Manual of the Hydrocyclone Software

CYCLONPLUS (Version 1.0)

by

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The Main Window of CYCLONPLUS

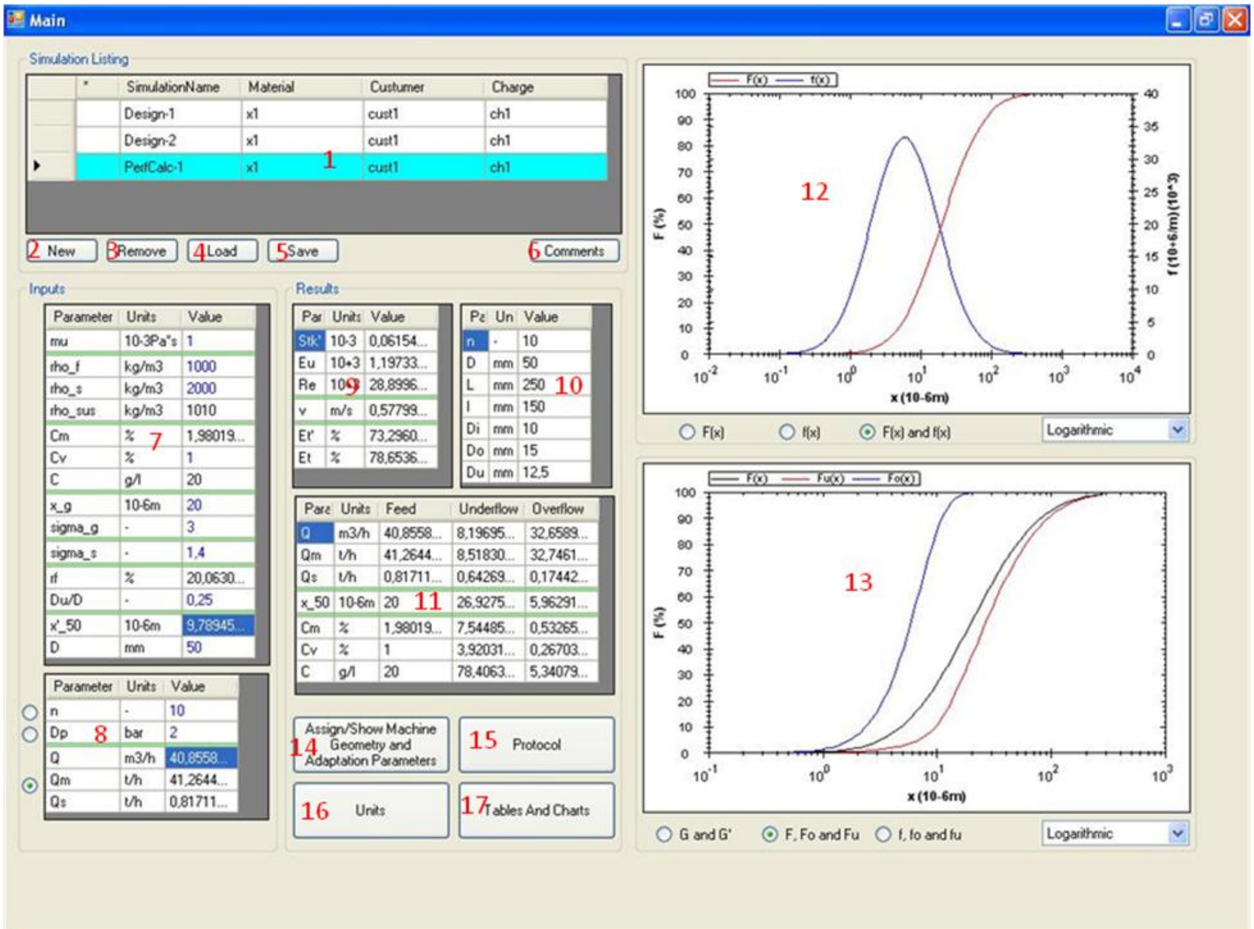


Fig. 1: The main window of CYCLONPLUS

1 Listing of all simulations. Each row represents one simulation. Each cell of the table is not only a display but also an input cell. Each simulation is characterized by the “SimulationName” (is not allowed that two simulations have the same name!) and the name of the suspension (Material-Customer-Charge). The first column (star-sign column) is to identify if one simulation is saved or has unsaved data. Having the star-sign in front of one simulation that means that we have unsaved data. The saving of the data is done by clicking “Save” (5). After saving the data the star-sign disappears.

2 *New*-Button creates a new simulation by adding and selecting a new row as the last table row and by duplicating the data of the last selected simulation. The program insert as default name the “_” sign in front of the name of the last selected simulation because it is not allowed for two simulations to have the same name. The user can change the name and any other data and save the new simulation by clicking the Save-command button (5)

3 *Remove*-button: Deletes the selected simulation

4 *Load*-button: For the selected simulation we can do any change. If these changes are not saved (indicated by the star-sign in front of the selected simulation) by clicking the Load-button we can return back to the saved data.

5 *Save*-button: Saves the current data of the selected simulation. It has only meaning to press "Save" if the star-sign is in front of the selected row as indication that we have unsaved data for this simulation.

6 *Comments*-button: Opens a small window allowing the writing of comments for the selected simulation.

7,8 Group of material, constructive and setting input/calculated parameters. We have to enter 6 "pure" material parameters and 5 constructive and setting parameters

Material Parameters:
-liquid viscosity (mu)
-liquid density (rho_f)
-solids or suspension density (rho_s or rho_sus)
-suspension solids mass fraction (Cm) or suspension solids volume fraction (Cv) or suspension solids concentration (C)
-median (x_g) of the particle size distribution by mass F(x)
-spread of the particle size distribution (sigma_g)

Constructive and setting parameters:

-spread of the reduced Grade Efficiency curve G'(x) (sigma_s)
-ratio of underflow volume rate to feed volume rate (rf) or ratio of underflow to cyclone diameter (Du/D)
-Cut size (x'_50) (=median of reduced Grade Efficiency curve) or cyclone diameter (D)
-2 of the following 3 parameters (number of cyclones (n), Pressure drop (Dp) and feed flow rate as volume rate, mass rate or solids mass rate (Q, Qm, Qs)

9 Values of the calculated dimensionless parameters: Stokes-Number (Stk'), Euler-Number (Eu) and Reynolds –Number (Re) as well as of the feed velocity: Feed flow rate Q related to the cyclone area A (= πD^2) and the reduced and absolute total grade efficiency E'_T and E_T.

10 Listing of the number of cyclones (n) and all geometrical parameters of the cyclone of the current simulation. These constructive data are based on the cyclone diameter D and the specific cyclone parameters which can be displayed and changed in the "Assign/show Machine Geometry and Adaptation Parameters" window (see command button (14)).

11 Listing of the flow rate, the median of the particle size distribution and the solids content for the Feed, the Underflow and the Overflow.

12 Particle size distribution of the feed by mass as Cumulative and/or Differential (F(x) and f(x)).

13 Reduced and absolute Grade Efficiency curves (G'(x) and G(x)) or particle size distributions for the feed the overflow and the underflow as cumulative or differential (F(x), Fo(x), Fu(x) or f(x), fo(x), fu(x))

14 *Assign/Show Machine Geometry and Adaptation Parameters* – Button: Opens the window for displaying and changing the 9 adaptation parameters, which are needed for the Cyclone calculation and the display and change of the specific geometrical parameters of the cyclone.

15 *Protocol*-button: Opens a small window for defining the options for the protocol as Word-document for the current simulation.

16 *Units*: Enables the changing of the units of the Volume and Mass flow rate.

17 *Tables And Charts*: Opens the Tables & Charts window for examining the influence of the suspension solids content and of all constructive and setting parameters on the cyclone performance. The results are displayed as diagrams and tables.

The Simulations Table: Displaying/ Selecting/ Creating/Saving/Deleting/Reloading Saved Simulations and Listing of all Simulations.

Fig. 2: The Simulations table in the main window

The simulations table enables the display of all saved simulations and the selection of any simulation. In the above example you see 3 saved simulations. The selected simulation is marked with a blue color and all data of the selected simulation are displayed in the main window.

One simulation is characterized by its Simulation Name (2). It is not allowed to have two simulations with the same name. Besides the simulation name we have 3 columns which characterize the suspension. Every suspension is characterized by a Material name (3), a Customer name (4) and a Charge name (5) (that is similar to the identification of a person by its family name, its father name and its first name). If for example we have a sand suspension then the material name is “Sand” but the customer name will depend on the company, which has the project or gave us the order. Although the same material and the same customer depending on the date we got a testing sample the particle size distribution and the suspensions concentration normally show variations. That’s why we need the Charge name to identify the sample, on which the tests or/and simulations are based.

Simulation name (2), Material name (3), Customer name (4) and Charge name (5) are directly entered in the table and any time can be changed. When doing a change in the selected simulation this is indicated by a star “*” in the first column of the table (1). The star-sign “*” in front of one simulation tells us that an unsaved change was done regarding this simulation. After selecting a simulation with “*” in the first column and after clicking the Save – button (9) then the new data are saved and the “*” disappears from this simulation.

If we exit the program and we have unsaved simulations (unsaved Simulations are indicated by the star-sign in front of the simulation) then we get the following message from the program:

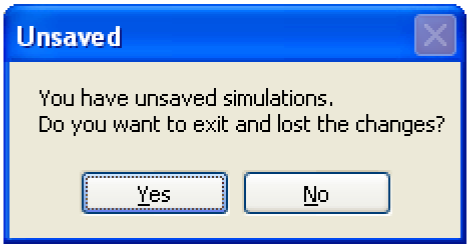


Fig. 3: When exiting the program we get this message for saving unsaved data

If we want to save the changes we have to click "No" and then select each simulation with the star-sign in the first column and press the "Save" button. We can not save all unsaved simulations at once!

The program enables to load the saved data of a simulation with changed data by selecting this simulation and by clicking the "Load" button (8). This enables the user to "play" with any simulation by changing the values of any parameter but then it has to possibility to return back to the saved data at any time by clicking the "Load" button.

To create a new Simulation we have to click the "New"-button (6). The program automatically duplicates the selected simulation and creates a new simulation in the last row of the table by giving a default Simulation name and displaying the star –sign in front of the new simulation as indication of an unsaved simulation. This new simulation is automatically selected (blue color). The default name of the new simulation is the same as the previous selected simulation with just the "_" sign in front of the name. The user can any time change this name by entering a new name in the Simulation name –field.

By clicking "Remove" (7) we delete the selected simulation.

To each simulation we can add a comment by clicking the Comments – button.

1. Column that shows if the data of the simulation are saved or not. When the star-sign "*" is displayed that means that the current data of the simulation differ from the saved data. By selecting the simulation with the star-sign and clicking the Save-button then the actual data of this simulation are saved and the star-sign disappears.
2. Input/display column for the name of the Simulation. It is not possible to have the same name for 2 simulations
3. Input/display column for the Material name of the suspension. A given suspension is characterized by the Material name, the Customer name and the Charge name (see also description below).
4. Input/display column for the Customer name of the suspension.
5. Input/display column for the Charge name of the suspension.
6. Creates a new simulation as duplication of the selected simulation and displays this new simulation in the last row as selected. The new created simulation has as default name the same as the previous selected with just an insertion of the "_" sign in front of the name and a star-sign in the first column as indication of an unsaved simulation.

7 Deletes the selected simulation

8 When we change the data of one simulation without saving the changes the star-sign is displayed in front of this simulation. When we select this simulation and we click “Load” the saved data of this simulation are displayed and the star-sign disappears. This “Load” possibility enables the testing of the influence of any parameter on the Cyclone performance with the possibility to return any time to the saved data.

9 Saves the selected simulation. The Save –button has sense only if the selected simulation has the star-sign in the first column (indication that this simulation has unsaved data).

10 Opens the comments –window that enables the input of comments to the current simulation. As soon as we start writing a comment the star-sign is displayed in front of the selected simulation. The comment is saved after clicking the Save –button (9).

The Input and Input/Calculated Material and Cyclon Geometrical & Setting Parameters

Parameter	Units	Value
mu 1	10-3Pa*s	1
rho_f 2	kg/m3	1000
rho_s 3	kg/m3	2600
rho_sus 4	kg/m3	1031.74...
Cm 5	%	5
Cv 6	%	1.98412...
C 7	g/l	51.5873...
x_g 8	10-6m	50
sigma_g 9	-	3
sigma_s 10	-	2
rf 11	%	6.94609...
Du/D 12	-	0.2
x'_50 13	10-6m	26.8510...
D 14	mm	100

Parameter	Units	Value
n 15	-	1
Dp 16	bar	0.75078...
Q 17	m3/h	10
Qm 18	t/h	10.3174...
Qs 19	t/h	0.51587...

Fig. 4: A listing of the necessary material, geometrical and setting parameters in the main window for the Hydrocyclone simulation:

The following material parameters are needed:

-viscosity and density of the mother liquid (mu and rho_f)
-density of the solids or the suspension (rho_s or rho_sus)
-suspension solids mass fraction or suspension solids volume fraction or suspensions concentration (Cm or Cv or C)
-median (x_g) and spread (sigma_g) of the particle size distribution by mass F(x)

The following constructive/setting parameters are needed:

-spread (sigma_s) of the Grade Efficiency curve G'(x)
- Ratio of underflow volume rate to feed flow rate (rf) or the specific underflow diameter Du/D
- Median of the reduced grade Efficiency curve (cut size) x'50 or the cyclone diameter D
-two of the following 3 parameters should be also input and the other one calculated (number of cyclones in parallel connection (n), pressure drop (Dp), feed flow rate (as volume feed rate Q, as mass feed rate Qm and as solids mass rate Qs).

Two typical calculation options are the following:
-Standard Calculation
-Cyclone Design

Typical Inputs for the Standard Calculation Option:
- D, n, Du/D, Q

We have as calculated parameters: x'50, Dp, rf

Typical Inputs for the Cyclone Design Option:
- x'50, Dp, rf, Q

We have as calculated parameters: D, n, Du/D

1 mu: Viscosity of the suspension liquid (mother liquid). Input in mili Pa s
2 rho_f:Density of the mother liquid
3 rho_s: Density of the solids. Instead of the solids density the suspension density can be entered and the solids density is calculated.
4 rho_sus: Suspensions density. Can be entered or calculated from the mother liquid density (rho_f) the solids density (rho_s) and the suspension solids concentration (cm or cv or c)
5 Cm: Solids mass fraction in the suspension (input/calculated)
6 Cv: Solids volume fraction in the suspension (input/calculated)
7 C: Suspension solids concentration (input/calculated)
8 x_g=x_{50}: Median particle size: F (x=x_g)=50% with F(x) the cumulative particle size distribution by mass
9 sigma_g: geometric standard deviation or spread of F(x)
10 sigma_s: geometric standard deviation or spread of the reduced Grade efficiency curve G'(x)
11 rf: Flow ratio: Ratio of Underflow volume rate to feed volume flow rate: rf=Qu/Q (input/calculated). When rf is entered then Du/D is calculated and vice versa.
12 Du/D: Ratio underflow diameter to cyclone diameter (input/calculated). When Du/D is entered then the rf is calculated and vice versa.

13 x’50: reduced cut size= median value of the reduced grade efficiency curve G’(x). (input/calculated). If calculated then the diameter D is input (standard calculation option)
14 D: cyclone diameter (input/calculated). If calculated then the x’50 (reduced cut size is input (design option)
15 n: number of cyclones in parallel connection (input/calculated)
16 Dp: Pressure drop (input calculated).
17 Q: Feed volume flow rate.
18 Qm: Feed mass flow rate
19 Qs: Feed solids mass flow rate.

The Result Parameters (Only Calculated Parameters)

Results

Par	Units	Value
Stk 1	10-3	0.22666...
Eu 2	10+3	1.20040...
Re 3	10+3	35.3677...
v 4	m/s	0.35367...
Et' 5	%	68.3892...
Et 6	%	70.5849...

Pa	Un	Value
n 7	-	1
D 8	mm	100
L 9	mm	431.7
l 10	mm	213.6
Di 11	mm	32.5
Do 12	mm	30.9
Du 13	mm	20

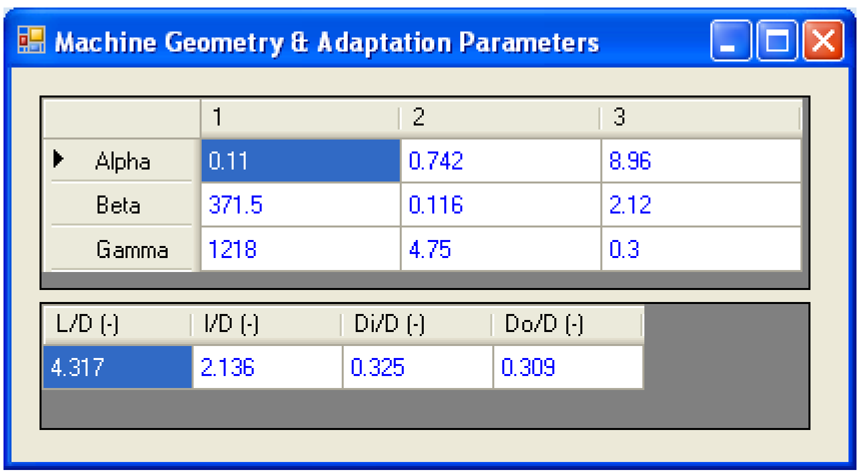
Para	Units	Feed	Underflow	Overflow
Q 14	m3/h	10	0.69460...	9.30539...
Qm 15	t/h	10.3174...	0.91868...	9.39877...
Qs 16	t/h	0.51587...	0.36412...	0.15174...
x_50 17	10-6m	50	74.3563...	18.2590...
Cm 18	%	5	39.6356...	1.61451...
Cv 19	%	1.98412...	20.1623...	0.62719...
C 20	g/l	51.5873...	524.220...	16.3071...

Fig. 5: Listing of only calculated parameters in the main window

For every Hydrocyclone simulation the program calculates the total efficiency E_T and reduced total efficiency E_T' (for the definitions see eq. (5) and eq. (6)). It also calculates the particle size distribution as cumulative and differential for underflow and overflow (Fu(x)/fu(x) and Fo(x)/fo(x)) and also the solids content in underflow and overflow as mass fraction, volume fraction and concentration. We also have as calculated the flow rates for underflow and overflow as suspension volume and mass flow rate and as solids mass flow rate. Flow rates, median sizes and solids contents are listed together for the feed, the underflow and the overflow enabling an easy comparison and judgment of the cyclone performance for the given material, constructive and setting parameters.

The program uses 3 dimensionless parameters for the calculation of the Cyclone performance: These are the Stokes Number (Stk'_{50}) the Euler Number (Eu) and the Reynolds Number (Re). For a given Hydrocyclone and a given flow rate the Stokes Number is related with the cut size x'_{50} (see definition equation (15)). The higher Stk’ the higher the cut size x'_{50}. The Euler Number (Eu) is for a given geometry and flow rate a dimensionless pressure drop. The higher the Eu-number the higher the pressure drop Dp. The Re-number is for a given Hydrocyclone proportional to the flow rate (for the definitions of the 3 dimensionless parameters see eq. (15), (16) and (17)). The values of all 3 dimensionless Parameters as well as the value of the velocity v=Q/A are also displayed in the main window.

The “heart of the Software” are physically based half-empirical mathematical models with adaptation parameters, which can be taken constant for a given cyclone-family. All cyclones belong to the same family if they have the same values for: L/D, l/D, Di/D, Do/D. For the explanation of the geometrical parameters see fig. 8. In fig. 6 we see the 9 adaptation parameters which are used to calculate the cyclone performance and which are related to the cyclones family with the geometry given also in fig. 6. For a given cyclone family the normal procedure is first the determination of the adaptation parameters based on test results with a cyclone of the given family. After having the adaptation parameters the cyclone performance can be calculated for any diameter D and any material and setting parameters. In case that for a given cyclone family no tests are existing, it is recommended as first approximation to use the adaptation parameters as given in fig. 6.



	1	2	3
Alpha	0.11	0.742	8.96
Beta	371.5	0.116	2.12
Gamma	1218	4.75	0.3

L/D (-)	l/D (-)	Di/D (-)	Do/D (-)
4.317	2.136	0.325	0.309

Fig. 6: Window for entering/displaying the adaptation parameters which are necessary for the calculation of the cyclone performance and for entering the specific parameters for the hydrocyclone geometry which characterize the cyclone family.

Entering or calculating the machine diameter D and the underflow diameter Du all absolute geometrical parameters of the given hydrocyclone are calculated and displayed (D, L, l, Di, Do, Du).

1 Stk’: Stokes number (see definition eq. (15))
2 Eu: Euler number (see definition eq. (16))
3 Re: Reynolds number (see definition eq. (17))
4 v: Feed average velocity (see definition eq. (18))
5 E_T': Reduced total efficiency (see eq. (7))
6 E_T: Total Efficiency (see definition eq. (5))
7 n: Number of Cyclones

8 D: Diameter of Cyclone(s)
9 L: Length of the Cyclone(s)
10 l: Length of cylindrical part of the cyclone(s)
11 Di: Inlet diameter of the cyclone(s)
12 Do: Outlet diameter of the cyclone(s)
13 Du: Underflow diameter of the cyclone(s). It is considered as setting parameter
14 Q: Volume flow rate for feed, underflow and overflow
15 Qm: Mass flow rate for feed, underflow and overflow
16 Qs: Mass solids flow rate for feed, underflow and overflow
17 x_50: Median particle size for feed, underflow and overflow
18 Cm: Solids mass fraction for feed, underflow and overflow
19 Cv:Solids volume fraction for feed, underflow and overflow
20 C: Solids concentration for feed, underflow and overflow

Tables & Charts Window

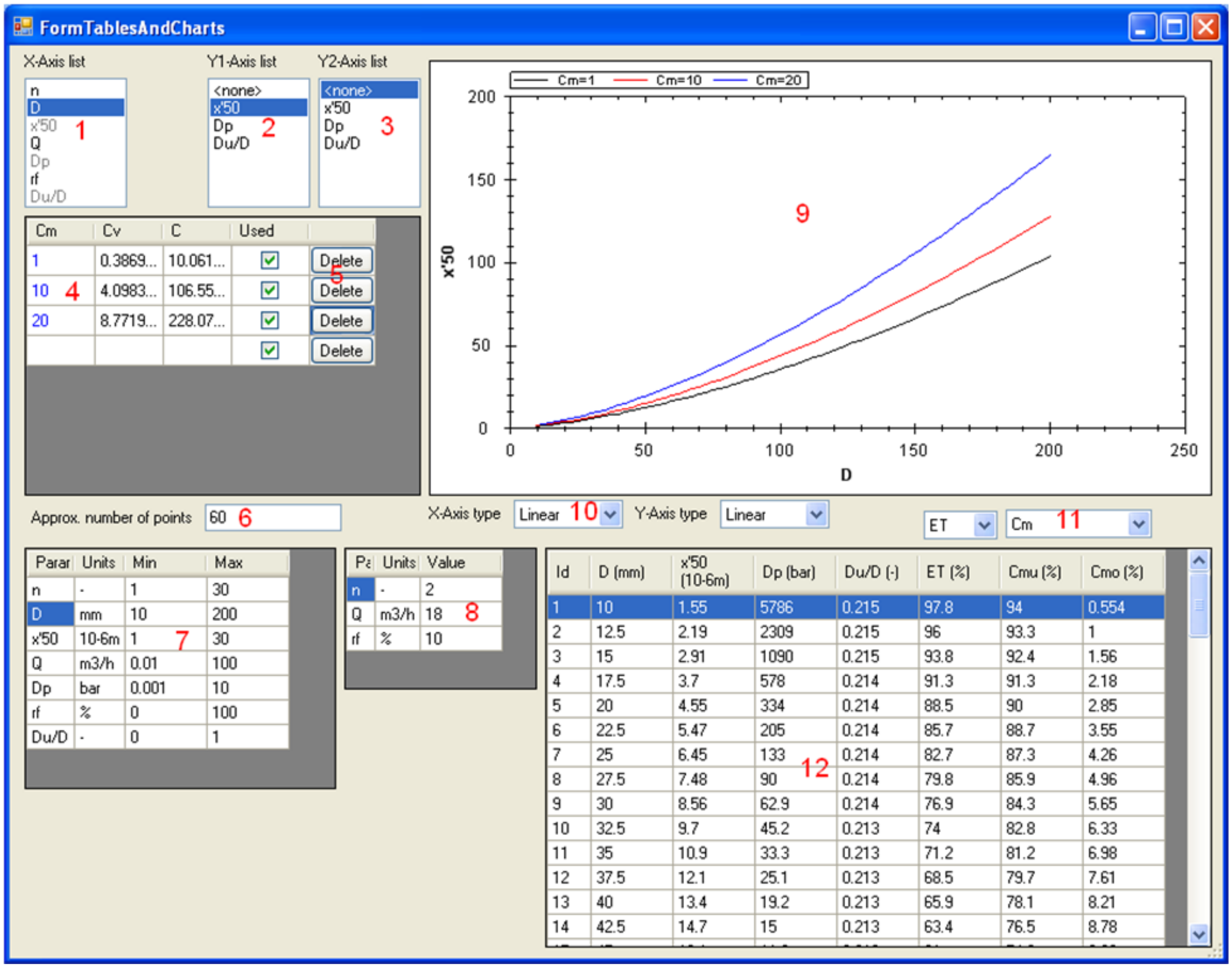


Fig. 7: The Tables & Charts window of CYCLONPLUS

The *Tables and Charts* Window enables the testing of the influence of different parameters on the cyclone performance as diagrams and tables. The x-axis parameter is selected in (1) and only those parameters can be selected which are input parameters in the current simulation. The parameters which can not be selected as x-axis parameters are displayed in weak grey color. The possible y-axis parameters also depend on the current simulation and are only calculated constructive and setting parameters. We can have 2 y-axes (double diagram). The y-axis parameters are selected in (2) and (3). We can have plots with the suspension solids content as parameter. Each curve represents definite suspension solids content expressed as solids mass fraction (Cm) or solids volume fraction (Cv) or solids concentration (C). A curve with different solids content is created by entering the suspension solids content in a new row in (4). The data of the table are related to the selected solids content in (4). In (6) we define how many calculations should be displayed in the table and in (7) we display and define the min-max values for all parameters which can be x-axis parameter. In (8) we display the constant parameters for the current diagram. The axes of the diagram (9) can be displayed in linear or logarithmic form (10). Besides the x-axis values (second column of the table) in the other columns of the table we display the main result parameters including the total efficiency E_T and the solids content for underflow and overflow. In (11) we can select as display parameter for the table alternatively E_T or E_T' and Cm or Cv or C. By right-clicking the diagram we can copy and paste it for example in a word document. Regarding the table data we can select the data we want to process and copy and paste them for example in an Excel file so that we can plot additional curves.

1 Selection of the x-axis parameter for the diagram. Only input parameters for the current simulation can be selected.
2 Selection of the y1-axis (left axis) parameter (only calculated parameters of the current simulation can be selected).
3 Selection of the y2-axis (left axis) parameter (only calculated parameters of the current simulation can be selected).
4 Field for entering a new solids content (that means creating a new curve) or deleting a curve for a definite solids content by selecting the corresponding row and clicking the *Delete*-button.
5 *Delete*-button: By clicking "Delete" the corresponding row is deleted and also the corresponding curve of the diagram.
6 *Aprox. Number of Points*: in this input field we enter how many rows (=how many simulations) the table approximately should have. The min and max values are always displayed.
7 Defining min and max values for all x-axis parameters.
8 Displaying the values of those parameters which are constant for the current simulation (=constant parameters of the diagram).
9 Diagram with the feed solids content as parameter. Curves with the same solids content have the same color. The value of the solids content is displayed as a legend above the diagram.
10 Selecting linear or logarithmic display of the x- and y-axis.
11 Selecting of the absolute or reduced total efficiency to be displayed in the table and the solids mass fraction Cm or the volume fraction Cv or the concentration C to be displayed in the table.
12 Table with the data of the current simulation with the selected feed solids content (the solids content is selected in (4)). As first column we have the numbering of the rows of the table and then the values of the x-axis parameter followed by the calculated parameters (displayed as weak grey in the x-axis parameters listing (1)) and by the total efficiency and the solids content for underflow and overflow.

The Theory and Necessary Relations to CYCLONPLUS

Project Description:

We have a given suspension and a given suspension flow rate Q (m^3/h). The suspension is characterized by its viscosity μ (mili Pas) its liquid density ρ, its solids density ρs, its solids concentration (mass fraction Cm(%) or volume fraction Cv(%) or C(g/l) and its cumulative particle size distribution F(x) by mass. As a first approximation we assume that the size distribution function F(x) has the following form:

$$F(x)=0,5\left[1+erf\left(\frac{\ln(x)-\ln(x_g)}{\sqrt{2}\ln(\sigma_g)}\right)\right] \qquad (1)$$

xg and σg are parameters defining the particle size distribution (xg is the so called median and σg is the geometric standard deviation which defines the spread of the curve).

This suspension and the given flow rate Q have to be treated in a Hydrocyclone (see fig. 1). The suspension (=feed or input) enters the hydrocyclone with the diameter D tangentially from the inlet Di. The suspension is separated into two parts: the overflow which exits the cyclone from the tube on the top with the diameter Do and the underflow, which exits the machine from an opening in the bottom with the diameter Du. The ideal case for the solid-liquid separation option is that we have in the overflow only liquid (no solid particles) and in the underflow all solids which enter the machine in a high solids concentration. The reality is that we have always little solids in the overflow (that means the solids concentration in the overflow is less than the solids concentration of the feed (inlet)) with small sizes. In the underflow we have higher solids concentration and coars particles because most of the small particles (depending on the Grade Efficiency –behaviour) can not be separated and flow in the overflow. For the Classification option we are interested to have a very sharp separation of coarse particles and fine particles. This can be done by a Grade –Efficiency curve with very small spread coefficient.

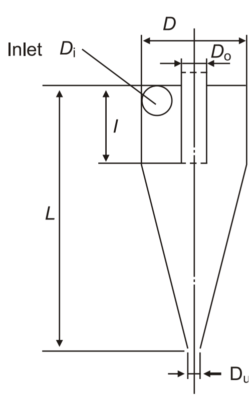


Fig. 8: Hydrocyclone and geometrical data (taken from the Book: Solid-Liquid Separation, 4th Edition, by L. Svarovsky)

One important parameter that characterizes the efficiency of separation is the cut size $x_{50}^{'}$ (μm). If for example $x_{50}^{'}$ =10 μm that means that particles with this size have the same probability to be in the overflow and in the underflow. Particles with size x> $x_{50}^{'}$ are more probable to be found in the underflow and particles with x< $x_{50}^{'}$ are more probable to be found in the overflow. For complete characterization of the separation efficiency it is not enough to have the $x_{50}^{'}$ - value but the so called reduced grade efficiency function G'(x). This function gives the probability for each particle size to be in the underflow. In most Hydrocyclone applications this function is given as follows (this function is also used by CYCLONPLUS):

$$G^{'}(x)=0,5\left[1+erf\left(\frac{\ln(x)-\ln(x_{50}^{'})}{\sqrt{2}\ln(\sigma_s)}\right)\right] \tag{2}$$

$x_{50}^{'}$ (μm) reduced cut size = so called median value of G'(x)
σs (-) geometric standard deviation or spread of G'(x)

The actual grade efficiency curve G(x) is calculated from the reduced grade efficiency curve from the following equation:

$$G(x)=(1-r_f)G^{'}(x)+r_f \tag{3}$$

The parameter r_f is the so called flow ratio and is defined as follows:

$$r_f=\frac{U}{Q} \tag{4}$$

U (m3/h) Underflow volume flow rate
Q (m3/h) suspension flow rate (input)

In fig. 2 a grade efficiency curve G(x) and a reduced grade efficiency curve G'(x) based on eq. (2) is displayed.

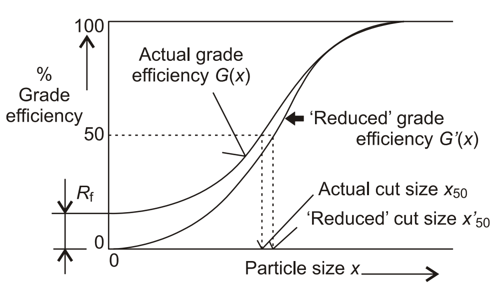


Fig. 9: Grade efficiency and reduced grade efficiency curves according to eq. (2) and (3) (taken from the Book: Solid-Liquid Separation, 4th Edition, by L. Svarovsky)

Having the particle size distribution function F(x) as described in eq. (1) and the reduced grade efficiency curve G'(x) as described in eq. (2) another important parameter, the so called total efficiency E_T can be calculated. The definition of total efficiency is:

$$E_T = \frac{M_{s,u}}{M_s} \quad (5)$$

Ms,u (kg) Solids mass in the underflow
Ms (kg) Solids mass entered in the Separator (input)

If for example E_T=1 means that we have a perfect (=not realistic) separation: all solid particles entered in the machine are found in the underflow and in the overflow we have no solid particles.

The total efficiency E_T is calculated from the reduced total efficiency E'_T as follows:

$$E_T = (1 - r_f)\, E_T^{'} + r_f \quad (6)$$

The reduced total efficiency E'_T is calculated from the parameters of the particle size distribution function F(x) and the relative grade efficiency function G'(x) curve as follows:

$$E_T^{'} = 0,5\left[1 + erf\left(\frac{\ln(x_g) - \ln(x_{50}^{'})}{\sqrt{2}\,\sqrt{\ln^2(\sigma_g) + \ln^2(\sigma_s)}}\right)\right] \quad (7)$$

From the reduced total efficiency E'_T the solids concentration in the underflow C_u(g/l) and in the overflow C_o(g/l) can be calculated:

$$C_u = C\,(1 + \frac{1 - r_f}{r_f}\, E_T^{'}) \quad (8)$$

$$C_o = \frac{C - r_f\, C_u}{1 - r_f} \quad (9)$$

C(g/l) Suspension solids concentration (inlet)
rf (-) flow ratio
E'_T (-) reduced total efficiency.

The calculation of the particle size for the overflow $F_o(x)$ and for the underflow $F_u(x)$ can be done as follows:

$$F_u(x) = \frac{1}{E_T}\int_0^x G(x)\,\frac{dF}{dx}\,dx \quad \mathbf{(}10\mathbf{)}$$

$$F_o(x) = \frac{1}{1-E_T} \int_0^x (1-G(x)) \frac{dF}{dx} dx \tag{11}$$

For the total efficiency E_T see eq. (6) and eq. (7). For the grade efficiency G(x) see eq. (3) and eq. (2). For the particle size distribution of the feed F(x) see eq. (1).

Two Calculation Options for the Hydrocyclone: Design – and Standard Calculation Option

For the Calculation of the Hydrocyclone we have two Options: The Design – option and the Standard calculation option. For the Design option we calculate the machine diameter D and we enter the cut size $x_{50}^{'}$ and for the Standard calculation option we enter the machine diameter D and we calculate the cut size $x_{50}^{'}$.

Design Option:

Input parameters: $x_{50}^{'}$, Q, Dp, r_f
Calculated parameters: D, n, D_u/D

Standard Calculation Option:

Input parameters: D, n, Du/D, Q
Calculated parameters: $x_{50}^{'}$, r_f, Dp

Input parameters (the same for Design and Standard calculation option)

- Viscosity of Liquid (10^{-3} Pa s)

- Liquid density (kg/m3)
- Solids density (kg/m3) or suspension density (kg/m3)

- Suspension solids mass fraction Cm(%) or
- Suspension solids volume fraction Cv(%) or
- Suspension solids concentration C(g/l)

Particle size distribution parameters for the feed:

-Median of the particle size distribution x_g (mm):
–Spread of the particle size distribution σ_g (-):

Spread of the reduced grade efficiency curve σs (-)(see eq.(2))

Please notice that the program uses groups of parameters. That means for parameters, which belong to the same group only one parameter is input and the others are calculated. Examples with regard to the material parameter are the solids density and suspension density or the solids mass fraction Cm, the solids volume fraction Cv and the solids concentration C.

Regarding the geometry/setting parameters we have the following groups:

- rf (-)	flow ratio
- Du/D (-)	underflow diameter related to cyclone diameter

- x'_{50} (μm)	reduced cut size
- D (mm)	diameter of the hydrocyclone

Regarding the parameters:

-Number of cyclones in parallel connection n
-Pressure drop Dp
-Feed flow rate (as volume flow rate Q or mass flow rate Qm or solids mass flow rate Qs)

we have to enter two of them and the third one is calculated.

That means we always calculate 3 of the above 7 parameters: (rf, Du/D, x'_{50}, D, n, Dp, Q). For the calculation of these 3 parameters we should use the following equations:

$$Stk'_{50}\,Eu = f(rf, c_v, \alpha_1, \alpha_2, \alpha_3) \qquad (12)$$

$$Eu = f(\mathrm{Re}, c_v, \beta_1, \beta_2, \beta_3) \qquad (13)$$

$$r_f = f\left(\frac{D_u}{D}, Eu, \gamma_1, \gamma_2, \gamma_3\right) \qquad (14)$$

$$Stk'_{50} = \frac{{x'_{50}}^2 (\rho_s - \rho)}{18\,\mu\,D} v \qquad (15)$$

$$Eu = \frac{2\,\Delta p}{\rho\,v^2} \qquad (16)$$

$$\mathrm{Re} = \frac{\rho\,D}{\mu} v \qquad (17)$$

$$v = \frac{4Q}{\pi\,D^2\,n} \qquad (18)$$

$Stk_{50}^{'}$ (-)	reduced Stokes number
Re (-)	Reynolds number
Eu(-)	Euler number
cv(-)	suspension solids volume fraction
rf(-)	flow ratio
Du/D (-)	underflow diameter related to cyclone diameter