# 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:

# Shear Stress = 5.87 \* Shear Rate <sup>0.678</sup>

#### Table 1. Results of the laboratory tests.

No.	Rotational speed,	Description of results
	rpm	
1	Max. speed -	Insertion of air. After separation (about 30 min) – good
	20000	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)

Project Edit input Calculate Supplements L	ast menu 🛛 Last input ta	able Wir	ndow View	Help
022 📓 📓 🛯 🕞 🖉 🖽				
Figure 1.				
🖬 Enter a project name		×		
Save in: 🚺 RSD projects 💌	← 🗈 📸 🖛			
Name	Date modified	т		
Ex1_Port.rsd	12/25/2010 4:18 PM	RS		
٠ III				
File name: Ex1_Port	Save			
Save as type: VisiMix Project Files (*.rsd)	✓ Cancel			

### 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)





Current o	hoice	
	r <mark>∛</mark> j	
	BS	
Ok	Cancel	Help



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.

	RSD SCHEME	AND RO	TATIONAL	. SPEED		
Rota	Rotational speed		e+04	Rpm	•	
		e L	<b>`</b>			
	ROT	ORS			STATORS	
Internal diameter		mm		21	mm	
External diameter	20	mm		25	mm	
Internal diameter		mm		<u> </u>	mm	
External diameter		mm		<u> </u>	mm	
Internal diameter		mm		[	mm	
External diameter		mm			mm	
ОК	Cancel	Choose n	ew schem	e	F	rint

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.

	S.	TATOR 1: S	LOT type	
Internal height (h1)	15	mm	•	
External height (h2)	18	mm		
Number of slots	12			Channel 1 Stator 1
Height of slots (h3)	14	mm		
Width of slots (w)	1	mm		
Reference values:				
Internal diameter 0.021 m External diameter 0.025 m	n			
OK Cano	el Choos	e new stator	Prin	t Help

# 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).

ROTOR 1: BI	ADE type
Number of blades 4 Height of blades (h) 14 mm	Channel 1 Stator 1
Reference values: Internal diameter 0 m External diameter 0.02 m	, and the second s
OK Cancel Print	Help

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.

PARAMETERS OF RHEOLOGY POWER-LAW NON-NEWTONIAN						
Constant K 5.87 Pa*(sec) n	$\begin{split} \tau &= \tau_{o} + \mathrm{K} \star \gamma^{n} \\ \mu &= \tau_{o} \star \gamma^{-1} + \mathrm{K} \star \gamma^{n-1}  , \end{split}$					
Exponent n 0.678 Yield stress 0t N/sq.m 💌	where μ -effective viscosity, Pa*sec; γ -shear rate, 1/sec; τ -shear stress, Pa; τ <sub>o</sub> -yield stress, Pa.					
OK Cancel Print	Help					

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).

Proje	ect	Edit input	Calculate	Supplements	Last menu	La	st input table	Window	View	Help
	POW	ER AND FLC	w		×					
	SHEA	AR CHARAC	TERISTICS OF	RSD CHANNELS	×		Shear Rates			
	CHA	RACTERISTI	CS OF EACH	CHANNEL	+		Shear Stresses			
	ном	IOGENIZATI	ION OF MEDI	A WITH RSD	+		Specific Powe	r		
	RESIE	DENCE TIME	OF MEDIA IN	I HIGH SHEAR ZO	DNE F		Effective Visco	osity		
	PASS	AGE OF ME	DIA THROUG	H RSD	•		Surface Veloci	ity of Rotors	;	
							Width of Char	nnels		

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.

SHEAR RATES								
Parameter name	Units	Value						
Channel 1	1/sec	12600						
	F	or HELP press	I					

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.

	RSD S	CHEME	AND RO	DTATIONAL	. SPEED		
Rota	Γ	15000	Rpm	T			
			, L	<b>i</b>			
		ROT	TORS			STATOR	S
Internal diameter			mm		21	mm	1 <b>T</b>
External diameter	20	)	mm		25	mn	ı 🔽
Internal diameter			mm			mm	1
External diameter			mm		ĺ	, mr	n 🔽
Internal diameter			mm	-		mn	ı 🔽
External diameter			mm			, mr	
ок	Cance		Choose	new schem	e		Print

Figure 13.

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

Γ	SHEAR RATES								
	Parameter name	Units	Value						
	Channel 1	1/sec	8270						
For HELP press F									

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.

	RSD SCHEM	IE AND ROT.	ATIONAL S	PEED		
Rota	3	000	Rpm	•		
		77				
		٦	ה			
	н	UTURS		51	ATURS	
Internal diameter	92	mm	•	102	mm	
External diameter	100	mm		110	mm	
Internal diameter		mm			mm	
External diameter		mm	ē		mm	
Internal diameter		mm			mm	
External diameter		mm	E [		mm	
ОК	Cancel	Choose ne	w scheme	]	F	rint

Figure 16.

	STATOR 1: SLOT	tvoe	
Internal height (h1)	mm		Pitel
External height (h2)	40 mm	•	
Number of slots	30		Channel ] Stator 1
Height of slots (h3)	30 mm		
Width of slots (w)	3 mm		
Reference values: Internal diameter 0.102 m External diameter 0.11 m			
OK Cance	el Choose new stator	Print	Help

Figure 17.

	ROTOR 1: S	LOT type	
Internal height (h1)	mm		Rotor 1
External height (h2)	33 mm		
Number of slots	30		Channel 1 Stator 1
Height of slots (h3)	28 mm	<b>_</b>	~.t~,
Width of slots (w)	3 mm		
Reference values:			
Internal diameter 0.092 m External diameter 0.1 m			्रिया स्व स्व स्व
OK Cance	el Print		Help

# 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** (Figure 19).

Proj	ect Edit input Calculate Supplements Last	menu	Las	t input table	Window	View	Help
	POWER AND FLOW	×		Power			
	SHEAR CHARACTERISTICS OF RSD CHANNELS	×		Flow Capacity			1
	CHARACTERISTICS OF EACH CHANNEL	×		Torque Momer	nt - total		
	HOMOGENIZATION OF MEDIA WITH RSD	×		Torque Momer	nts of Roto	rs	
	RESIDENCE TIME OF MEDIA IN HIGH SHEAR ZONE	•	-	*** draft *** DE	EBUG ***		
	PASSAGE OF MEDIA THROUGH RSD	•					

Figure 19.

POWER							
Parameter name	Units	Value					
Power	w	1550					
For HELP press F							

# 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).

Project	t Edit input	Calculate	Supplements	Last menu	La	st input table	Window	View	He
PC	OWER AND FLC	W		•					
SF	HEAR CHARACT	TERISTICS OF	RSD CHANNELS	•		Shear Rates			
CI	HARACTERISTI	CS OF EACH	CHANNEL	•		Shear Stresse	s		1
H	IOMOGENIZATI	ON OF MEDI	A WITH RSD	•		Specific Powe	er		Т
RE	ESIDENCE TIME	OF MEDIA IN	N HIGH SHEAR Z	DNE 🕨		Effective Visc	osity		Т
PA	ASSAGE OF ME	DIA THROUG	H RSD	•		Surface Veloc	ity of Rotors	;	1
						Width of Cha	nnels	_	J

Figure 21.

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

_				
		SHEAR RATES		
	Parameter name	Un	its Value	•
	Channel 1	1/s	ec 2200	D
			For HEL	P press F

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).

RSD SCHEME AND ROTATIONAL SPEED							
Rota	Rotational speed			Rpm	•		
		Ľ	<u>,</u>				
	RC	TORS		S	TATORS		
Internal diameter	92	mm		102	mm		
External diameter	100	mm		110	mm	•	
Internal diameter External diameter	[ [	mm			mm		
Internal diameter		jmm mm			jmm jmm		
External diameter	<u></u>	mm			mm		
ОК	Cancel	Choose n	ew scheme		F	Print	

Figure 23.

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

			٦				
SHEAR RATES							
Parameter name	Units	Value					
Channel 1	1/sec	8180					



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).

Project Edit input Calculate Supplements Last r	menu	Last input table Window View Help
POWER AND FLOW	•	
SHEAR CHARACTERISTICS OF RSD CHANNELS	×	
CHARACTERISTICS OF EACH CHANNEL	×	
HOMOGENIZATION OF MEDIA WITH RSD	•	Time required for homogenization
RESIDENCE TIME OF MEDIA IN HIGH SHEAR ZONE	•	Non-homogenized fraction of media-final value
PASSAGE OF MEDIA THROUGH RSD	F	Dynamics of homogenization Untreated Fraction of Media
	_	

### Figure 25.

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

	м	IIXING TAN	IK DATA	۱.		
Volume of media	l	<u> </u>	•			
Number of impellers						
Process duration		min	-	Impollon		
Mixing time *		s	-	Impener	$\neg \square$	
Visimix program	Choose progra	m	┏			RSD
* Mixing time is defined usir	ng one of Visimix p	rograms				
OK Cano	el Choose	e new RSD	installati	ion	Print	Help

# 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).

MIXING TANK DATA							
Volume of media	450	<u> </u>	•				
Number of impellers	1						
Process duration	30	min	•				
Mixing time *	23.5	s	⊡	Impeller		1	
Visimix program	Turbulent						
* Mixing time is defined using one of Visimix programs							
OK Cancel Choose new RSD installation Print Help							

Figure 27.

TIME REQUIRED FOR HOMOGENIZATION				
Parameter name	Units	Value		
Time for 95% homogenization	s	846		
Time for 98% homogenization	s	1100		
Time for 99% homogenization	s	1300		
Time for 99.9% homogenization	s	1950		
Time for 99.99% homogenization	s	2600		
For HELP press F				

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		



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).

MIXING TANK DATA							
Volume of media	450		<b>_</b>				
Number of impellers	1			Г		- <b>h</b>	RSD
Process duration	40	min	·				KOD
Mixing time *	23.5	s	<b>_</b>	Impeller			
Visimix program	Turbulent		•	L	-		
* Mixing time is defined using one of Visimix programs							
OK Cance	el Choc	ose new RSI	D installa	tion	Print		Help

Figure 30.

-				_	
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					

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

Figure 31.

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