

VisiMix RSDE. Emulsifying with In-line RSD. Scaling-up.

Problem description.

Purpose of the operation – production of emulsion of organic solution in water on a construction site for an immediate consequent application. Necessary production rate – from 30 to 50 liter/min, volume relation of oil to water – 3:7. The emulsion is stabilized with a relatively mild emulsifier. Physical properties of the oil and water phased are presented in the Table 1 below.

Table 1.

Parameter	Value
Density of continuous phase	1000 kg/cub.m
Dynamic viscosity of continuous phase	1 cP
Density of disperse phase	860 kg/cub.m
Dynamic viscosity of disperse phase	3 cP
Interfacial tension	About 0.012 Pa.s
Volume fraction of the disperse phase	0.3

Testing of a new technology was performed using a rotor-stator disperser (RSD) with design characteristics presented in the Table 2. The positive results have been obtained at rotation velocity 6500 rpm and flow rates of emulsion 10-20 liter/min.

Table 2. Dimensions of the pilot RSD, mm.

Detail name	Internal diameter	External diameter	Internal height	External height	Number of slots	Height of slots	Width of slots
Rotor 1	41	47	11	12	32	11	1.7
Stator 1	48	54	12	12	32	12	1.7
Rotor 2	55	61	12	12	32	12	1.7
Stator 2	62	68	12	12	32	12	1.7
Rotor 3	69	75	12	14	32	12	1.7
Stator 3	75.5	82	14	14	32	12	1.7

A sample of the emulsion obtained after process stabilization was and analyzed. The main part of the disperse phase in the emulsion (about 80%) was presented by droplets with diameters less than 8 μm . The mean diameter of the droplets was estimated as 6-7 μm . However, further increase of the emulsion flow rate proved to be impossible because of formation of larger droplets. In response to the developer's request, supplier of equipment recommended an in-line homogenizer with 3 consecutive dispersing rotor/stator stages and rotational speed up to 5800 rpm. The main dimensions of rotors and stators are shown in the Tables 3 - 5.

Table 3. Dimensions of the 3-stage RSD, mm. Stage 1.

Detail name	Type	Internal diameter	External diameter	Internal height	External height	Number of slots	Height of slots	Width of slots
Rotor 1	Slot	75	83	10	10	15	10	4
Stator 1	Slot	84	92	10	14	12	10	4

Table 4. Dimensions of the 3-stage RSD,mm. Stage 2.

Detail name	Type	Internal diameter	External diameter	Internal height	External height	Number of slots	Height of slots	Width of slots
Rotor 1	Slot	57	65	10	10	24	10	3
Stator 1	Slot	66	74	10	10	21	10	3
Rotor 2	Slot	75	83	10	10	24	10	3
Stator 2	Slot	84	92	10	14	21	10	3

Table 5. Dimensions of the 3-stage RSD, mm. Stage 3.

Detail name	Type	Internal diameter	External diameter	Internal height	External height	Number of slots	Height of slots	Width of slots
Rotor 1	Slot	42	49.5	10	10	42	10	1.2
Stator 1	Slot	50	58	10	10	54	10	1
Rotor 2	Slot	58.5	66.5	10	10	42	10	1.2
Stator 2	Slot	67	75	10	10	54	10	1
Rotor 3	Slot	75.5	83.5	10	10	42	10	1.2
Stator 3	Slot	84	92	10	14	54	10	1

Subject of application of the program VisiMix RSDE – to evaluate applicability of this device for manufacturing of the described emulsion (see Table 1) with production capacity up to 50 l/min.

Step 1. Mathematical modeling of emulsifying in the pilot installation.

1.1. Entering initial data for the pilot RSD.

1.1.1. Start VisiMix RSDE. Open a new project by selecting **Project > New** in the main menu and save it under the name **RSDE_002_pil**.

1.1.2. In the arriving visual menu (Fig.1) select the scheme **RSRSRS** corresponding to the 3-stage pilot RSD and confirm selection with **OK** (Fig.2).

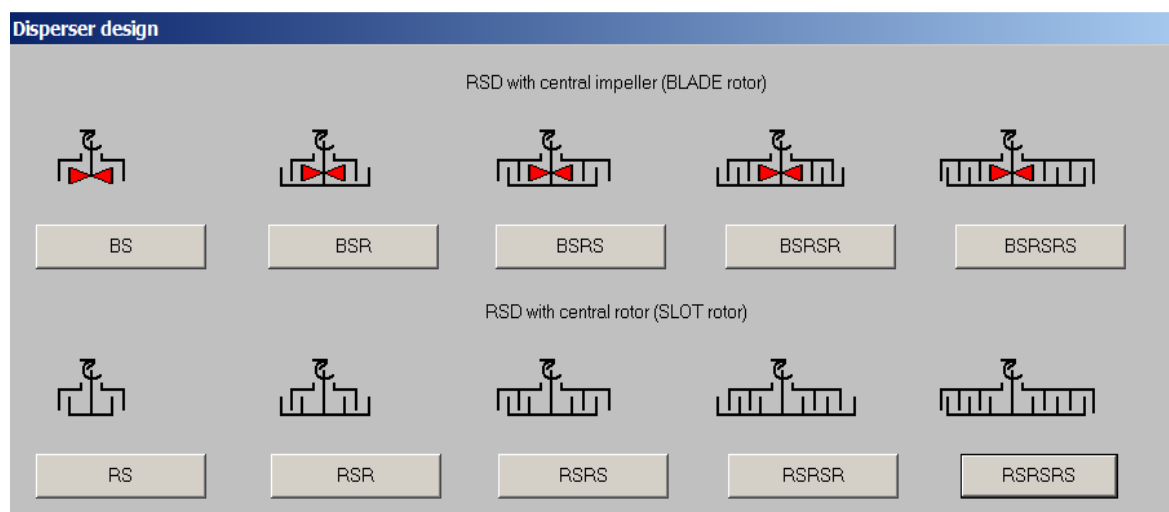


Figure 1.

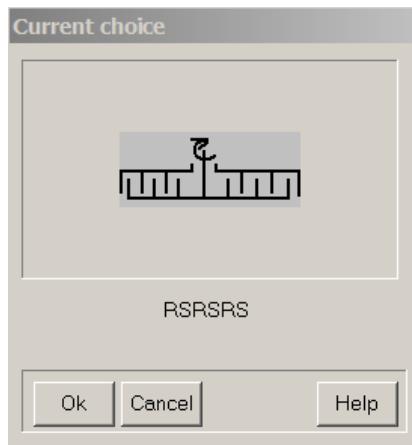
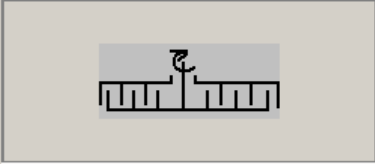


Figure 2.

1.1.3. Using data of the Table 2, enter rotor speed and diameters of rotors and stators accordingly to requests of the arriving input table (Fig.3).

Rotational speed Rpm



	ROTORS		STATORS	
Internal diameter	<input type="text" value="41"/>	<input type="text" value="mm"/>	<input type="text" value="48"/>	<input type="text" value="mm"/>
External diameter	<input type="text" value="47"/>	<input type="text" value="mm"/>	<input type="text" value="54"/>	<input type="text" value="mm"/>
Internal diameter	<input type="text" value="55"/>	<input type="text" value="mm"/>	<input type="text" value="62"/>	<input type="text" value="mm"/>
External diameter	<input type="text" value="61"/>	<input type="text" value="mm"/>	<input type="text" value="68"/>	<input type="text" value="mm"/>
Internal diameter	<input type="text" value="69"/>	<input type="text" value="mm"/>	<input type="text" value="75.5"/>	<input type="text" value="mm"/>
External diameter	<input type="text" value="75"/>	<input type="text" value="mm"/>	<input type="text" value="82"/>	<input type="text" value="mm"/>

Figure 3.

1.1.4. Confirm the input with **OK** and go to **Calculate**. Select **Drop diameter – cumulative density function** in the **Continuous flow emulsifying** sub-menu (Fig.4).

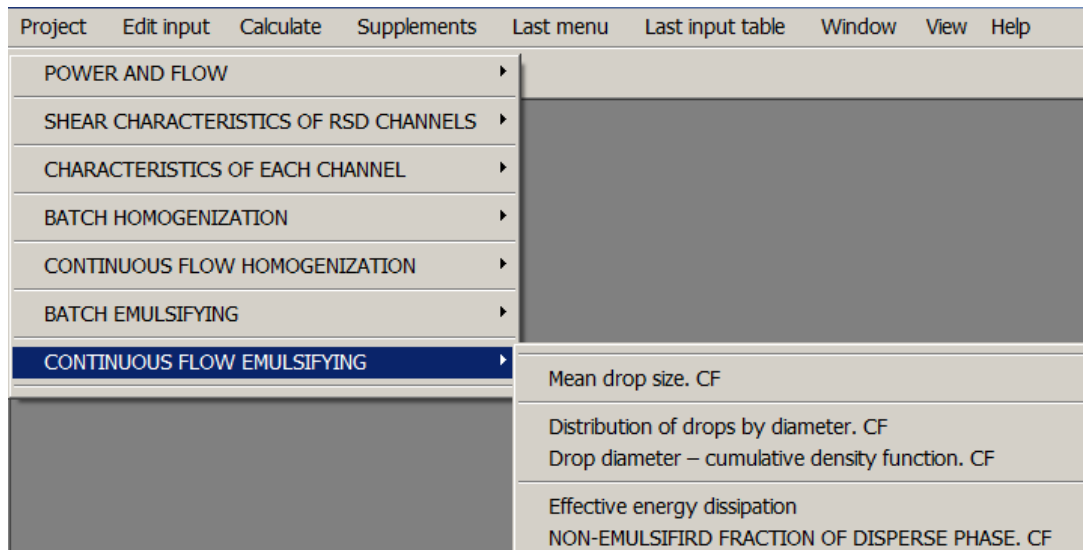


Figure 4.

Now, we have to enter **Average properties of media**. In general case, average density and viscosity of emulsion may depend on concentration and density of the disperse phase.

Average density of media is easily calculated basing on the densities and relative quantities of phases:

$$1000 \cdot 0.7 + 860 \cdot 0.3 = 968 \text{ kg/cub.m.}$$

After entering this figure and defining type of media as **Newtonian** (Fig.5), we have to enter average viscosity of media (Fig.6).

Change of viscosity caused by presence of disperse phase usually is not significant and its influence on shear rate in turbulent regime of flow can be neglected. So, in the current case viscosity of the continuous phase can be entered.

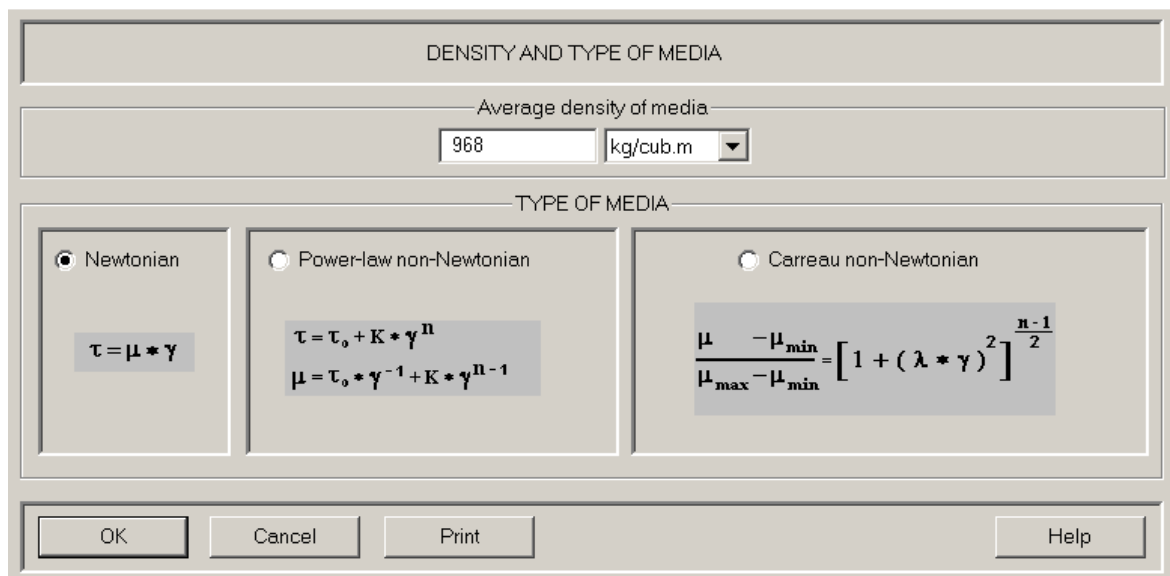


Figure 5.

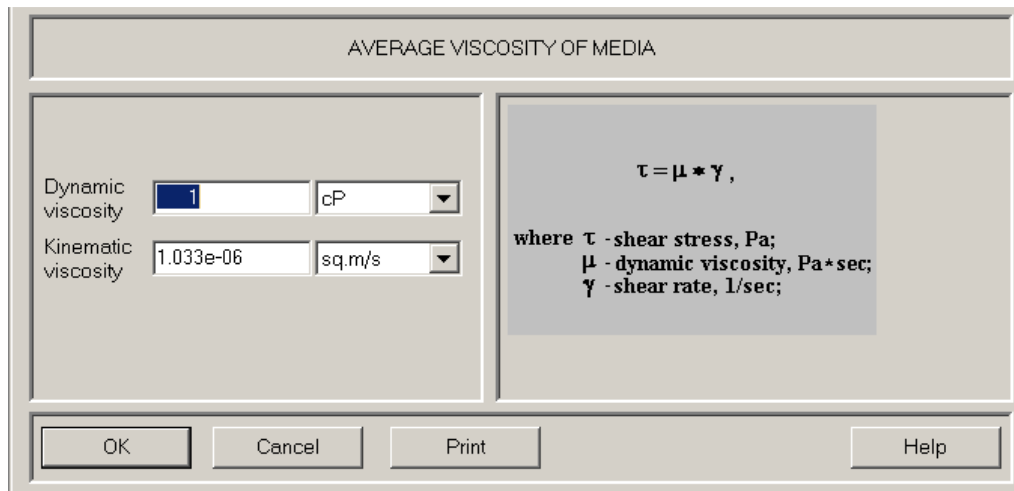


Figure 6.

1.1.5. After the data are confirmed with **OK**, a visual menu for selection of type of stator is displayed by the program (Fig.7). Select the **Slot** type and enter the data of the Table 2 for each stator, following the appearance of the input tables. Input table for the Stator 1 is shown in the Fig. 8.

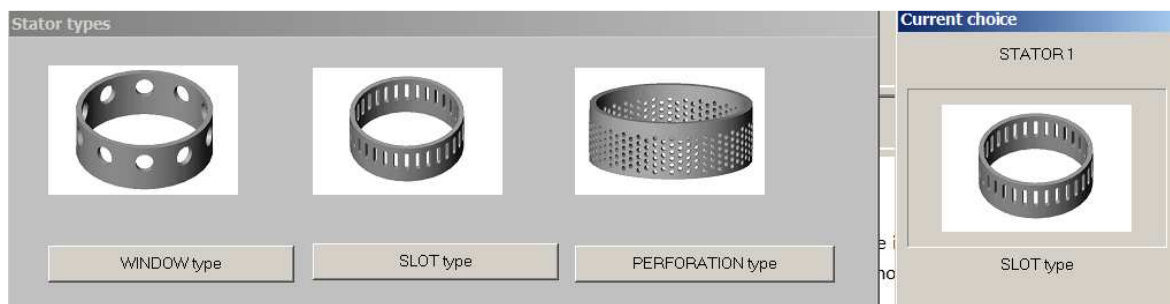


Figure 7.

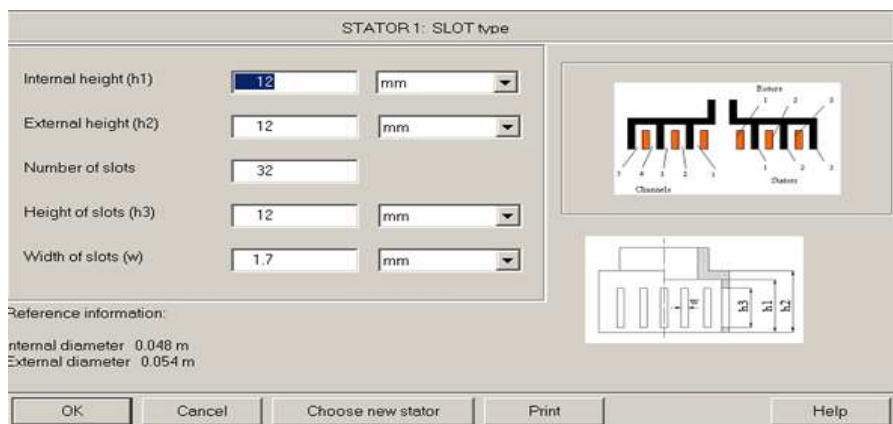


Figure 8.

1.1.6. Now, the program provides input tables for the **Slot** type rotors. Enter the data of the Table 2 for each rotor, following the appearance of the input tables. Input table for the Rotor 2 is shown in the Fig. 9.

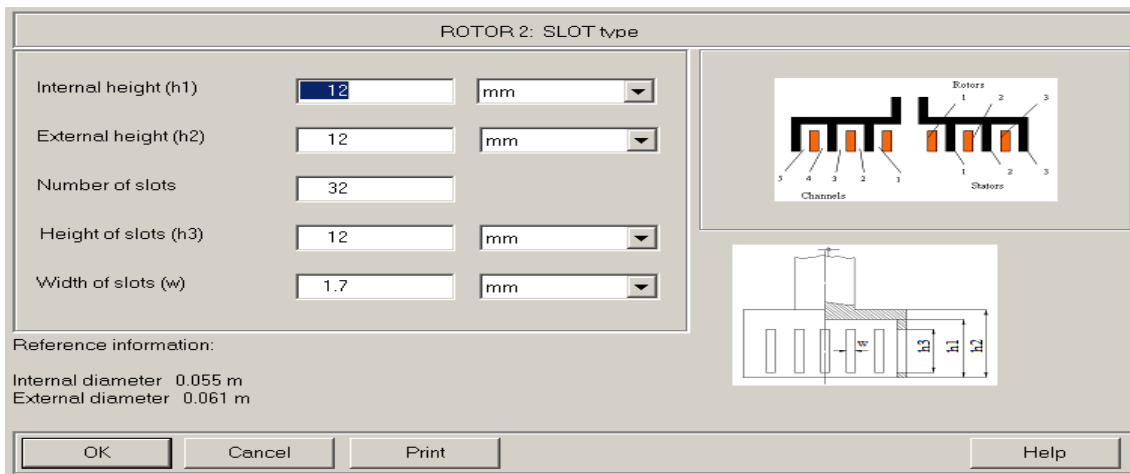


Figure 9.

1.2. Entering process data for the installation.

1.2.1. After the dimensions of the RSD are entered, the program provides a visual menu for selection of an installation scheme (Fig.10).

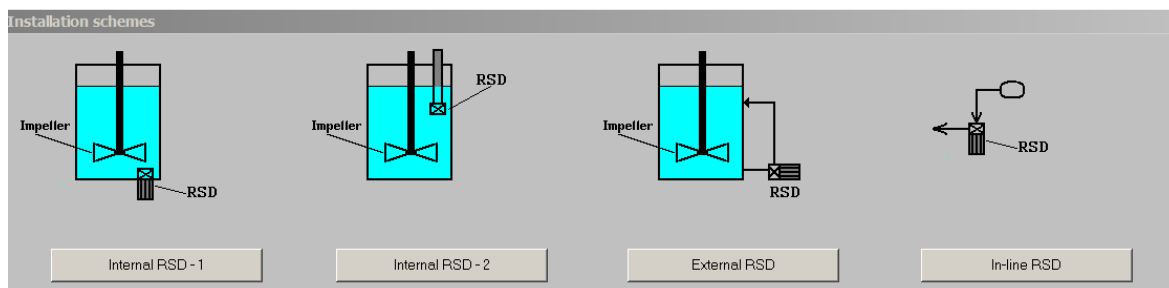


Figure 10.

Select **In-line RSD** and confirm the selection with **OK** (Fig.11).

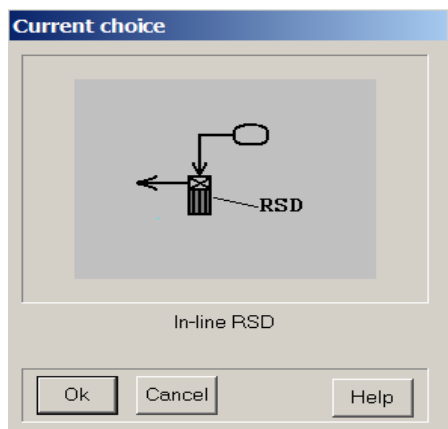


Figure 11.

1.2.2. Enter volume flow rate of emulsion corresponding to the process regime of the pilot emulsifier (Fig. 12).

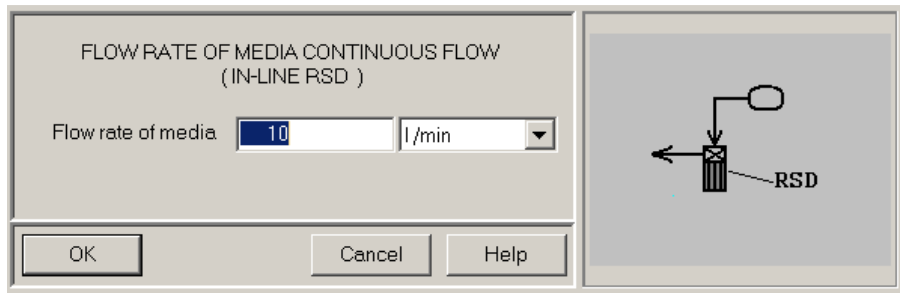


Figure 12.

1.2.3. After all general data are entered, the program displays request for specific information necessary for modeling of emulsifying. First of all, it is a table that defines necessary physical properties of phases (Fig.13). The most of data requested for input are accessible (see Table 1 above). The only un-known parameter in this table – **Index of admixtures**. As can be seen in the accompanying documentation (Help or User’s Guide), value of the **Index of admixtures** is a measure of an interphase electrostatic repulsing pressure: the higher is the **Index**, the higher is the repulsing pressure and the lower is probability of coalescence of droplets. Approximate value of the **Index** can be estimated basing on the recommendations presented in the reference part of the input table (Fig.13). In our case, for emulsion with a mild emulsifier, let us enter 0.5 as the first approximation.

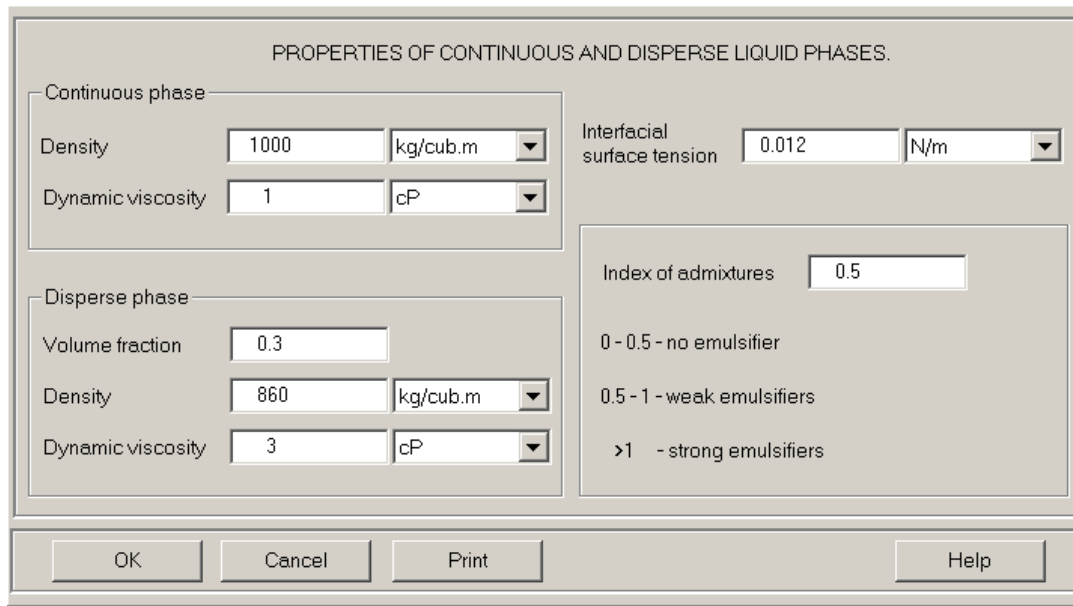


Figure 13.

1.2.4. The last input parameter of this section - **Initial drop size** requested in the Fig.14. The reference value presented in the Fig.14 is based on assumption that the two liquid phases are injected into the RSD separately. As can be learned in Help section, influence of this parameter on the final drop size is not significant, and the maximum value accepted by the program is 1 mm. So, we confirm the value 1000 micrometers that is displayed in the input line of the input table (Fig.14).

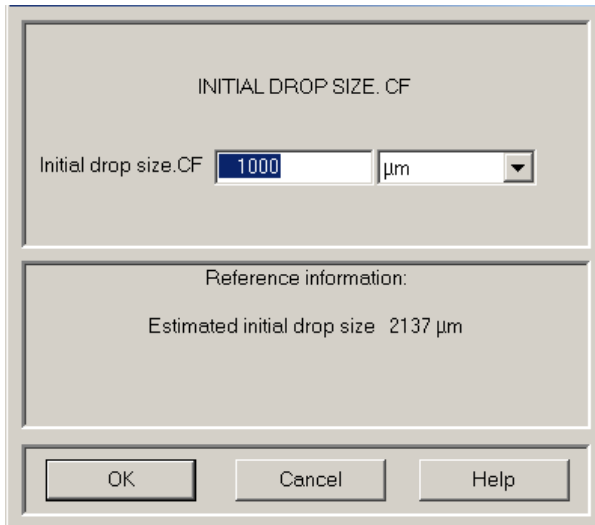


Figure 14.

1.3. Analysis of results.

1.3.1. After the value of Initial drop size has been confirmed with **OK**, the set of initial data is complete. Accordingly to our request (see par.1.1.4), the program performs mathematical modeling of the **Continuous flow emulsifying** and provides the output table containing the calculated values of the **Drop diameter - cumulative density function**. In the arriving graph (Fig.15) click **Start**. This graph provides information on expected distribution of droplets by size in the 'virtual' emulsion corresponding to the results of modeling. As follows from the graph, fraction of the droplets with diameter lower than 8 µm is about 60% only, i.e. too low as compared to the emulsion in the pilot tests. Presence of a relatively high quantity of large droplets (up to 15 µm) means that frequency of coalescence in the 'virtual' emulsion is higher than in the tested one.

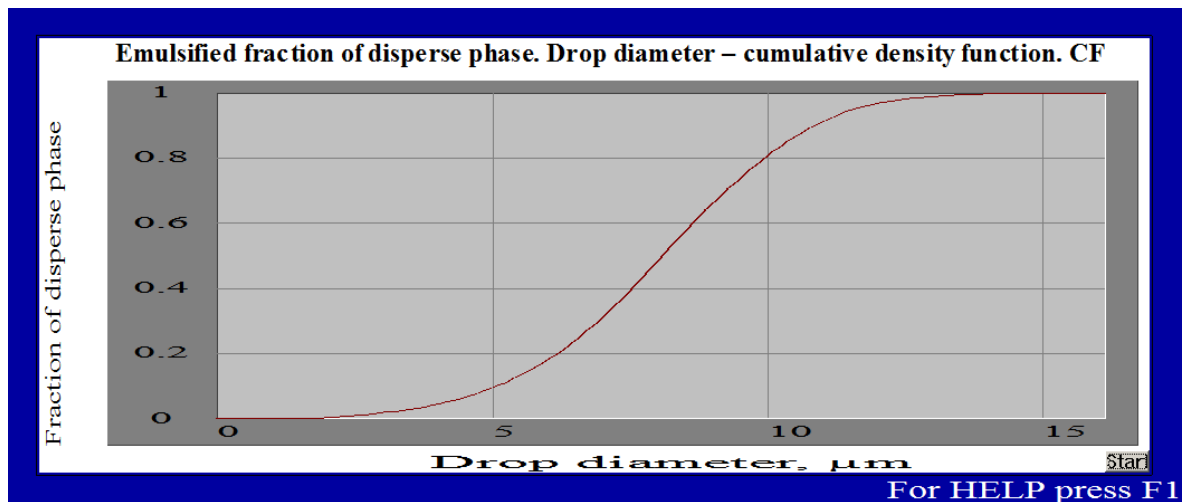


Figure 15.

1.3.2. Let us open the **Last menu** and select the **Mean drop size** (Fig 16).

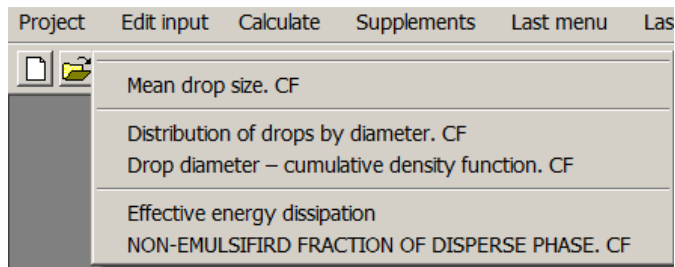


Figure 16.

EMULSIFIED FRACTION OF DISPERSE PHASE. MEAN DROP SIZE. CF		
Parameter name	Units	Value
Mean drop size of emulsified fraction. CF	µm	8.06
Emulsified fraction of disperse phase. CF	%	100

For HELP press F1

Figure 17.

The calculated value of Mean drop size (Fig.17) is also higher than the experimentally evaluated limits (see above).

1.3.3. Comparison of results of modeling with the measured values shows that frequency of coalescence in the 'virtual' emulsion is higher than in the tested one. In order to draw the model closer to the real data, we are going to correct the **Index of admixtures**. Select **Edit input > Properties & regime > Continuous and disperse liquid phases** and enter **Index of admixture** value '1' instead of '0.5'. Now repeat the calculations.

As it follows from the data in Figs 18 and 19, results of modeling with the **Index** value **1.0** are close enough to measured characteristics of the tested emulsion. Accordingly to the graph in the Fig.18, diameters of about 85% of droplets are less than 8 µm. The calculated value of the **Mean drop size** (Fig.19) is also close to the measured values.

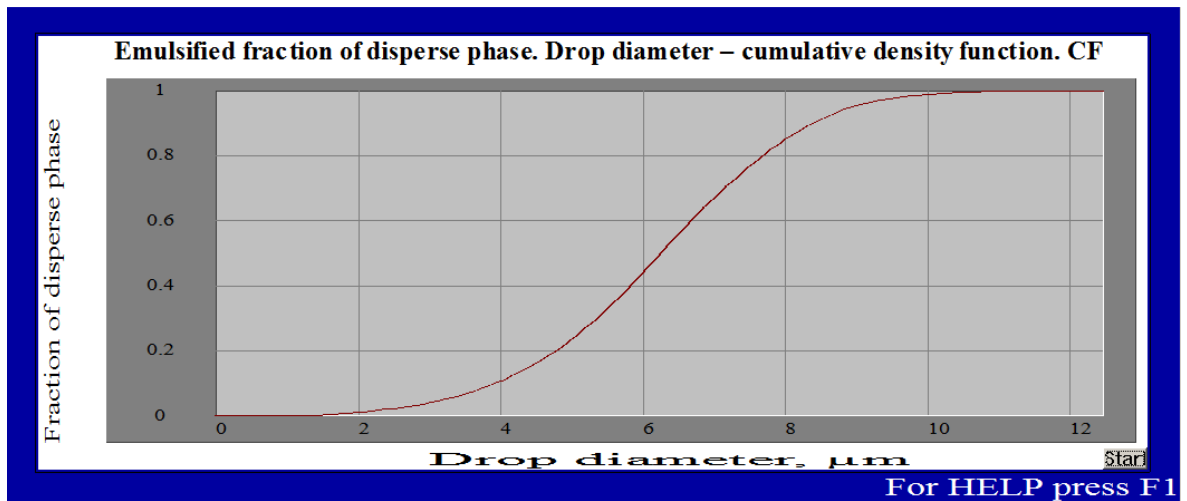


Figure 18.

EMULSIFIED FRACTION OF DISPERSE PHASE. MEAN DROP SIZE. CF		
Parameter name	Units	Value
Mean drop size of emulsified fraction. CF	μm	6.22
Emulsified fraction of disperse phase. CF	%	100

Figure 19.

So, the Index of admixture equal to 1 can be accepted for the further calculations.

Step 2. Modeling of emulsifying in the 3-stage in-line RSD (production scale).

2.1. Emulsifying in the 1st dispersing stage.

In order not to repeat entering physical properties of liquids (Figs 5, 6 and 13), let us create new project by editing the existing one. Go to the main menu, select **Project>Save as** and save the current project under a name **RSDE_002_St_1**.

2.1.1. Select **Disperser design** option via **Edit input** or using the corresponding icon. Now press **Change device** button in lower part of the **RSD DESIGN** window (Fig. 20).

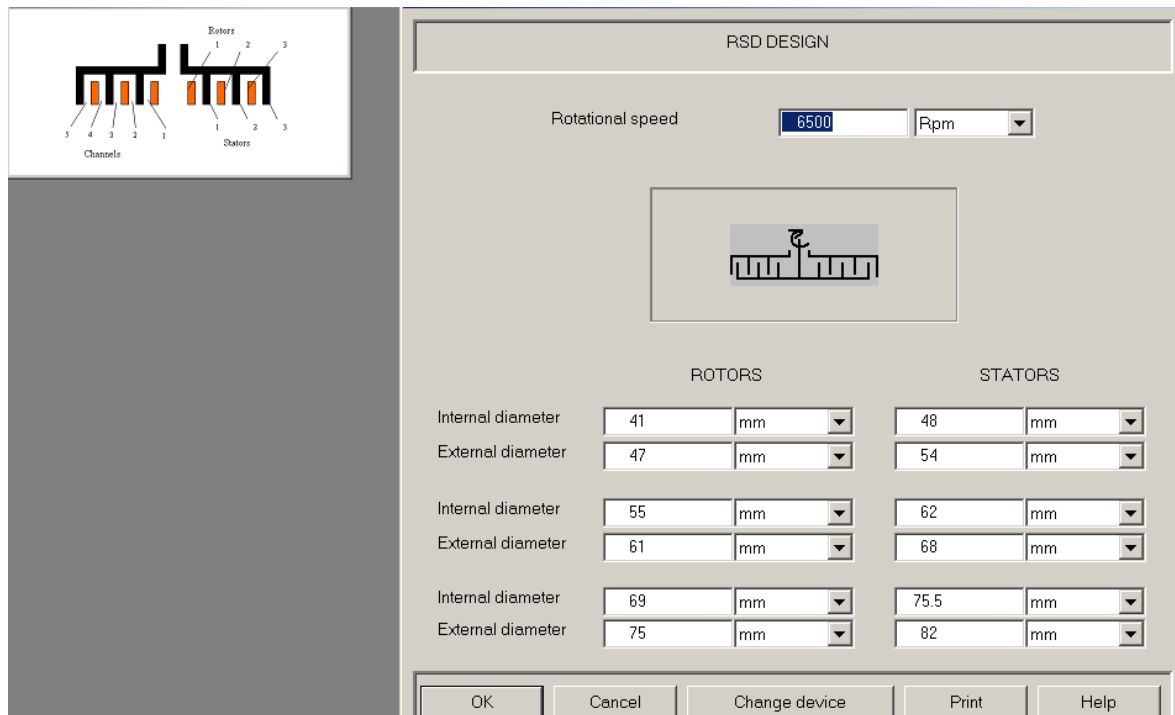


Figure 20.

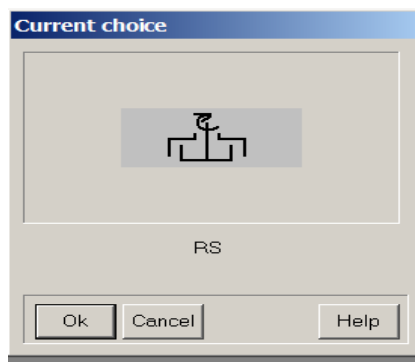


Figure 21.

In the arriving visual menu select scheme **RS** corresponding to design of the 1st stage of the 3-stage RSD (Fig. 21) and fill the input table for **RSD DESIGN** (Fig.22) using the data of the Table 3.

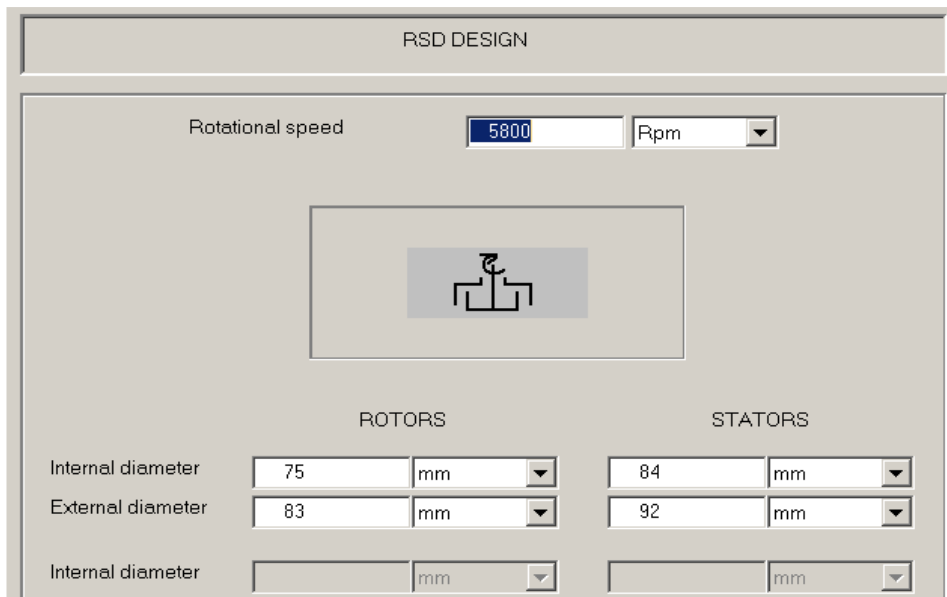


Figure 22.

2.1.2. Using the menu options **Edit input > Stators > Stator 1** and **Edit input > Stators > Rotor 1**, and enter dimensions of the slot stator and rotor from the Table 3 into corresponding input tables (Figs 23 and 24).

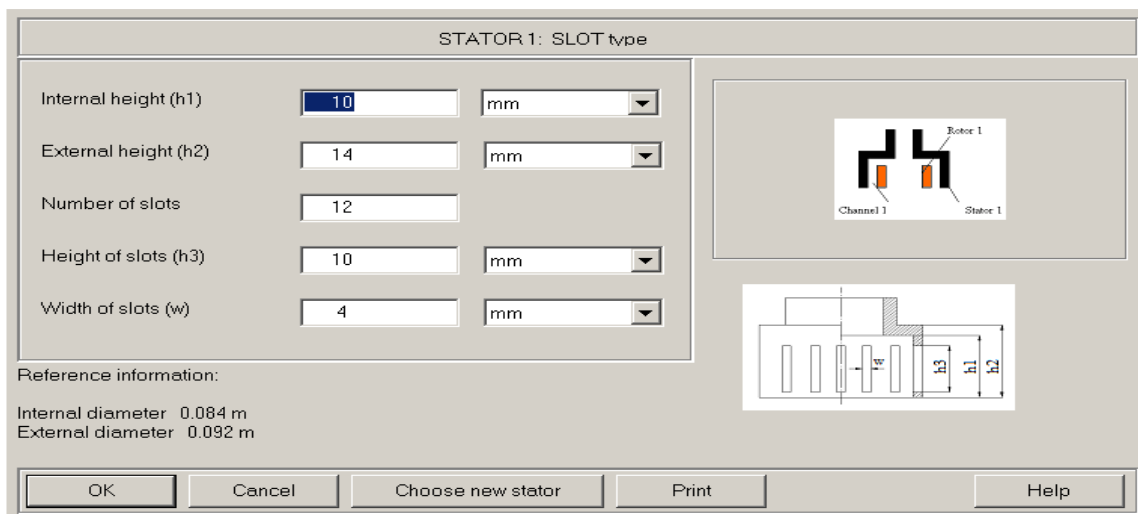


Figure 23.

ROTOR 1: SLOT type

Internal height (h1)	<input type="text" value="10"/>	mm
External height (h2)	<input type="text" value="10"/>	mm
Number of slots	<input type="text" value="15"/>	
Height of slots (h3)	<input type="text" value="10"/>	mm
Width of slots (w)	<input type="text" value="4"/>	mm

Reference information:
 Internal diameter 0.075 m
 External diameter 0.083 m

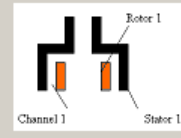
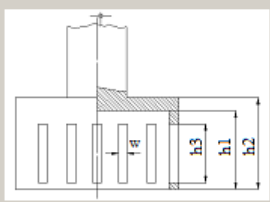



Figure 24.

2.1.3. After the design data are entered, let us go to the **Edit input** submenu and select **Properties & regime > Flow rate**. As a response, the program provides input tables for data on installation and regime parameters. As before (see par. 1.2), select the **In-line RSD** scheme (Fig. 25). Enter the maximum value of production capacity - 50 l/min - as the **Flow rate of media** into the next input table (Fig.26).

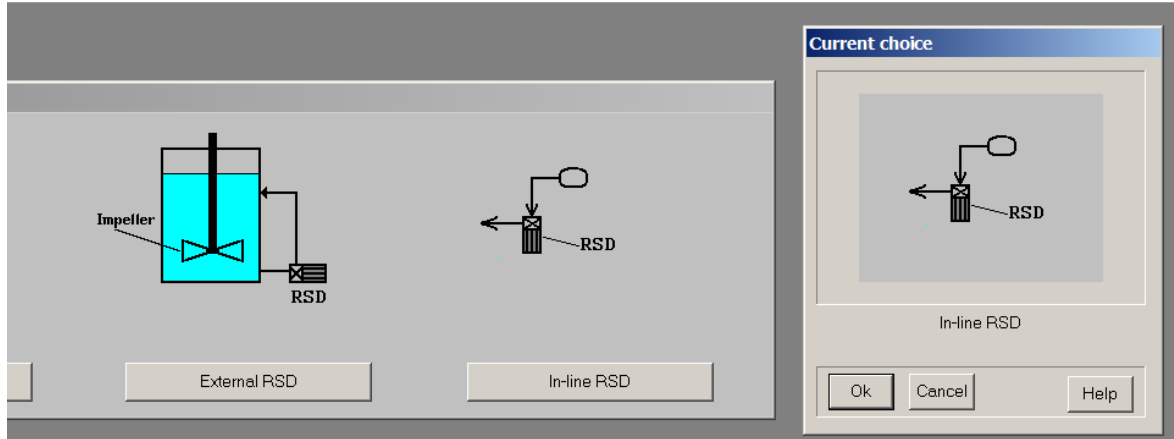


Figure 25.

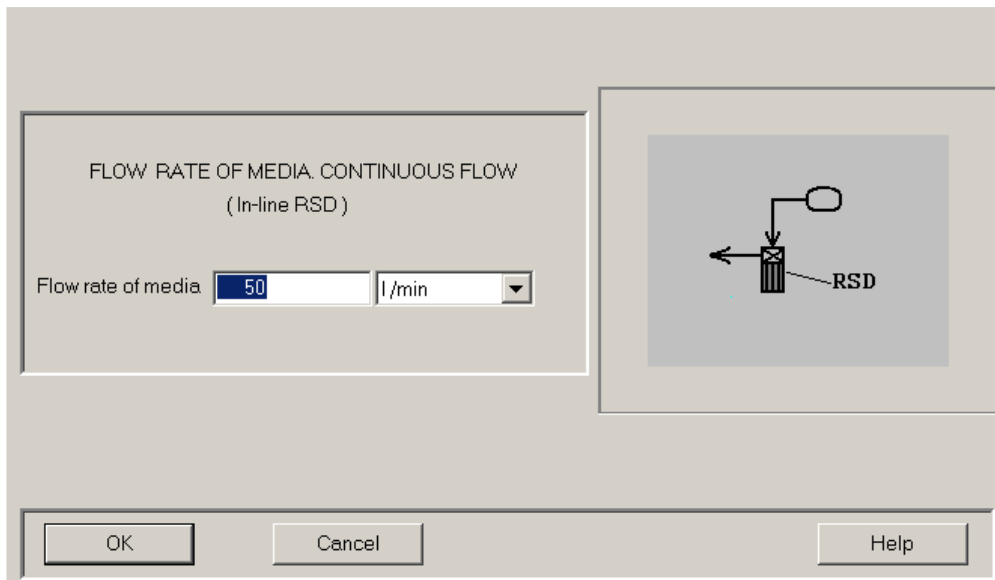


Figure 26.

2.1.4. Go to **Calculate** and select **Mean drop size** in the **Continuous flow emulsifying** sub-menu, as it has been done in the course of modeling of the pilot emulsifying test (Fig.4). The program provides the input table for entering the **Initial drop size**. Accordingly to the reference data in the lower part of the table (Fig 27), in this case estimated value of the Initial drop size – 384 μm - is within the acceptable limits, and we can enter this value in the input line (Fig. 28).

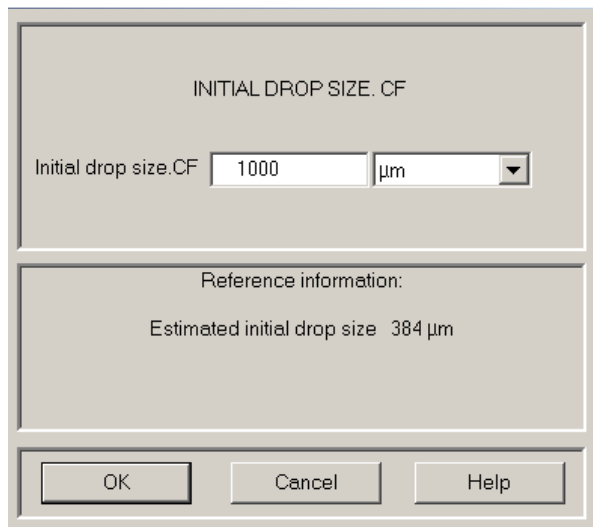


Figure 27.

INITIAL DROP SIZE. CF

Initial drop size.CF

Reference information:
Estimated initial drop size 384 µm

Figure 28.

EMULSIFIED FRACTION OF DISPERSE PHASE. MEAN DROP SIZE. CF

Parameter name	Units	Value
Mean drop size of emulsified fraction. CF	µm	61.9
Emulsified fraction of disperse phase. CF	%	100

For HELP press F1

Figure 29.

After the input is confirmed with **OK**, output window corresponding to our request arrives in the screen. **The calculated value of mean drop size of emulsion in the outlet flow of the 1st dispersing stage of RSD shown in this table will be used as the Initial drop size for modeling of emulsifying in 2nd dispersing stage.**

2.2. Emulsifying in the 2nd dispersing stage.

In order not to repeat entering physical properties of liquids (Figs 5, 6 and 13), let us create new project the same way as it has been done for the Stage 1 (par. 2.1). Go to the main menu, select **Project > Save as** and save the current project under a new name **RSDE_002_St_2**.

2.2.1. Select **Disperser design** option via **Edit input** or using the corresponding icon. Now press Change device button in lower part of the RSD DESIGN window (Fig. 20). In the arriving visual menu select the scheme **RSRS** corresponding to design of the 2nd stage of the 3-stage RSD and fill the input table for **RSD DESIGN** (Fig.30) using the data of the Table 4.

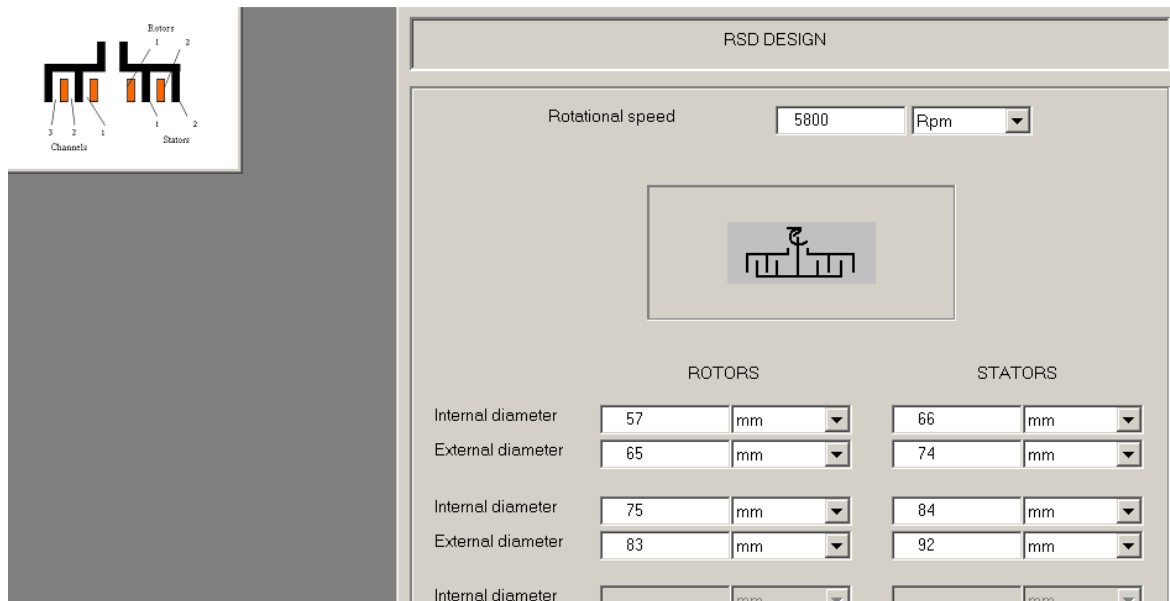


Figure 30.

2.2.2. As in par. 2.2.1, select **Slot types** and enter dimensions of the rotors and stators accordingly to data of the Table 4.

2.2.3. Select **Edit input > Properties & Regime > Flow rate**. Select **In-line RSD** in the visual menu (Fig. 25) and confirm **Flow rate** 50 l/min (Fig. 26).

2.2.4. Go to **Calculate** and select **Mean drop size** in the **Continuous flow emulsifying** sub-menu, as it has been done in the course of modeling of the pilot emulsifying test (Fig.4). The program provides the input table for entering **Initial drop size** (Figure 31). Enter value of the mean drop size 61.9 μm –accordingly to the results of modeling of the 1st dispersing stage (par.2.1.4). After the input is confirmed with **OK**, output window corresponding to our request arrives in the screen (Fig. 32).

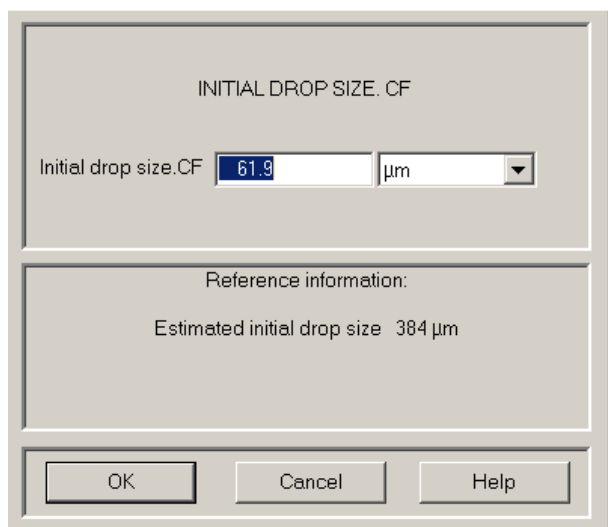


Figure 31.

The calculated value of **Mean drop size** of emulsion in the outlet flow of the 2nd stage of RSD shown in this table will be used as the Initial drop size for modeling of emulsifying in 3d stage of the RSD device.

EMULSIFIED FRACTION OF DISPERSE PHASE. MEAN DROP SIZE. CF		
Parameter name	Units	Value
Mean drop size of emulsified fraction. CF	μm	10.4
Emulsified fraction of disperse phase. CF	%	100

For HELP press F1

Figure 32.

2.3. Emulsifying in the 3d dispersing stage.

As follows from data of the Table 5, the rotor / stator disperser of the 3d stage consists of 3 concentric slot type rotors and stators and corresponds to the scheme RRSRS in the visual menu (Fig.1). So,save the current project as **RSDE_002_St_3**.

2.3.1. Select **Disperser design** option via **Edit input** or using the corresponding icon. Now press Change device button in lower part of the RSD DESIGN window (Fig. 20). In the arriving visual menu select the scheme **RRSRS**. Fill the input table for **RSD DESIGN** (Fig.33) using the data for the rotors and stators presented in the Table 5.

	ROTORS		STATORS	
Internal diameter	42	mm	50	mm
External diameter	49.5	mm	58	mm
Internal diameter	58.5	mm	67	mm
External diameter	66.5	mm	75	mm
Internal diameter	75.5	mm	84	mm
External diameter	83.5	mm	92	mm

Figure 33.

2.3.2. As in par. 2.2.1-2.2.4:

- select **Slot types** and enter dimensions of the rotors and stators accordingly to data of the Table 4.
- select **Edit input > Properties & Regime > Flow rate**. Select **In-line RSD** in the visual menu (Fig. 25) and confirm **Flow rate** 50 l/min (Fig. 26).
- go to **Calculate** and select **Mean drop size** in the **Continuous flow emulsifying** sub-menu (Fig.4). The program provides the input table for entering **Initial drop size** (Figure 34). Enter 10.4 μm – accordingly to the results of modeling of the 2nd dispersing stage (par.2.2.4).

Figure 34.

After the input is confirmed with OK, output window corresponding to our request arrives in the screen (Fig. 35).

Parameter name	Units	Value
Mean drop size of emulsified fraction. CF	μm	5.61
Emulsified fraction of disperse phase. CF	%	100

For HELP press F1

Figure 35.

2.3.3. Now select **Last menu > Drop diameter – cumulative density function** (Fig.36) and click **Start** button in the arriving window. The graph of drop size distribution arrives in the Fig.37.

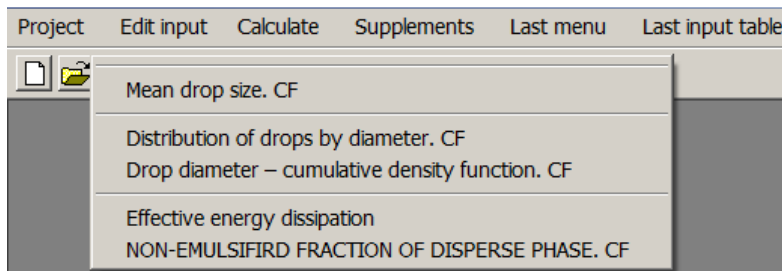


Figure 36.

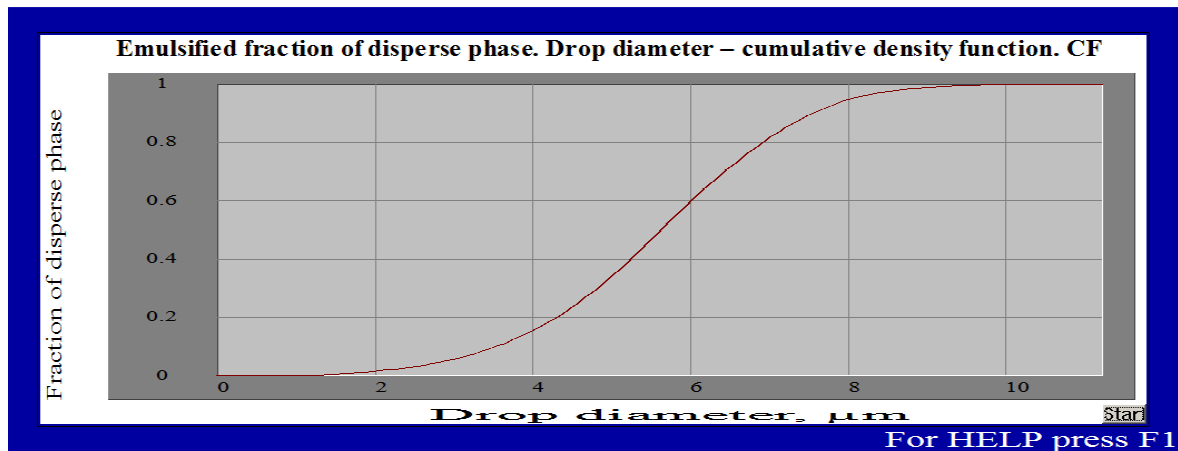


Figure 37.

2.3.4. The results of mathematical modeling presented in the Figs 35 and 37 characterize expected parameters of emulsion in the outlet of the 3-stage disperser. For evaluation, these data are compared in the Table 6 with parameters of the tested emulsion (results of the pilot emulsifying) and with results of mathematical modeling of the pilot operation.

Table 6.

Parameter of emulsion	Pilot - test	Pilot-modeling	Production-modeling
Mean drop size	6 – 7 μm	6.22 μm	5.61 μm
Fraction of drops with diameter less than 8 μm	About 80%	About 85%	About 90%

Data of the Table 6 allow to assume that dimensions of drops in the emulsion produced with the simulated 3-stage in-line RSD will be close enough to the parameters achieved in the pilot tests.