VisiMix RSD. Homogenizing of a Shampoo. Scaling-up.

Problem: Check possibility of manufacturing of a shampoo in a 500 liter mixing tank (volume of media – 450 liter) with anchor agitator and bottom-entering Rotor-Stator homogenizer (further – the **bottom entering RSD**) , and evaluate necessary duration of the operation.

General approach.

The main requirement to the process conditions can be defined as follows:
1. In order to achieve required micro-scale homogeneity, the RSD device must create some relatively high shear stress.
2. Practically all media must be subjected to effect of the high shear stress.

Zone of the high shear rates is placed in concentric channels between cylindrical surfaces of rotors. Rotation of RSD rotor creates an axial suction of media into its central part and pumping it out in radial direction through the opening of the stator. On this way the flow of material is subjected to effect of high shear stress.
Limits of necessary shear stress are individual for each product. They must be defined with laboratory or pilot tests using laboratory RSD devices, and are used as a base for scaling-up in order to fulfill the first of the above mentioned requirements.

The second requirement is related to macro-scale homogeneity of composition: the composition and micro-scale homogeneity of small samples of product must be the same in all points of the batch volume. Theoretically this requirement can be satisfied if all 100% of the shampoo passed the high shear zones at least once. Practically, due to stochastic nature of mixing process in the tank, the media always contains some un-treated fraction, and this fraction decreases with increase of the process duration.
Acceptable degree of completeness of high shear treatment, i.e. the minimum homogenized fraction – 98%, 99% or 99.9%, and accordingly – the maximum un-treated fraction of media – 2%, 1% or 0.1% - is dependent on specific features and requirements to the product.

Initial data and statement of the scaling-up problem.

Formulation of the shampoo was developed in laboratory. For final tuning of the product a 2.5 liter vessel with a portable rotor-stator homogenizer (further mentioned as **portable RSD**) was used. To achieve required quality of the product, it was mixed during 10-15 min. Data on rotation velocity of the laboratory RSD are presented in the Table 1.

It is assumed that in order to reproduce quality of the product, the production-scale process must ensure the following conditions:
1. Provide the same quality of micro-mixing: level of shear stress in high shear zone of the RSD must be approximately the same as in laboratory tests.
2. To provide satisfactory uniformity of the batch: not less than 99.9% of shampoo must undergo the high shear treatment in RSD channels, i.e. un-treated fraction of product cannot be more than 0.01 % of the total volume..

Characteristics of the portable RSD:

Number of revolutions – variable, up to 20 000 RPM
Power of drive – 400 W
Stator – shallow cylinder with radial slots.
      External diameter – 25 mm,
      Thickness – 2 mm,
      Internal height – 15 mm,
      Slots:
      Number – 12,
      Height – 14 mm,
      Width – 1 mm.

Rotor – 4-blade impeller
      External diameter – 20 mm,
      Height of blades – 14 mm.

Physical characteristic of the shampoo: Non-Newtonian solution with density 1050 kg / cub.m and rheological behavior that can be approximated with Power Law function:

$$\text{Shear Stress} = 5.87 * \text{Shear Rate}^{0.678}$$

Table 1. Results of the laboratory tests.

No.	Rotational speed, rpm	Description of results
1	Max. speed - 20000	Insertion of air. After separation (about 30 min) – good uniformity and quality
2	About 15000	Good uniformity and quality
3	10000 and lower	Worse quality of product.

Characteristics of the bottom-entering RSD:

Number of revolutions – variable, from 1400 to 3000 RPM
Power of drive – 3 kW.
Stator – shallow cylinder with radial slots.
      External diameter – 110 mm,
      Thickness – 4 mm,
      Internal height – 35 mm,
      Wall thickness – 4 mm,
      Slots:
      Number – 30,
      Height – 30 mm,
      Width – 3 mm.
Rotor - shallow cylinder with radial slots.
      External diameter – 100 mm,
      Wall thickness – 4 mm,
      Internal height – 28 mm,

External height – 33 mm
Slots:
Number – 30,
Height – 28 mm,
Width – 3 mm.

Step 1. Defining range of shear rates that correspond to good quality of the product.

1. Entering the initial data.

1.1. After opening the program, select **Project>New** in the main menu or the icon New in the upper bar and enter name for the new project- for example, **Ex.1-Port** (Figure 1, 2)
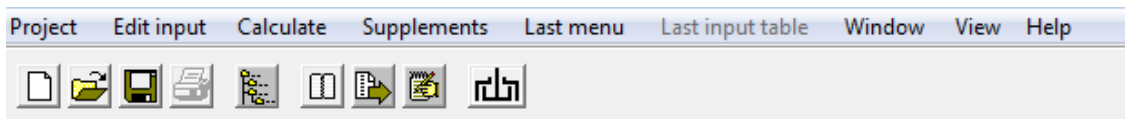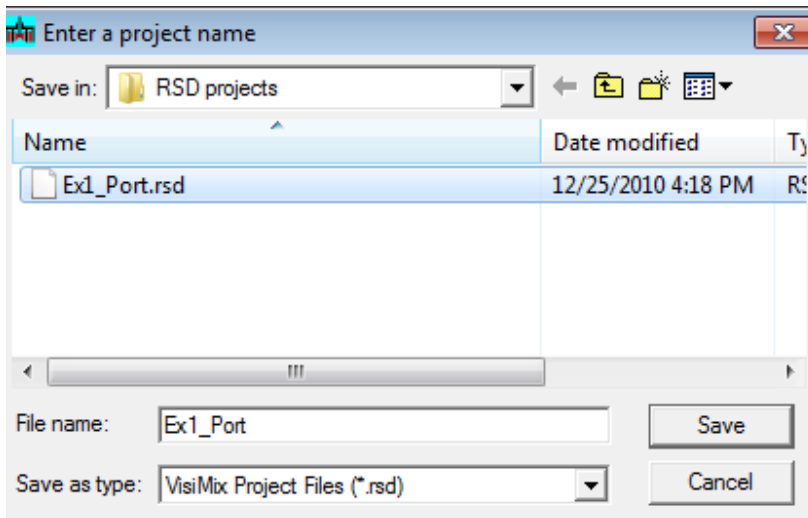

Figure 1.

Figure 2.

1.2. After you click **Save**, the **RSD scheme** selection visual menu appears (Figure 3). Select scheme **BS** - **a single-stage RSD with central Blade-type rotor** - that corresponds to design of the portable RSD.

1.3. Click on this image, and the selected scheme appears in the **Current choice** window (Figure 4)
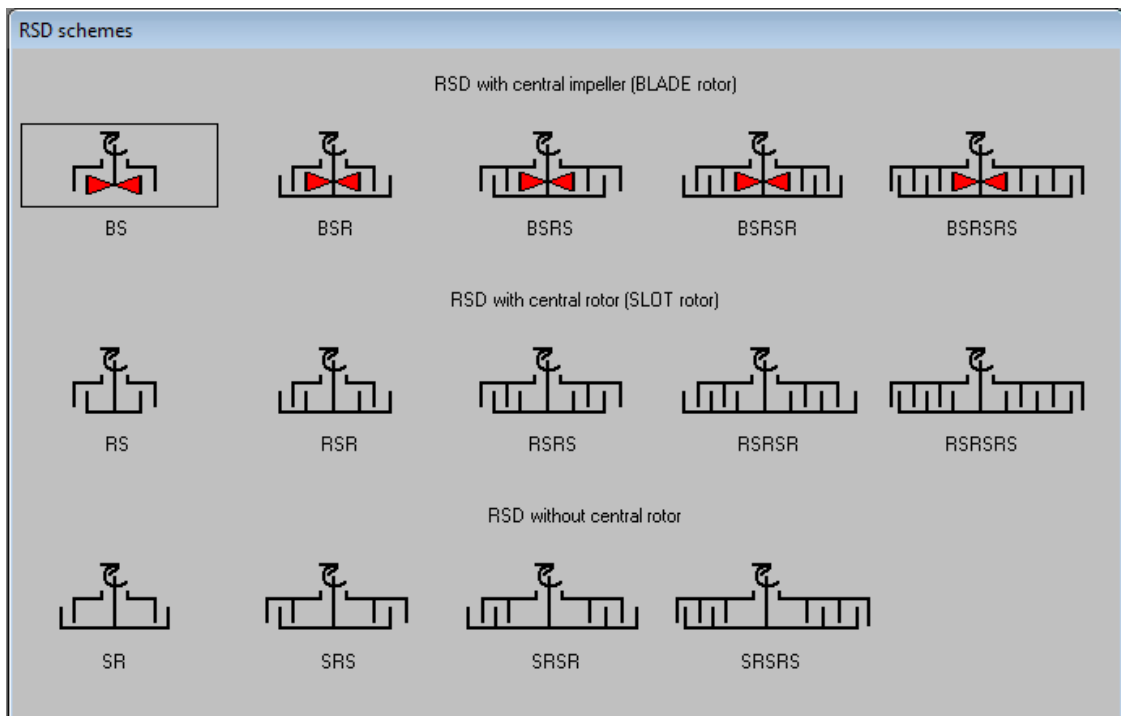
Figure 3.
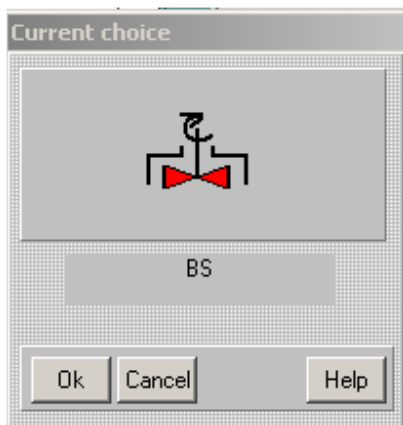
Figure 4.

Click **OK** to confirm your choice. The **RSD scheme and rotational speed** input table appears in the screen (Figure 5). Enter maximum number of revolutions of the RSD shaft and internal and external diameters of the main elements.
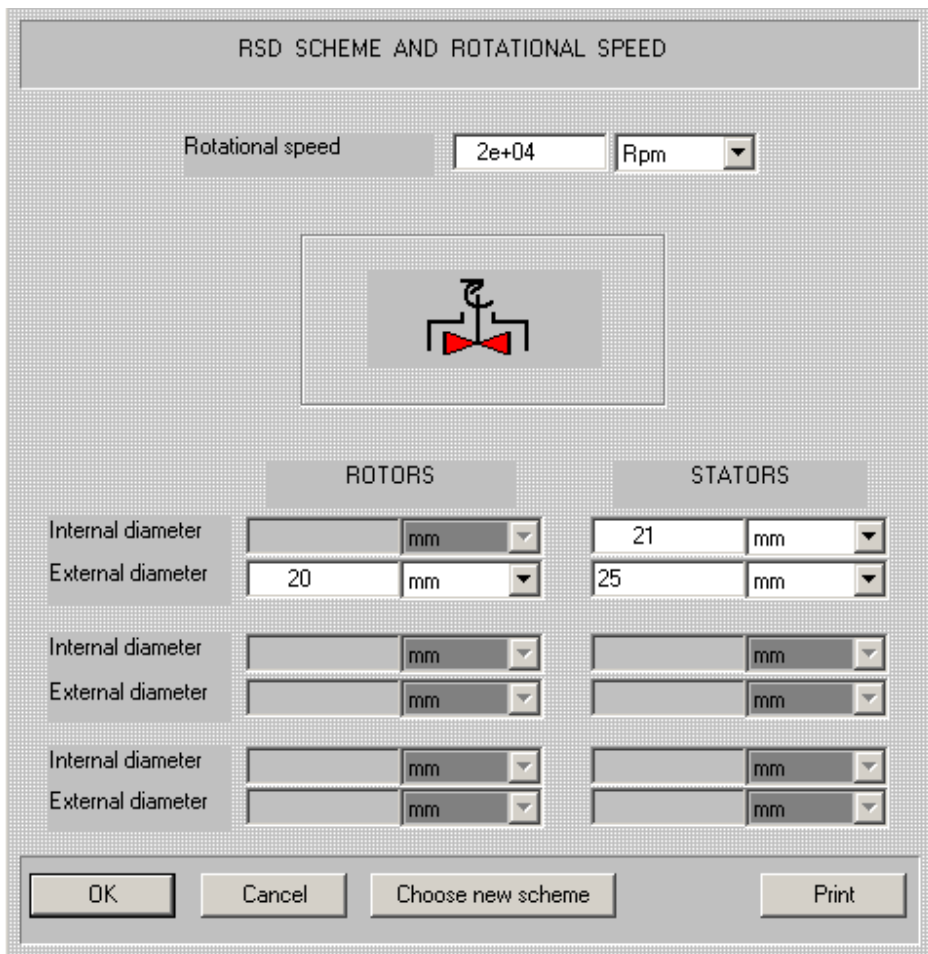
Figure 5.

1.3. After the input is confirmed with **OK**, a visual menu of stators will be opened for selection. In correspondence with the initial data, select the **SLOT-type** stator (Figure 6). Click on this image, and the selected scheme appears in the **Current choice** window. Confirm the choice with **OK**.

Figure 6.
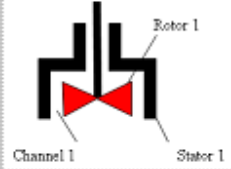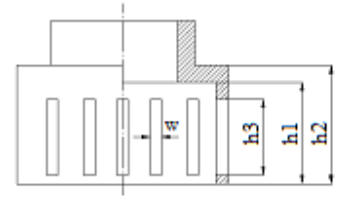
Figure 7.

After the choice is confirmed, input table for stator of the selected type will be opened automatically (Figure 7). For reference, internal and external diameter of the stator are printed in the lower part of the input window.
Enter dimensions of the stator accordingly to the scheme and push the **OK** button. The program will open the input table for rotor (Figure 8).
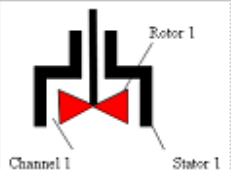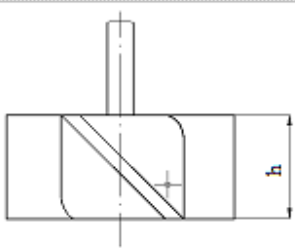
Figure 8.

1.4. After all dimensions have been entered, you are asked to enter average properties of media. Order of input is the same as in other VisiMix programs. On the first stage, density of liquid is entered, and its rheological type is defined (Figure 9). On the next step, viscosity of Newtonian liquid or rheological constants of a non-Newtonian media are entered (Figure 10).

Figure 9.

Figure 10.

NOTE. If the rheological constants for media are not known, it is possible to define them approximately. The program provides data for typical commercial non-Newtonian products, including shampoos (See **Help**).

2. Defining limits of shear rate created by portable RSD.

2.1. Select **Calculate >SHEAR CHARACTERISTICS OF RSD CHANNELS >Shear Rates** in the main menu (Figure 11).
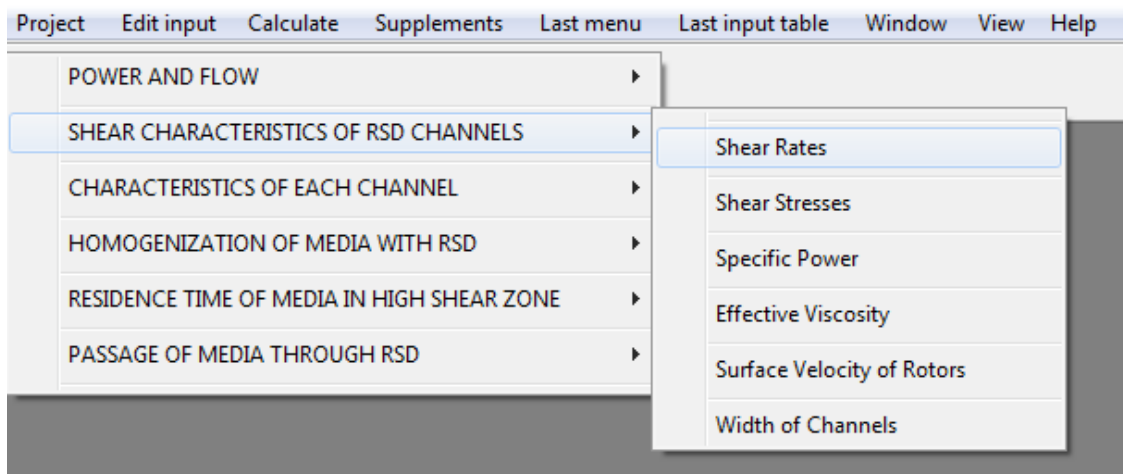
Figure 11.

The output table showing shear rate in the channel between the rotor and stator will arrive in the screen (Figure 12).

2.2. The calculated shear rate value – 12600 1/s - corresponds to the maximum rotational speed of rotor – 20000 rpm.

Figure 12.

2.3. Accordingly to the results of tests (Table 1), lower limit of rotational speed that provides good quality of the shampoo is somewhere between 15000 rpm and 10000 rpm. So, it is desirable to provide the value of shear rate not lower then corresponding to 15000 rpm. To define it, we have to change rotational speed of the rotor and repeat the calculation. Select **Edit inputs>RSD scheme** in the main menu. In the arriving input table change **Rotational speed** from 20000 to 15000 (Figure 13) and click **OK**.

Figure 13.

Value of shear rate corresponding to the new input arrive in the output window (Figure 14).

Figure 14.

2.4. It can be concluded that producing of the shampoo with the required quality can be ensured if shear rate create by the homogenizer is in the limits **8270 – 12600 1/s.**
It can be supposed that application of regimes with higher shear rates is also possible. However, taking into account lack of experimental confirmation, it would be more safe to use equipment that creates shear rates within the tested limits.

The obtained data allow to check if the 500 liter tank with bottom-entering RSD is applicable this production process.

Step 2. Checking applicability of the tank with bottom-entering RSD.

1. Entering data of the bottom-entering RSD.

1.1. Open a new project **Ex1- Bot.vrs** via **Project>New** in the main menu and save it in the same directory. In the arriving visual selection menu (Figure 15) select scheme **RS** - **a single-stage RSD with central SLOT-type rotor** - that corresponds to design of the bottom-entering RSD.
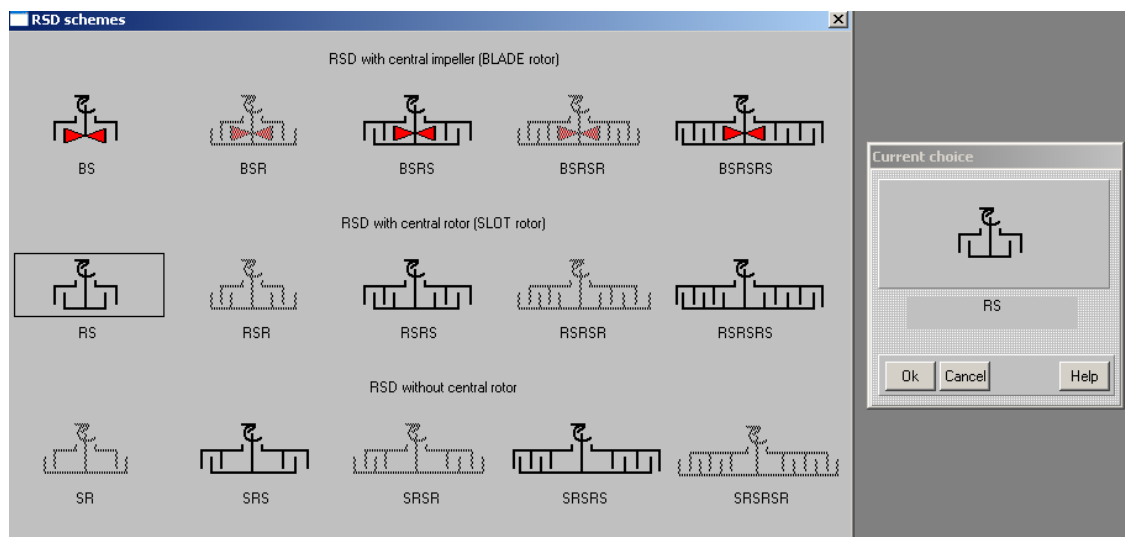

Figure 15.

1.2. The next steps – entering the data in to Input tables for **RSD scheme, Stator 1** and **Rotor 1 –** are illustrated with Figures 15 – 18.
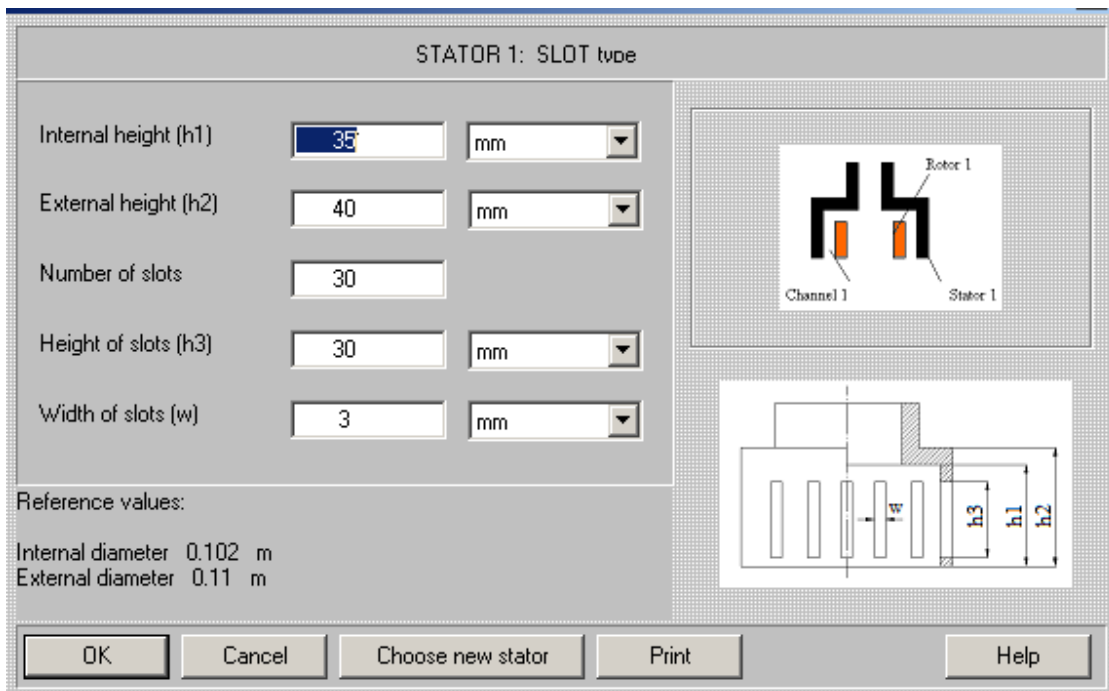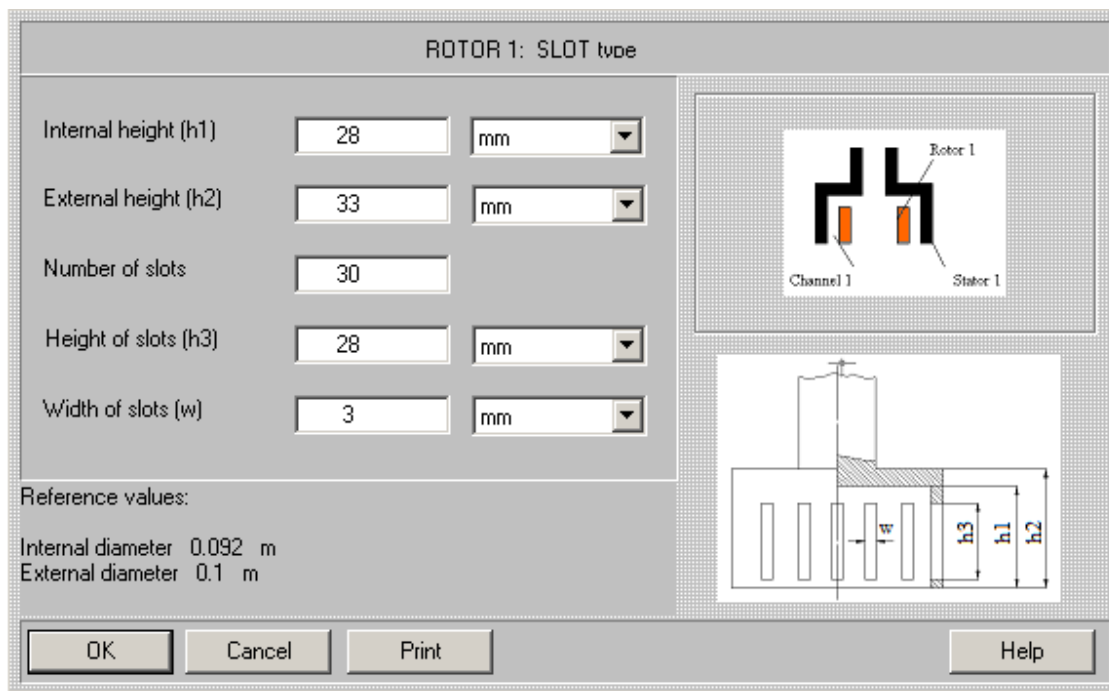
Figure 16.

Figure 17.

Figure 18.

Obviously, the **Average properties of media** in the new project are the same as in the previous input (see Figures 9 and 10).

2. Calculation of power and shear rates for the bottom-entering RSD.

Applicability of the bottom-entering RSD in the current case is defined with two criteria:
1. **Power consumption must correspond to power of the RSD drive.**
2. **Shear rates created by the RSD must be within the limits defined above: from 8270 – 12600 1/s.**

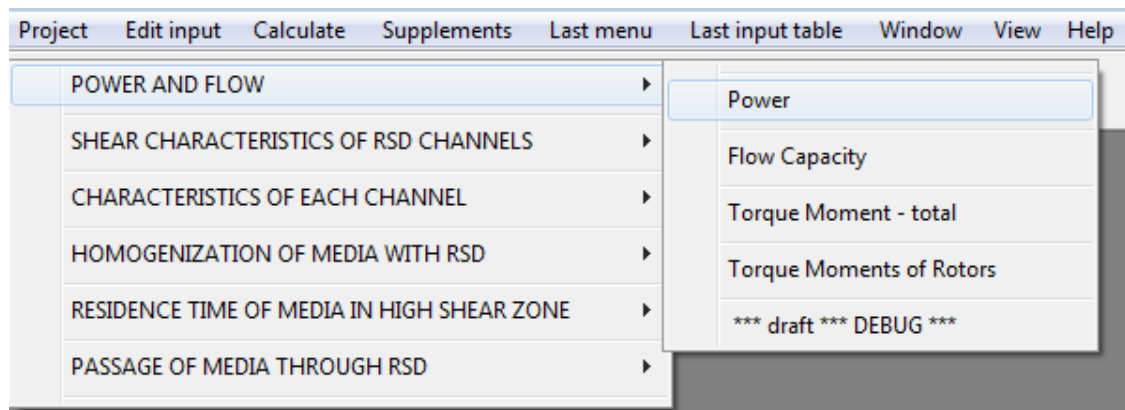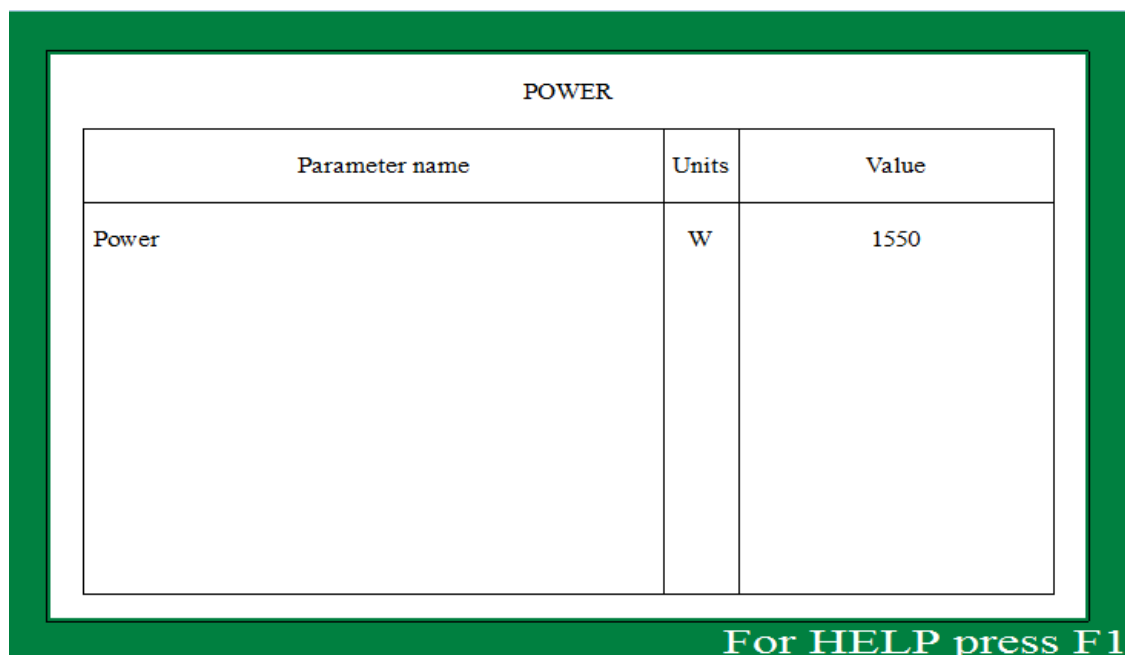2.1. To define the power consumption, **select POWER AND FLOW>POWER** in menu **Calculate** (Figure19).

Figure 19.

Figure 20.

As it follows from the output table (Figure 20), even at the maximum number of revolutions – 3000 rpm - power consumption of the device in the product solution is significantly lower than nominal power of drive – 3 kW.

2.2. The next step – calculation of limits of shear rates created by the RSD. To perform the calculation for the rotational speed 3000 rpm, select **Calculate>SHEAR CHARACTERISTICS OF RSD CHANNELS > Shear Rates** (Figure 21).
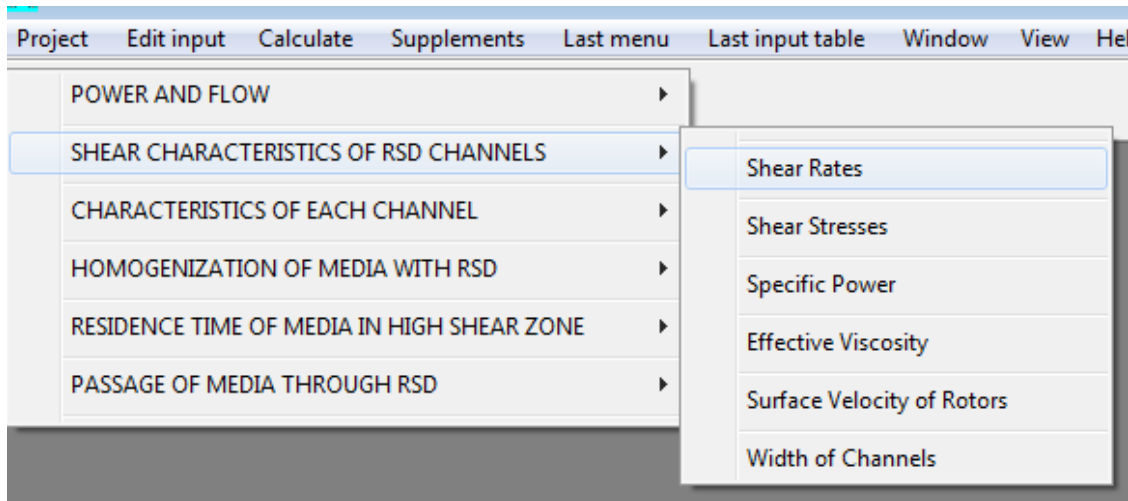

Figure 21.

The output table showing shear rate in the channel between the rotor and stator will arrive in the screen (Figure 22).

Figure 22.

This value – **22000 1/s** – is much higher than the maximum value of the shear rates corresponding to the laboratory tests.

2.3. The bottom-entering RSD is provided with a variable speed motor. So, the nest step – to define values of rotation speed that provide shear rates in the desirable limits.

Select **Edit input>RSD scheme** in the main menu and change Rotational speed in the arriving input table from 3000 to 1500 rpm (Figure 23).

Figure 23.

Value of shear rate corresponding to the new input arrives in the output window (Figure 24).

Figure 24.

Repeat the calculations for a few different values of rotational speed using the **Last input table** option of the main menu. Results of such calculations are presented in the Table 2.

Table 2.

Rotational speed, rpm	Shear rate, 1/s
1500	8180
1700	9670
1900	11300
2100	13000

Accordingly to these data, the range of shear rates defined based on laboratory tests can be provided at rotational speeds of bottom-entering RSD from 1500 to 2100 rpm.

Step 3. Evaluation of a batch duration in the 500 liter tank.

Accordingly to the Initial data above, duration of the batch has to be long enough in order to provide 99.9% completeness of high shear treatment of the media, i.e. untreated fraction must be less than 0.01%.
In order to evaluate necessary process duration, select HOMOGENIZATION OF MEDIA WITH RSD>Time required for homogenization in the CALCULATE menu (Figure 25).
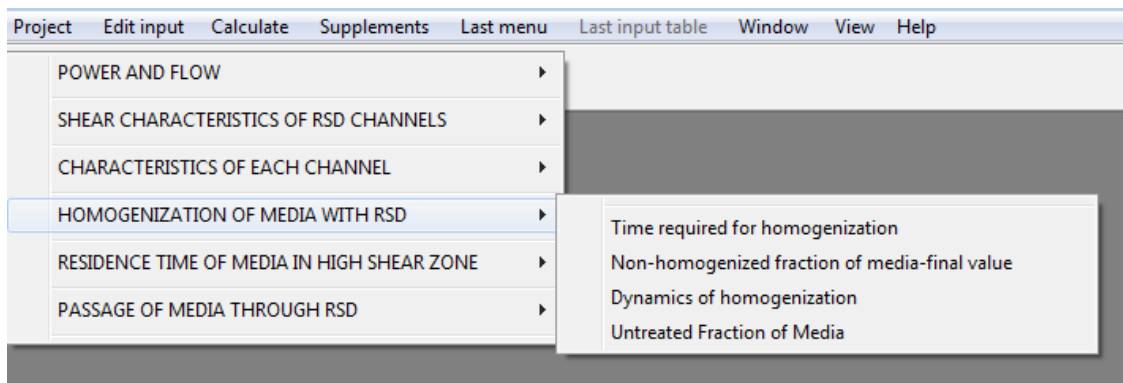
Figure 25.

In response, the program provides a list of initial data necessary for mathematical modeling (Figure 26).
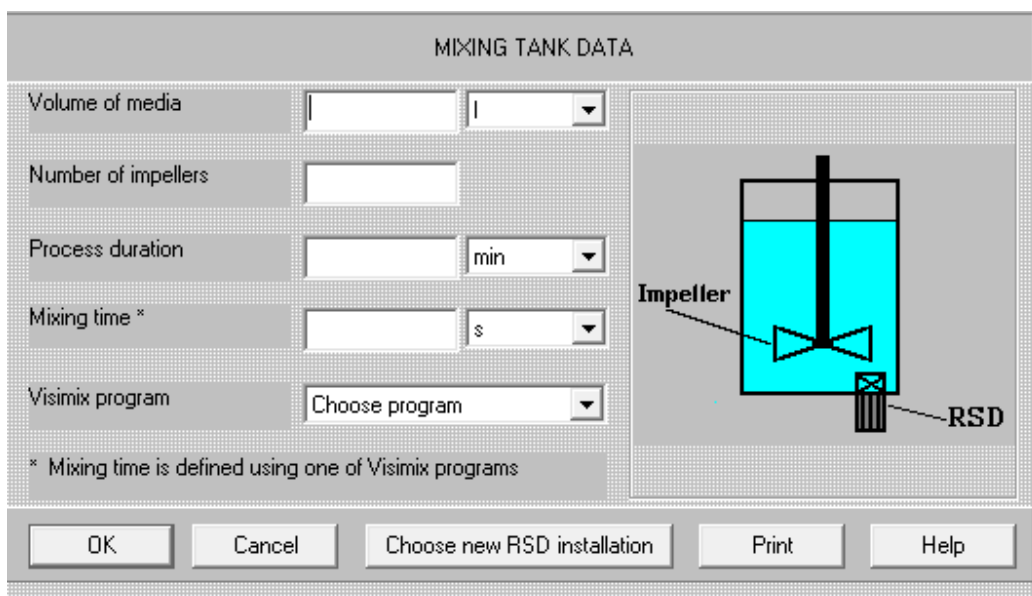

Figure 26.

Filling of the first two boxes is clear – you enter 450 l as **Volume of media** and 1 as **Number of impellers** – accordingly to the **Initial data** presented above.
Value of **Process duration** has to be estimated preliminarily as desirable or reasonable duration of batch. In our case – for 450 liter volume – 30 min seems to be a reasonable value. The last necessary input parameter – Mixing time – is necessary in order to define intensity of macro-scale mixing in the tank. It has to be calculated using one of the VisiMix programs. Our case – mixing with anchor agitator – corresponds to field of application of the program VisiMix Turbulent, calculated mixing time value is 23.5 sec.

After the data are entered (Figure 27), results of mathematical modeling are displayed (Figure 28).
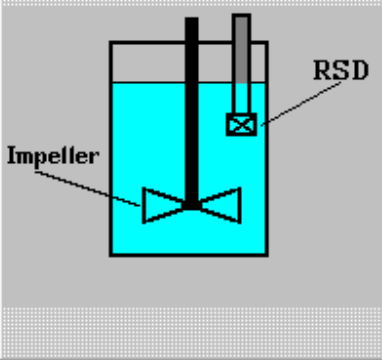
Figure 27.

Figure 28.

For additional information, click **Last menu** and select **Non-homogenized fraction of media – final value.**

NON-HOMOGENIZED FRACTION OF MEDIA-FINAL VALUE

Parameter name	Units	Value
Process duration	s	1800
Non-homogenized fraction of media-final value	%	0.170

For HELP press F1

Figure 29.

Accordingly to results presented in these tables (Figures 28 and 29), the preliminarily entered process duration 30 min (1800 sec) is not long enough to achieve the outlined completeness of homogenization – the non-homogenized fraction is 0.17% instead of the required 0.1%. However, as it follows from the table in the Figure 28, the necessary process duration is close to the preliminary evaluation.

Select **Edit input>Mixing tank data** and enter 40 min as Process duration instead of 30 min (Figure 30).
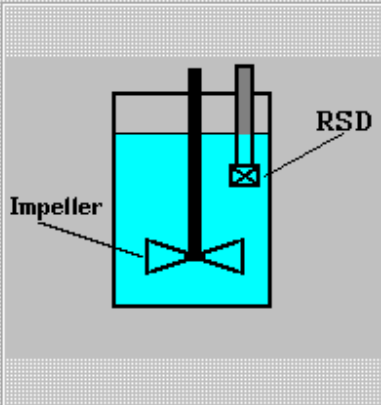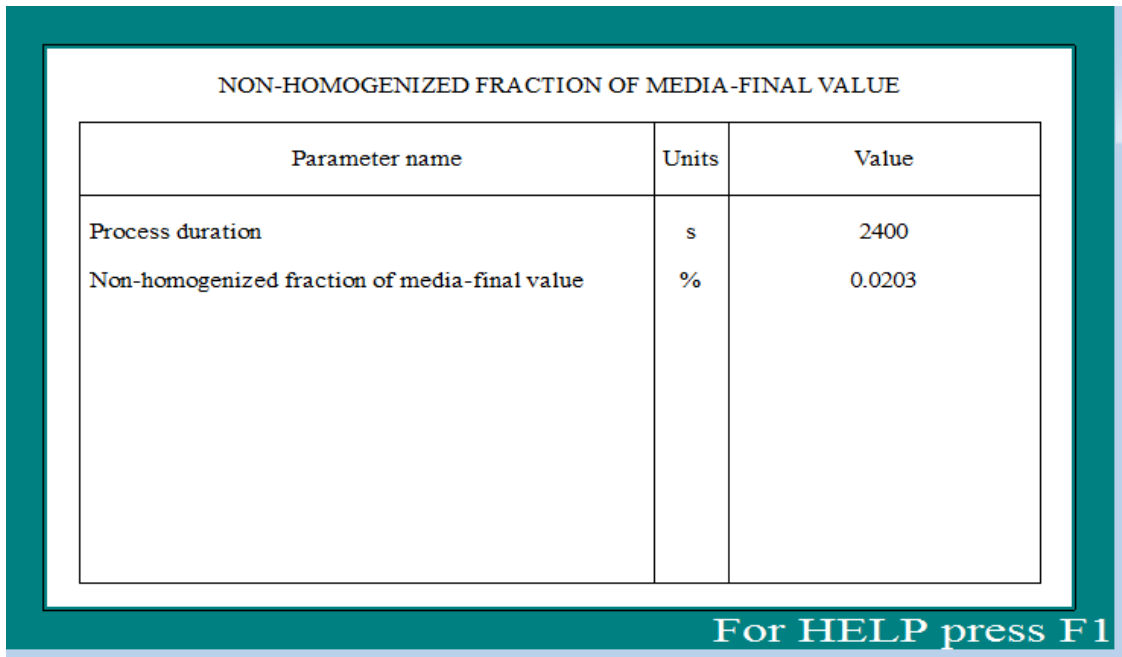

Figure 30.

Press OK. Results corresponding to the new input arrive in the output table (Figure 31).

NON-HOMOGENIZED FRACTION OF MEDIA-FINAL VALUE

Parameter name	Units	Value
Process duration	s	2400
Non-homogenized fraction of media-final value	%	0.0203

For HELP press F1

Figure 31.

It can be seen that the new value of **Non-homogenized fraction of media** corresponds to requirements mentioned above.