
| <b>Flow rate</b>                  |  |   |
| Flow rate – mass                  | X lbm/s                                      | 0.4536*X kg/s                                       |
|                                   | X lbm/min                                    | 0.007560*X kg/s                                     |
|                                   | X lbm/h                                      | 0.000126*X kg/s, 0.4356*X kg/h                      |

| Parameter   | Value in US customary or commonly used units | Corresponding value in SI or technical metric units |
|---|--|---|
| flow rate – volume                                | X cub. ft/s                                  | 0.02832*X cub. m/s                                  |
|   | X cub. ft/min                                | 0.000472*X cub. m/s, 1.699*X cub.m/h                |
|   | X cub. ft/h                                  | 0.02832*X cub. m/h                                  |
|   | X gal US/h                                   | 0.003785*X cub. m/h                                 |
|   | X gal US/min                                 | 0.2271*X cub. m/h<br>6.308E-5*X cub. m/s            |
| flow rate – molar                                 | X lb. mol/s                                  | 453.6*X mol/s                                       |
|   |  | 0.4536*X kmol/s                                     |
|   | X lb. mol/min                                | 7.560*X mol/s<br>0.007560*X kmol/s                  |
| <b>Velocity</b>                                   |  |   |
| Velocity  | X ft/s                                       | 0.3048*X m/s  |
|   | X in/s                                       | 0.0254*X m/s  |
| <b>Force</b>                                      |  |   |
| Force   | X lbf  | 4.448*X N   |
| <b>Shear stress</b>                               |  |   |
| shear stress                                      | X lbf/sq. in                                 | 6895*X Pa   |
|   | X lbf/sq. ft                                 | 47.88*X Pa  |
| <b>Torque</b>                                     |  |   |
| Torque  | X lbf*ft                                     | 1.356*X N*m   |
|   | X lbf*in                                     | 0.113*X N*m   |
| <b>Energy, Power</b>                              |  |   |
| Energy  | X lbf*ft                                     | 1.355*X J   |
|   | X B.t.u.                                     | 1.055*X kJ, 1055*X J                                |
| Power   | X B.t.u./s                                   | 1055*X W  |
|   | X hp   | 746*X W, 0.746*X kW                                 |
| <b>Specific power, turbulent dissipation rate</b> |  |   |
| specific power (turbulent dissipation rate)       | X hp/cub. ft                                 | 26.33*X kW/cub. m                                   |
|   | X Btu/(cub. ft*s)                            | 37.26*X kW/cub. m                                   |
|   | X lbf*ft/(lbm*s)                             | 2.989*X W/kg  |
|   | X Btu/(lbm*s)                                | 2326 X W/kg   |
| <b>Specific reaction rate</b>                     |  |   |
| specific reaction rate                            | X cub. ft/(lb.mol*s)                         | 0.0624*X l/(mol*s)                                  |
|   | X cub. ft(lb.mol*h)                          | 1.734E-5*X l/(mol*s)                                |

| Parameter       | Value in US customary or commonly used units | Corresponding value in SI or technical metric units |
|-----------------|--|---|
| <b>Pressure</b> |  |   |
| Pressure        | X psi  | 0.068*X Atm   |
|                 | X mm H <sub>2</sub> O                        | 9.806*X Pa  |
|                 | X mm Hg                                      | 133.3*X Pa  |
|                 | X lbf/sq. ft                                 | 47.88*X Pa  |
|                 | X psi  | 6895*X Pa   |

| <b>Thermal Units</b>             |                         |   |
|----------------------------------|-------------------------|---|
| <b>Specific heat</b>             |                         |   |
| Specific heat                    | X Btu/(lbm*°F)          | 4187*X J/(kg*K)                           |
|                                  | X cal/(kg*°C)           | 4.184*X J/(kg*K)                          |
| <b>Heat conductivity</b>         |                         |   |
| Heat conductivity                | X Btu*ft/(h*sq.ft.* °F) | 1.73*X W/(m*K)                            |
|                                  | X Btu*in/(h*sq.ft.* °F) | 0.1442*X W/(m*K)                          |
|                                  | X cal*cm/(s*sq. cm*°C)  | 418.4*X W/(m*K)                           |
|                                  | X kcal*m/(h*sq. m*°C)   | 1.162*X W/(m*K)                           |
| <b>Temperature</b>               |                         |   |
| Temperature                      | X °F                    | 5/9*(X - 32) °C                           |
|                                  | X °F                    | 5/9*(X + 459.4) K                         |
| <b>Energy of activation</b>      |                         |   |
| Energy of activation             | X Btu/(lb*mol)          | 2.326*X J/mol                             |
| <b>Arrhenius constant</b>        |                         |   |
| Arrhenius constant               | X cub. ft/(lb*mol*s)    | 0.06243*X cub. m/(Kmol*s)                 |
|                                  | X cub. ft/(lb*mol*h)    | 1.734*10 <sup>-5</sup> *X cub. m/(Kmol*s) |
| <b>Heat transfer rate</b>        |                         |   |
| Heat transfer rate               | X Btu/(h*sq.ft)         | 3.155*X W/sq. m                           |
| <b>Thermal resistance</b>        |                         |   |
| Thermal resistance               | X °F *sq.ft*h/Btu       | 0.1761*X K*sq. m/W                        |
| <b>Heat transfer coefficient</b> |                         |   |
| HT coefficient                   | X Btu/(s* sq. ft* °F)   | 2.044*10 <sup>4</sup> *X W/(sq. m*K)      |
|                                  | X Btu/(h* sq. ft* °F)   | 5.678*X W/(sq. m*K)                       |
|                                  | X kcal/(h*sq. m*°C)     | 1.162*X W/(sq. m*K)                       |

### Conversion of SI units to US customary and commonly used units

| Parameter                        | Value in SI or Technical metric units | Corresponding value in US customary or commonly used units |
|----------------------------------|---------------------------------------|--|
| <b>Linear size, area, volume</b> |                                       |  |
| linear size                      | X mm                                  | 0.03937*X in   |
|                                  | X m                                   | 3.2808*X ft  |
| area                             | X sq.m                                | 10.76*X sq. ft   |
| volume                           | X liter                               | 0.03531*X cub. ft, 0.2642*X gal US                         |
|                                  | X cub. m                              | 35.31*X cub. ft, 264.2*X gal US                            |
| <b>Specific area</b>             |                                       |  |
| Specific area                    | X sq.m/cub. m                         | 0.3048*X sq. ft/cub. ft, 0.0254*X sq. in/cub. in           |
| <b>Mass, Density</b>             |                                       |  |
| mass                             | X kg                                  | 2.205*X lbm  |
|                                  | X mol                                 | 0.002205*X lb. mol   |
|                                  | X kmol                                | 2.205*X lb. mol  |
| density                          | X kg/cub. m                           | 0.06243*X lbm/cub. ft, 0.008345*X lbm/gal US               |
| <b>Viscosity</b>                 |                                       |  |
| dynamic viscosity                | X Pa*s                                | 1000*X cP, 0.02089*X lbf*s/sq. ft                          |
|                                  | X cP                                  | 2.089E-5*X lbf*s/sq. ft                                    |
| kinematic viscosity              | X sq.m/s                              | 1E6*X cSt, 10.76*X sq. ft/s                                |
|                                  | X cSt                                 | 1.076E-5*X sq. ft/s  |
| <b>Surface tension</b>           |                                       |  |
| surface tension                  | X N/m                                 | 1000*X dyn/cm, 0.0685*X lbf/ft                             |
| <b>Concentration</b>             |                                       |  |
| Concentration (mass/volume)      | X kg/cub. m                           | 0.06243*X lbm/cub. ft, 8.345*X lbm/1000 gal US             |
| Concentration (molar/volume)     | X kmol/cub. m<br>(mol/liter)          | 0.06243*X lb. mol/cub. ft<br>0.008345*X lb. mol/gal US     |
| <b>Flow rate</b>                 |                                       |  |
| flow rate – mass                 | X kg/s                                | 2.205*X lbm/s, 132.3*X lbm/min                             |

|                    |            |  |
|--------------------|------------|--|
| flow rate - volume | X cub. m/s | 35.31*X cub. ft/s, 2119*X cub. ft/min                          |
|                    | X cub. m/h | 35.31*X cub. ft/h, 0.5886*X cub. ft/min,<br>4.403*X gal US/min |

| Parameter   | Value in SI or technical metric units | Corresponding value in US customary or commonly used units |
|---|---------------------------------------|--|
| flow rate - molar                                 | X mol/s                               | 0.002205*X lb. mol/s                                       |
|   | X kmol/s                              | 2.205*X lb. mol/s  |
| <b>Velocity</b>                                   |                                       |  |
| Velocity  | X m/s                                 | 3.2808*X ft/s  |
|   |                                       | 39.37*X in/s   |
| <b>Force</b>                                      |                                       |  |
| Force   | X N                                   | 0.2248*X lbf   |
| <b>Shear stress</b>                               |                                       |  |
| shear stress                                      | X Pa                                  | 0.000145*X lbf/sq. in                                      |
|   |                                       | 0.02089*X lbf/sq. ft                                       |
| <b>Torque</b>                                     |                                       |  |
| Torque  | X N*m                                 | 0.738*X lbf*ft   |
|   |                                       | 8.851*X lbf*in   |
| <b>Energy, Power</b>                              |                                       |  |
| Energy  | X kJ                                  | 0.9478*X Btu   |
|   | X J                                   | 0.738*X lbf*ft   |
| Power   | X W                                   | 0.0009478*X Btu/s  |
|   |                                       | 0.00134*X hp   |
|   | X kW                                  | 1.34*X hp  |
|   |                                       | 0.9478*X Btu/s   |
| <b>Specific power, turbulent dissipation rate</b> |                                       |  |
| specific power (turbulent dissipation rate)       | X kW/cub. m                           | 0.03797*X hp/cub. ft                                       |
|   |                                       | 0.0268*X Btu/(cub. ft*s)                                   |
|   | X W/kg                                | 0.3346*X lbf.ft/(lbm*s)                                    |
|   |                                       | 0.0004299*X Btu/(lbm*s)                                    |
| <b>Specific reaction rate</b>                     |                                       |  |
| specific reaction rate                            | X l/(mol*s)                           | 16.02*X cub. ft/(lb.mol*s)                                 |
|   |                                       | 57666*X cub. ft/(lb.mol*h)                                 |
| <b>Pressure</b>                                   |                                       |  |
| Pressure  | X Pa                                  | 0.9869*10 <sup>-6</sup> *X atm                             |
|   | X atm                                 | 14.696* X lbf/sq. in (psi)                                 |
|   | X Pa                                  | 0.102*X mm H <sub>2</sub> O                                |
|   | X Pa                                  | 0.0075*X mm Hg   |
|   | X atm                                 | 1.01325*X bar  |
|   | X Pa                                  | 10*X dyn/sq. cm  |

## Thermal Units

| Parameter                        | Value in SI or technical metric units | Corresponding value in US customary and commonly used units |
|----------------------------------|---------------------------------------|---|
| <b>Specific heat</b>             |                                       |   |
| specific heat                    | X J/(kg*K)                            | 0.0002388*X Btu/(lbm*°F)                                    |
|                                  | X J/(kg*K)                            | 0.239*X cal/(kg*°C)   |
| <b>Heat conductivity</b>         |                                       |   |
| heat conductivity                | X W/(m*K)                             | 0.578*X Btu*ft/(h*sq.ft.* °F)                               |
|                                  | X W/(m*K)                             | 6.933*X Btu*in/(h*sq.ft.* °F)                               |
|                                  | X W/(m*K)                             | 0.00239*X cal*cm/(s*sq. cm*°C)                              |
|                                  | X W/(m*K)                             | 0.8604*X kcal*m/(h*sq. m*°C)                                |
| <b>Temperature</b>               |                                       |   |
| Temperature                      | X °C                                  | 9/5*X + 32 °F   |
|                                  | X K                                   | 9/5*X - 459.4 °F  |
| <b>Energy of activation</b>      |                                       |   |
| energy of activation             | X J/mol                               | 0.4298*X Btu/(lb*mol)                                       |
| <b>Arrhenius constant</b>        |                                       |   |
| Arrhenius constant               | X cub. m/(Kmol*s)                     | 0.01602*X cub. ft/(lb*mol*s)                                |
|                                  | X cub. m/(Kmol*s)                     | 57.67*10 <sup>3</sup> *X cub. ft/(lb*mol*h)                 |
| <b>Heat transfer rate</b>        |                                       |   |
| heat transfer rate               | X W/sq.m                              | 0.317*X Btu/(h*sq.ft)                                       |
| <b>Thermal resistance</b>        |                                       |   |
| thermal resistance               | X K*sq.m/W                            | 5.678*X °F *sq.ft*h/Btu                                     |
| <b>Heat transfer coefficient</b> |                                       |   |
| HT coefficient                   | X W/(sq. m*K)                         | 4.8924*10 <sup>-5</sup> *X Btu/(s* sq. ft* °F)              |
|                                  | X W/(sq. m*K)                         | 0.1761*X Btu/(h* sq. ft* °F)                                |
|                                  | X W/(sq. m*K)                         | 0.8606*X kcal/(h*sq. m*°C)                                  |

## APPENDIX 2. THERMAL RESISTANCE OF FOULING FOR VARIOUS MEDIA

| Medium                          | Thermal resistance, m <sup>2</sup> *K/W |
|---------------------------------|---|
| <b>WATER:</b>                   |   |
| Distilled water                 | 0.00004                                 |
| Sea water                       | 0.00011                                 |
| Pure service water              | 0.00023                                 |
| Polluted service water          | 0.00055                                 |
| River water                     | 0.00017                                 |
| Hard water                      | 0.00025                                 |
| <b>OIL:</b>                     |   |
| Motor oil                       | 0.00086                                 |
| Lubricating oil                 | 0.0042                                  |
| Quenching oil                   | 0.001                                   |
| Transformer oil                 | 0.00015                                 |
| Vegetable oil                   | 0.00031                                 |
| Fuel oil                        | 0.0005                                  |
| Petroleum                       | 0.0002                                  |
| <b>A C I D:</b>                 |   |
| Hydrochloric acid               | 0.00005                                 |
| Phosphoric acid                 | 0.00005                                 |
| Sulfuric acid                   | 0.00005                                 |
| Acetic acid                     | 0.0005                                  |
| <b>SOLUTIONS &amp; BRINES:</b>  |   |
| Aluminate solution              | 0.00015                                 |
| Caustic solution                | 0.0002                                  |
| Alkaline solution               | 0.0004                                  |
| Salt solution                   | 0.0002...0.0005                         |
| Ammoniac brine                  | 0.0003                                  |
| <b>MISCELLANEOUS MATERIALS:</b> |   |
| Scale                           | 0.00033                                 |
| Iron vitriol                    | 0.001                                   |
| Coke                            | 0.00072                                 |
| Gypsum                          | 0.00083                                 |
| Lime                            | 0.00042                                 |
| Organic heat-transfer media     | 0.0002                                  |
| Polymer-forming liquids         | 0.00045                                 |
| Rust                            | 0.0005                                  |
| Soot                            | 0.01                                    |
| Carbon bisulphide               | 0.0002                                  |
| Refrigerant liquids             | 0.00007                                 |
| Aromatic hydrocarbon            | 0.00018                                 |
| Asphalt and residuum            | 0.0017                                  |



### APPENDIX 3. PHYSICAL PROPERTIES OF VARIOUS MEDIA

| <b>WATER</b>                           |                  |          |          |
|--|------------------|----------|----------|
| Parameter                              | Temperature, ° C |          |          |
|  | 20               | 40       | 60       |
| Density, kg/cub m                      | 998              | 992      | 983      |
| Dynamic viscosity, Pa*s                | 0.001002         | 0.000651 | 0.000463 |
| Heat Conductivity, W/(m*K)             | 0.602            | 0.630    | 0.653    |
| Specific Heat, J/(kg*K)                | 4182             | 4179     | 4185     |
| Cubic Expansion                        | 0.000207         |          |          |
| <b>HYDROCHLORIC ACID, 10% Solution</b> |                  |          |          |
| Parameter                              | Temperature, ° C |          |          |
|  | 20               | 25       |          |
| Density, kg/cub m                      | 1055             |          |          |
| Dynamic viscosity, Pa*s                |                  | 0.00127  |          |
| Heat Conductivity, W/(m*K)             | 0.59             |          |          |
| Specific Heat, J/(kg*K)                | 2975             |          |          |
| Cubic Expansion                        | 0.000279         |          |          |
| <b>HYDROCHLORIC ACID, 20% Solution</b> |                  |          |          |
| Parameter                              | Temperature, ° C |          |          |
|  | 20               | 25 C     |          |
| Density, kg/cub m                      | 1110             |          |          |
| Dynamic viscosity, Pa*s                |                  | 0.00150  |          |
| Heat Conductivity, W/(m*K)             | 0.57             |          |          |
| Specific Heat, J/(kg*K)                | 2609             |          |          |
| Cubic Expansion                        | 0.000279         |          |          |
| <b>HYDROCHLORIC ACID, 38% Solution</b> |                  |          |          |
| Parameter                              | Temperature, ° C |          |          |
|  | 20               | 25       |          |
| Dynamic viscosity, Pa*s                |                  | 0.00217  |          |
| Heat Conductivity, W/(m*K)             | 0.535            |          |          |
| Specific Heat, J/(kg*K)                | 2270             |          |          |
| Cubic Expansion                        | 0.000478         |          |          |
| <b>SULFURIC ACID , 60% Solution</b>    |                  |          |          |
| Parameter                              | Temperature, ° C |          |          |
|  | 20               |          |          |
| Density, kg/cub m                      | 1498             |          |          |
| Dynamic viscosity, Pa*s                | 0.00770          |          |          |
| Heat Conductivity, W/(m*K)             | 0.485            |          |          |
| Specific Heat, J/(kg*K)                | 2228             |          |          |
| Cubic Expansion                        | 0.000560         |          |          |
| <b>SULFURIC ACID , 75% Solution</b>    |                  |          |          |
| Parameter                              | Temperature, ° C |          |          |
|  | 20               |          |          |
| Density, kg/cub m                      | 1669             |          |          |
| Dynamic viscosity, Pa*s                | 0.00318          |          |          |
| Heat Conductivity, W/(m*K)             | 0.329            |          |          |
| Specific Heat, J/(kg*K)                | 1948             |          |          |
| Cubic Expansion                        | 0.000383         |          |          |
| <b>SODIUM HYDROXIDE, 30% Solution</b>  |                  |          |          |
| Parameter                              | Temperature, ° C |          |          |
|  | 20               |          |          |
| Heat Conductivity, W/(m*K)             | 0.58             |          |          |
| Specific Heat, J/(kg*K)                | 3268             |          |          |
| Cubic Expansion                        | 0.000451         |          |          |
| <b>SODIUM HYDROXIDE, 50% Solution</b>  |                  |          |          |
| Parameter                              | Temperature, ° C |          |          |
|  | 20               |          |          |
| Dynamic viscosity, Pa*s                | 0.046            |          |          |
| Heat Conductivity, W/(m*K)             | 0.565            |          |          |
| Specific Heat, J/(kg*K)                | 2715             |          |          |
| Cubic Expansion                        | 0.000475         |          |          |

| <b>POTASSIUM HYDROXIDE, 10% Solution</b> |                  |       |         |
|--|------------------|-------|---------|
| Parameter                                | Temperature, ° C |       |         |
|  | 20               |       |         |
| Dynamic viscosity, Pa*s                  | 0.001226         |       |         |
| Heat Conductivity, W/(m*K)               | 0.58             |       |         |
| Specific Heat, J/(kg*K)                  | 3689             |       |         |
| Cubic Expansion                          | 0.00031          |       |         |
| <b>GLYCERIN</b>                          |                  |       |         |
| Parameter                                | Temperature, ° C |       |         |
|  | 20               | 100   | 200     |
| Density, kg/cub m                        | 1260             | 1208  | 1090    |
| Dynamic viscosity, Pa*s                  | 1.48             | 0.013 | 0.00022 |
| Heat Conductivity, W/(m*K)               | 0.278            | 0.289 | 0.303   |
| Specific Heat, J/(kg*K)                  | 2350             | 2790  | 3340    |
| <b>HEAVY FUEL OIL</b>                    |                  |       |         |
| Parameter                                | Temperature, ° C |       |         |
|  | 15               | 50    | 100     |
| Density, kg/cub m                        | 943.5            | 924.1 | 896.1   |
| Dynamic viscosity, Pa*s                  | 7.925            | 0.296 | 0.024   |
| Heat Conductivity, W/(m*K)               | 0.121            | 0.119 | 0.116   |
| Specific Heat, J/(kg*K)                  | 1772             | 1895  | 2070    |

**NOTE:**

For all solutions, mass concentration is given.

## APPENDIX 4. A LIST OF ABBREVIATIONS

|            |                              |
|------------|------------------------------|
| <b>BH</b>  | Batch process                |
| <b>CF</b>  | Continuous flow process      |
| <b>FT</b>  | Fixed temperature regime     |
| <b>HT</b>  | Heat transfer                |
| <b>HTA</b> | Heat transfer agent          |
| <b>HTD</b> | Heat transfer device         |
| <b>LA</b>  | Liquid heat transfer agent   |
| <b>SB</b>  | Semibatch process            |
| <b>VA</b>  | Vaporous heat transfer agent |