DOCUMENTATION

FILASTRA 2016

(Advanced Filtration Calculator)

SEPTEMBER 2015

CONTENTS

Introduction: Why Filtration Programs?

The use of experiment based and practice oriented up to date filtration theory for the analysis of test data (including the optional steps of cake washing and cake deliquoring) for judging the quality of the experimental data, for characterizing the suspension behavior and for comparing the filterability of various suspensions by establishing a suspension typology as well as the reliable design and performance optimization of filters and filtering centrifuges for any material and any filter geometrical and setting parameters and especially the implementation of these theoretical methods and equations in user friendly programs (as this is performed by the newest versions of *FILOS* and *CENTRISTAR*) can be described without exaggeration as revolutionary step in the filtration practice.

There was always a great need for such tools in order to enable, among other advantages, the saving of time and money for both program-user groups: users and manufacturers of filters and centrifuges. The saving of time and money can be explained due to the considerable reduction of the necessary experimental effort especially with regard to the minimization of the necessary pilot tests. Further more such theory and experiment based programs enable the saving of all measured and analysis result data as well as all simulations in an “intelligent” database (as Microsoft Access- program files) in form of tables and graphs, which can easily be used for the reports and for comparisons. In many cases only the use of such programs can give reliable and convincing answers. That is due to the implementation of physically and experimental based equations which enable reliable predictions and extrapolations even for material and setting parameters, which can not be tested experimentally. The pure empirical approach, which was until the recent years a daily practice and is still (unfortunately) being practiced by some companies has mainly the following big disadvantages:

- The design of a filter or a filter centrifuge is only done for the given test conditions and with relatively high experimental procedure (if the pilot tests are also considered) without the possibility for reliable extrapolation and process optimization. If for example we have to determine the cake height that gives maximal capacity (optimal cake height) for a nutsche filter or a filtering centrifuge under consideration of the cake washing and deliquoring performance (definite cake wash out and moisture content) or if we have to determine for the cake deliquoring and/or cake washing the efficiency of these steps, this can only be done by using theoretically based equations, which enable the reliable calculation of the solids throughput, the wash out content in the cake and the cake moisture content for various material and setting parameters.

- Even for difficult filtration applications (difficult in the sense of such a suspension behavior which in interaction with a given filter or filtering centrifuge doesn’t allow quantitatively reliable extrapolations) but also for cases with not enough test data (as for example not having any pilot test data for cases which demand these tests), such programs enable at least the determination of the optimization potential of the given device by calculating the ideal (=best) expected performance.

- The characterization of the suspension filterability as well as the washing and deliquoring behavior of the filter cake can not be done in a satisfactory way if not using practice oriented and reliable, physically based equations. For example the empirical approach to use the filtrate

rate as average volume or mass flow rate in $l/(m^2 \, min)$ or $kg/(m^2 \, min)$ for characterizing the filterability of the suspension has the disadvantages that this parameter depends not only on the cake structure but also on the cake height, the pressure difference, the viscosity of the filtrate and the filter medium resistance. That means, for every combination of the mentioned influencing parameters different values of the filtrate rate are expected and no extrapolations and comparisons of different suspensions can be done in a reliable way. Even for the cases that physically based equations are used, if these equations are too simple (for example by not determining the cake compressibility or the filter medium resistance) in many applications filterability predictions for any pressure difference or/and predictions regarding the behavior of the filter medium and the correct filter medium selection can not be reliably done. Regarding the cake washing and deliquoring the pure empirical approach doesn't allow the optimization of the washing and deliquoring time and the quantification of the washing and deliquoring efficiency.

All above described drawbacks of the empirical approach are not existing any more if the software FILOS and/or CENTRISTAR are used in a proper way because in these programs practice oriented, physically and experiment-based reliable equations for all steps, formation, washing and deliquoring of the filter cake are implemented. Instead of the filtrate flow rate, the standard cake permeability pc0, the cake compressibility nc and the filter medium resistance (Rm as absolute value and hce as cake specific value) are used, allowing predictions for any setting parameters (any pressure difference, any cake height, any filtration time) and even for variations of material parameters like suspension solids content and viscosity of the mother liquid. Furthermore, such equations enable the proper filter medium selection by quantifying the filter medium resistance. Of greatest importance is the theory based analysis of the test data, which is essential part of the programs and which, besides the correct determination of all necessary parameters, enables the judgment of the quality of the tests and the saving of all test and analysis results data in a database.

Furthermore, the use of the standard cake permeability pc0 (or the standard cake resistance as rc0 or alpha0) and the cake compressibility nc as cake structure characterizing parameters allows the establishment of a suspension typology, the comparison of different suspensions as well as the selection of the proper filter device based on the knowledge of these two parameters.

The use of the cake saturation S (=liquid volume in the cake related to the cake voids volume) and the use of the cake deliquoring index K, which includes the influence of cake height, pressure difference, deliquoring time, cake permeability, liquid viscosity and filter medium resistance on the deliquoring behavior, allows the determination of the cake moisture content for any setting parameters and the optimization of the setting parameters as for example the determination of the optimal deliquoring time or/and the optimal pressure difference and cake height. Similar is with the cake washing: The use and calculation of the washing ratio w (=wash liquid volume related to the voids volume of the cake) as a function of material and setting parameters allows predictions regarding the wash out content in the cake and the optimization of the washing step.

For both steps: cake deliquoring and cake washing, the determination of the adaptation parameters (exponents in the equations calculating the cake wash out content X and the cake saturation S / cake moisture content Rf) allows the definition and quantification of the washing and deliquoring efficiency. If for example when analyzing the cake deliquoring test data with FILOS (see module *Cake Deliquoring*) we determine $Bd<0.1$ (Bd is defined as the deliquoring efficiency when Ad-value is set equal 5) we know that we have a very low deliquoring efficiency and this is an evidence that the deliquoring step needs an optimization (normal Bd values are between 0.3 and 0.5). Such a low value indicates not a homogeneous displacement of the liquid in the cake as is given for example when cake cracking occurs or when we have uneven cake etc. Regarding now the cake washing behavior: Determining a too low Bw-value, as for example Bw<0.3, when analyzing the wash test data by using the analysis module *Cake Washing*, that means that the washing efficiency for this case is too low as this can happen when for example the wash liquid viscosity is much lower than the mother liquid viscosity (not homogeneous displacement of mother liquid, the so called fingering effect) or/and the spread of the pore size distribution is too high or/and the wash liquid distribution is not covering the cake homogeneously etc. (Please notice that in analogy to deliquoring the Bw-adaptation parameter is defined as the washing efficiency parameter if the Aw value is set equal 10).

Why the Program *FILASTRA* (ADVANCED FILTRATION CALCULATOR)?

In many cases people dealing with the filtration of suspensions have to determine the values of some parameters without having to use the big programs FILOS or CENTRISTAR which are mainly written for solving more challenging tasks, like the analysis of test data, the design and optimization of filters and filtering centrifuges. Furthermore the use of FILOS and/or CENTRISTAR needs the knowledge of some input parameters, which sometimes or always are not directly measured and have to be determined from other parameters. The program *FILASTRA* was written to serve among others the above described cases. In Fig. 1 we see a screenshot of the program with all modules listed in tree-structure. On the left we select the module which is highlighted with blue background color and on the right we see the listing of the parameters for the selected module. On page 10 you find a short description of all modules followed by a detailed description of each module separately.

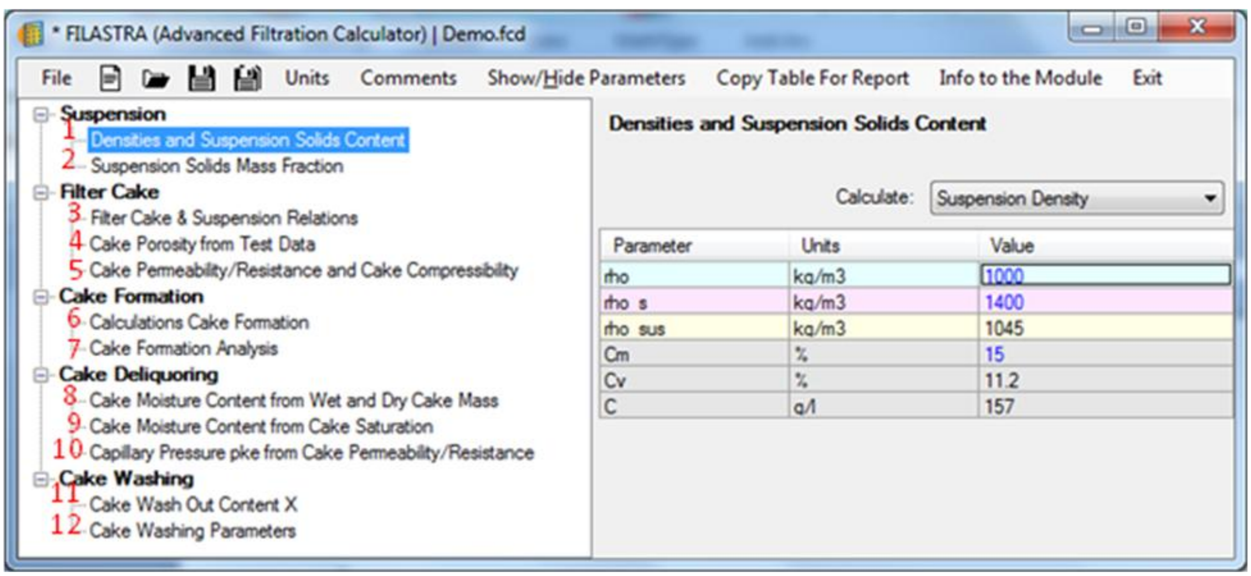


Fig. 1: Screenshot of the Program *FILASTRA* with a tree structure for selecting one of the 12 program modules. The selected module is highlighted by a blue background color and is displayed on the right of the window.

This user friendly program has high flexibility regarding the input and calculated parameters by building group of parameters. The parameters which belong to the same group are placed next to each other and have the same background color. For every group only one parameter is input and all others are calculated. Input parameters are indicated by blue color and calculated by black. We have some groups with only one parameter; that means this parameter has to be entered always.

The new Filtration Calculator is an Advanced Filtration Calculator and is named *FILASTRA*. Compared to the previous program version (2013) it is considerably improved and became now a powerful software. The saving of every session is now enabled. Every module of a given session can have individual settings (for example individual units). Even for some options of some modules individual settings for each option can be selected and saved. File-New, Open-File, Save, Save As are new implemented functions. The *Units*-window is optimized. Default units for Laboratory-, Pilot- and Industrial Scale Apparatuses can be saved. Also US-units can be selected and saved. To each of the modules individual comments can be entered and saved. The *Show-Hide* Function enables the user to determine which parameters of each group she/he wants to display. And what is very important for reports: The data of each module can be copied as a table or as a picture and pasted for example in a Word-document enabling an easy preparation of the report. Furthermore, compared to the previous version a new module was added (*Cake Washing Parameters*, see description on page 38). The module *Filter Cake & Suspension Relations* was done more powerful by adding more parameters and more options. Worth mentioning are also the following functions: the program does an automatical resizing of the window height when selecting a module with many parameters. When starting the program *FILASTRA* remembers the last opened file and the last used module and bring us to the last opened file and last opened module.

Typical tasks which can be solved by *FILASTRA*

Densities and Suspension Solids Content

Do you have a suspension and you know the densities of mother liquid and suspension and the solids mass fraction Cm (=Mass of solids related to suspension mass) and you want to determine the solids density (material parameter) or/and the solids content in the suspension as volume fraction Cv (a parameter that is not depending on densities) or as a suspension solids concentration C(g/l)?

Or, do you have a value of the solids density and you want to check if this can be correct? Do you need a flexibility to calculate any density (liquid, suspension, solids density) and any suspension solids content parameter (as mass or volume fraction or concentration) by having two of the three densities and one of the three solids content parameters?

Or, you don't have the suspension solids content and you want to determine it (as mass fraction, volume fraction and solids concentration) by knowing the densities of liquid, solids and suspension?

Suspension Solids Mass Fraction

Are you dealing with filtration tests and you want to determine the solids mass fraction in the suspension C_m from the suspension mass of the sample and the corresponding solids mass even for cases of not negligible nonvolatile substances solved in the mother liquid?

Filter Cake & Suspension Relations

You have a filter apparatus with a definite plane area A or a filtering centrifuge (concave cylindrical area) with a given diameter D and a given height/width b (alternatively instead of b the ratio b/D or the area A can be entered) or a candle filter (convex cylindrical area) with a given area A and a given diameter d and you want to know for a given suspension amount (as mass of suspension Msus or volume of suspension Vsus) what is the expected cake height hc if the liquid density and the suspension density (or the solids density) as well as the solids mass fraction Cm (or the solids concentration C or the solids volume fraction Cv) and the cake porosity are given?

Or, what is the expected cake height in the centrifuge if we know the densities of solids and liquid, the suspension solids content, the cake porosity, the filter geometry and the suspension amount of one cycle.

Or what suspension solids content we should have if for a given filter, given solids and liquid density, given porosity with a given suspension amount a definite cake height was formed? Similar question: the solids content can be known and the cake porosity can be determined. Or both: the solids content and the cake porosity are known and the needed filter geometry can be calculated, so that we can have a definite cake height for a given suspension amount.

When the cycle time is known, also the performance of the filter can be calculated for example as suspension mass or suspension volume flow rate, as solids mass flow rate etc. (absolute and specific parameters). Alternatively, the needed cycle time can be calculated in order to have a definite filter performance.

Cake Porosity from Test Data

You want to determine the cake porosity (voids volume related to cake volume) from laboratory or pilot/industrial scale data and you don't want to be restricted to tests with only plane area but you want to consider data from a cylindrical area like in filtering centrifuges or in candle filters? And you need the flexibility to determine the cake porosity without knowing the cake geometry (that means without knowing the cake height) and without doing an error when the mother liquid includes non volatile substances?

Cake Permeability/Resistance and Cake Compressibility

You want to know the values of the cake permeability pc (m^2) or cake resistance as rc (m^{-2}) and cake resistance alpha (m/kg) for compressible cakes for any pressure difference Dp if the cake compressibility nc and the standard values (related to Dp=1 bar) of cake permeability or cake resistance (pc0, rc0, alpha0) are given? Or you want to know for which pressure difference Dp you will have a definite cake permeability/cake resistance or for which cake compressibility nc a definite pressure difference gives a definite cake permeability?

Calculations Cake Formation

Are you carrying out laboratory filtration tests with constant pressure difference Dp (typical vacuum and pressure nutsche laboratory tests) or you want as filter manufacturer or filter user to predict the filtration time for pilot/industrial filter devices for any suspension amount or any cake height? Or you want to know the expected cake height and the corresponding Mass of suspension for a given filtration time? Do you want to study the influence of the mother liquid viscosity, the suspension solids content, the cake permeability/cake resistance, the cake compressibility and the filter medium resistance on the filtration performance?

Cake Formation Analysis

Are you dealing with laboratory vacuum and pressure filtration tests (cake formation with constant pressure difference) and you want to analyze the test results to get both parameters at once: cake porosity and cake permeability? Do you want to have the maximal flexibility regarding the input parameters (for example you have the filtrate rate qf (l/m2 min) and the solids mass Ms and you want to know the permeability and porosity of the cake)?

Do you have the performance data of an Industrial Filter (Continuous or Batch Filter) in terms of cake height hc and solids throughput Qms for given geometry and given settings and you want to judge your filtration performance by determining the cake porosity and cake permeability?

Cake Moisture Content from Wet and Dry Cake Mass

Are you dealing with filtration tests and you want to calculate the cake moisture content from the wet and dry cake mass also by consideration of non volatile soluble substances in the cake liquid?

Cake Moisture Content from Cake Saturation

Do you want to determine the cake moisture content Rf (mass of liquid in the cake related to the mass of the cake) from the cake saturation S (liquid volume in the cake related to the voids volume of the cake) and the cake porosity (voids volume of the cake related to the cake volume) and vice versa?

Do you want to check if a definite cake moisture content can be correct or for a given cake you want to calculate the maximal possible cake moisture content? Or for a given cake moisture content you want to determine what can be the minimal possible cake porosity?

Capillary Pressure pke from Cake Permeability/Resistance

Do you want to determine the minimal pressure difference that is necessary for cake deliquoring (capillary threshold pressure pke) for a given liquid in the cake (given surface tension) as a function of the cake permeability/cake resistance?

Cake Wash Out Content X

Do you want to determine the wash out content in the washed and deliquored filter cake X from the wash out concentration of the liquid in the cake and the cake moisture content? Or you want to determine the wash out content of the cake X from the wash out concentration of the wash filtrate after re suspending the filter cake with wash liquid?

Cake Washing Parameters

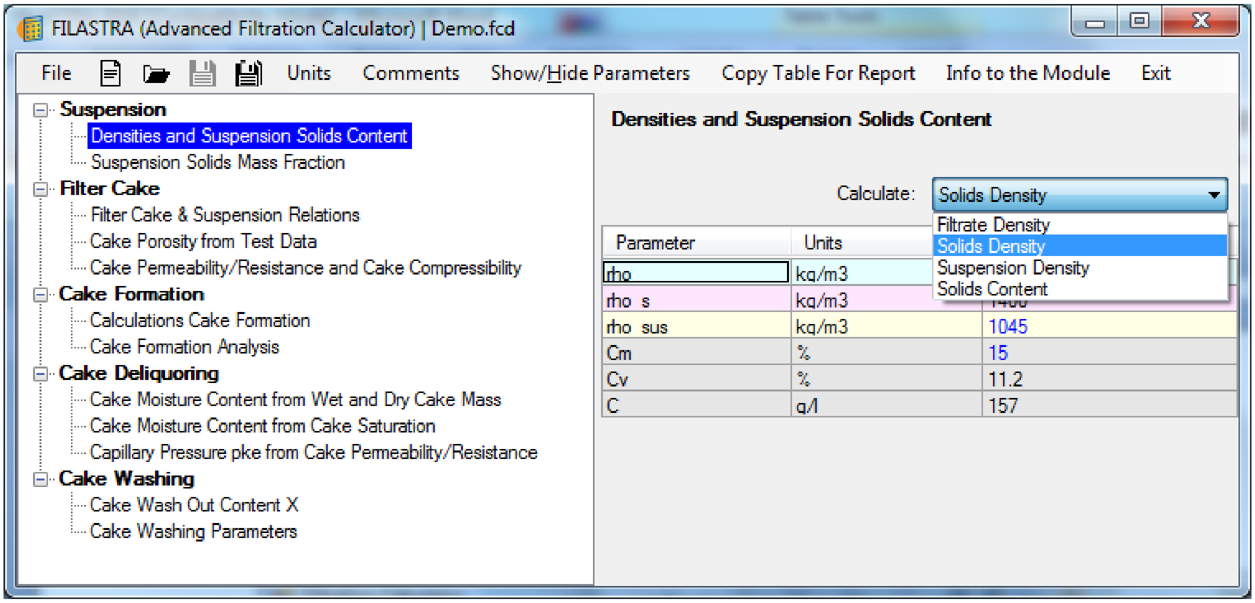
For any filter area geometry: Plane area, concave area (filter centrifuges), convex area (candle filters): What is the needed washing liquid amount (in mass or in volume Mw, Vw) for a given filter area and a given cake height in order to achieve a definite specific wash liquid consumption? Or, having the wash liquid amount what is the specific wash liquid consumption for a given filter area and a given cake (cake height and cake porosity)? Knowing the cycle time what is the needed average wash liquid flow rate?

All above questions and even more can be answered by the *FILASTRA –software(Advanced Filtration Calculator)*. In the following you find a detailed description of all 12 *FILASTRA*- modules.

The Modules of *FILASTRA* (Advanced Filtration Calculator) – Short Explanations

Nr.	Module Name	Why this module (short explanation)
1	Densities and Suspension Solids Content	Calculates solids or suspension or mother liquid density if 2 densities and the suspension solids content as mass or volume fraction or concentration are given. Calculates the solids content if the 3 densities: for liquid, solids and suspension are given.
2	Suspension Solids Mass Fraction	Calculates the solids mass fraction in the suspension Cm if the suspension mass and the solids mass (after drying) are given. Non volatile solutes in the liquid are also considered.
3	Filter Cake & Suspension Relations	Calculation of the Suspension amount (Msus/Vsus) for a given area A and a given cake height hc for plane filter area or convex area (candle filters) or concave area (centrifuges) if the solids density or suspension density and the cake porosity or the kappa-parameter are given. High flexibility of the calculations: Instead of Msus/Vsus the cake height or the geometry of the machine or the cake porosity or the suspension solids content or the densities can be calculated.
4	Cake Porosity from Test Data	Calculation of the cake porosity from tests with filters with plane or convex or concave filter area under consideration of nonvolatile solutes in the cake liquid. Two options: Saturated cake (all voids filled with liquid) and non saturated cake are considered.
5	Cake Permeability/Resistance and Cake Compressibility	Calculation of the cake permeability/cake resistance for any pressure difference and any cake compressibility if the standard cake permeability/cake resistance (values for Dp=1 bar) are given. The module is so flexible that the cake compressibility or the pressure difference or the standard cake permeability/cake resistance can be calculated when the other parameters are entered.
6	Calculations Cake Formation	Calculation of the filtration time for given suspension and cake parameters (viscosity and density of mother liquid, density of solids or suspension, solids content as mass or volume fraction or concentration, standard cake permeability/cake resistance, cake compressibility and filter medium resistance), for a given pressure difference and a given cake height. Alternatively the cake height or the amount of suspension Msus/Vsus can be calculated.
7	Cake Formation Analysis	Most important module. It determines from one experiment both parameters: cake porosity and cake permeability/cake resistance with the highest flexibility regarding the input parameters. Enables the determination of cake porosity and cake permeability not only from batch filter tests data but also from data of continuous filters. This module can be also used to simulate the performance of batch and continuous filters if the porosity and permeability of the cake are entered instead of calculated.
8	Cake Moisture Content from Wet and Dry Cake Mass	Calculation of the cake moisture content from the wet and dry cake mass. The case of not volatile solutes in the cake liquid is also considered.
9	Cake Moisture Content from Cake Saturation	Calculation of the cake moisture content from the cake porosity and the cake saturation. Alternatively the cake saturation can be calculated if the cake moisture content and the cake porosity are entered or the cake porosity can be determined if the cake saturation and the cake moisture content are given.
10	Capillary Pressure pke from Cake Permeability/Resistance	Calculation of the capillary threshold pressure if the cake permeability/cake resistance is given. Additional input parameters are the surface tension of the liquid in the cake and the standard capillary threshold pressure pke_st: That is the value for the standard cake permeability pc,st=10^{-13} m^2 and water 20 °C as cake liquid.
11	Cake Wash Out Content X	Determination of the wash out content in the cake X as g/kg_dry solids by re suspending the wet cake with a definite amount of wash liquid, re filtering and measuring the wash out concentration in the filtrate. Besides the wash out content X also the cake moisture content is calculated.
12	Cake Washing Parameters	For Filters and Filter Centrifuges (plane, concave and convex filter area) determination of the needed washing liquid amount (specific and absolute) and knowing the cycle time additionally the average wash liquid flow rate (absolute and area specific). Needed inputs are filter geometry parameters, liquid and solids density, cake porosity and cake height. Instead of the cake height the aboslute or the specific solids mass or (when cycle time is known) the solids throughput can be given.

1. Module: Densities and Suspension Solids Content



<u>Fig. 1-1:</u> Calculation of the solids density or the suspension density or the mother liquid density if two of the three densities and the suspension solids content are given. Possible is also the calculation of the solids content as mass and volume fraction as well as solids concentration in g/l if the three densities are given.

This module enables the calculation of the following parameters:

1) <u>The density of the mother liquid</u> in the suspension (filtrate density) if the following parameters are given:
   -Solids density
   -Suspension density
   -Solids content in the suspension as: Solids mass fraction (Cm in %) or solids volume fraction (Cv in %) or solids concentration (C in g/l)
2) <u>The density of the Solids</u> if the following parameters are given:
   -Filtrate density
   -Suspension density
   -Solids content in the suspension as: Solids mass fraction (Cm in %) or solids volume fraction (Cv in %) or solids concentration (C in g/l)
3) <u>The density of the Suspension</u> if the following parameters are given:
   -Filtrate density
   -Solids density
   -Solids content in the suspension as: Solids mass fraction (Cm in %) or solids volume fraction (Cv in %) or solids concentration (C in g/l)
4) <u>The solids content in the suspension as mass fraction Cm and volume fraction Cv and solids concentration C</u> if the following parameters are given:
   -Filtrate density
   -Solids density
   -Suspension density

2. Module: Suspension Solids Mass Fraction

This module enables the determination of the solids mass fraction Cm (solids mass related to suspension mass in %) from one experiment by measuring the mass of a suspension sample (Msus) and the corresponding mass of the dry solids in the suspension sample (Mcd). We have 2 calculation options:

-neglecting the non volatile solutes in the mother liquid
-consideration of the non volatile solutes in the mother liquid

In some cases only the consideration of the non volatile solutes can give accurate Cm-values. The possibility for calculation of the solids mass fraction with both options enables also the quantification of the error we will have in case of neglecting the influence of existing non volatile solutes in the mother liquid on the solids mass fraction.

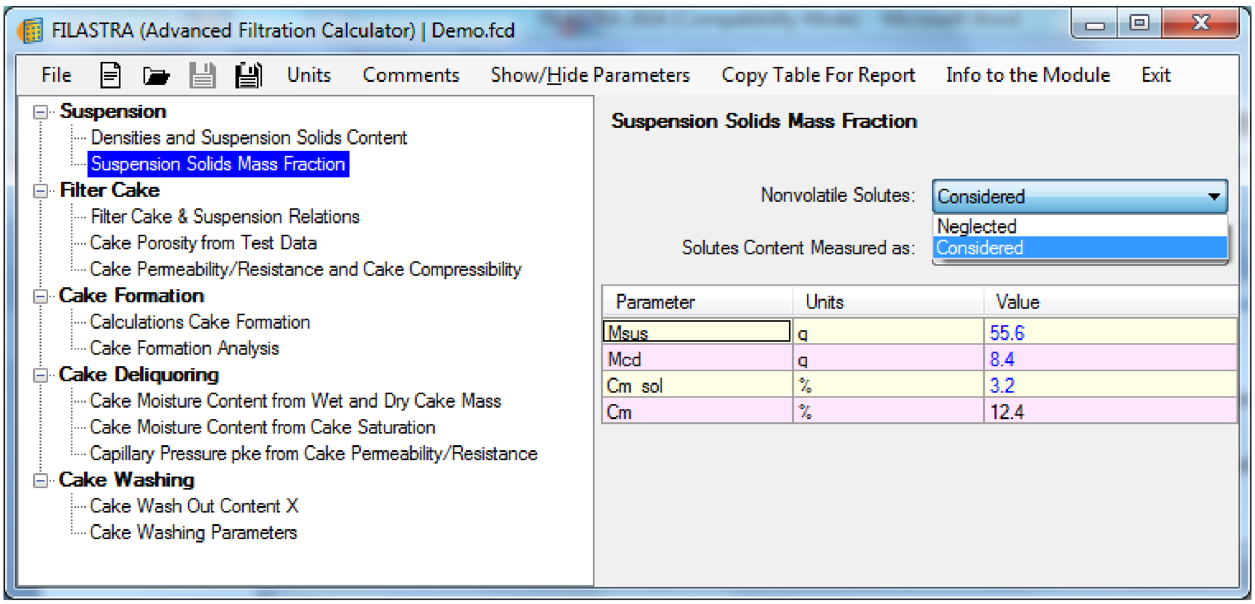


Fig. 2-1: Calculation of the solids mass fraction Cm of a given suspension for the option: Neglected nonvolatile solutes in the mother liquid. As input parameters we have the suspension mass Msus and the mass of the dry solids in the suspension sample Mcd (Mcd is for example the mass after drying the sample).

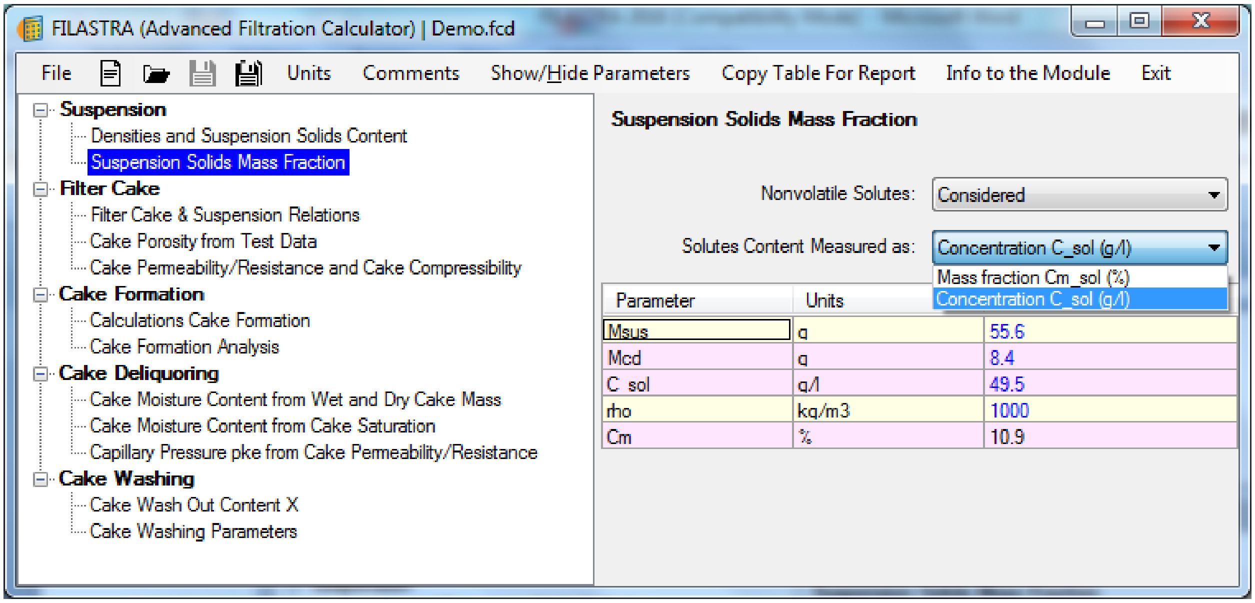


Fig. 2-2: Calculation of the Solids mass fraction of a given suspension Cm for the option: Nonvolatile solutes in the mother liquid considered. As input parameters we have the suspension mass (Msus), the mass of the dry solids in the suspension sample (Mcd) and the non volatile solutes content in the mother liquid as mass fraction (Cm_sol in %) or as concentration (C_sol in g/l). When the concentration C_sol is entered the density of the mother liquid is needed.

The knowledge of the suspension solids mass fraction Cm (mass of solids related to the mass of suspension in %) is a *must* for any calculation of the performance of Solid-Liquid Separation Apparatuses as necessary input parameter. The parameter Cm is a default input parameter for the suspension solids content in *FILOS*, *CENTRISTAR*, *FILTRAPLUS* and *CYCLONPLUS*.

The consideration of non volatile solutes in the mother liquid enables for any case accurate calculations of the Cm-value and the quantification of the errors if such an existing influence is neglected.

By using the first module (*Densities and Suspension Solids Content*) the calculated solids mass fraction in the suspension Cm can be used to determine the suspension solids volume fraction (Cv) or the suspension solids concentration (C in g/l) or even the densities of solids or suspension or mother liquid if besides the solids mass fraction two of the three densities are also given (see Module 1).

3. Module: Filter Cake & Suspension Relations

That is the module for the relations between suspension (densities, suspension solids content and suspension amount), filter cake (cake porosity and cake height) and Filter or Centrifuge geometry. For the filter area three cases are considered: Plane, convex and concave area. For convex area, as we have it in cylindrical candle filters, besides the filter area A the filter diameter (cylinder diameter) is needed. For the concave area as we have it in filtering centrifuges the centrifuge diameter D and one of the following parameters are needed (centrifuge width or height b, ratio b/D, filter area A). This module can be considered as the expansion of the first module (*Densities and Suspension Solids Content*).

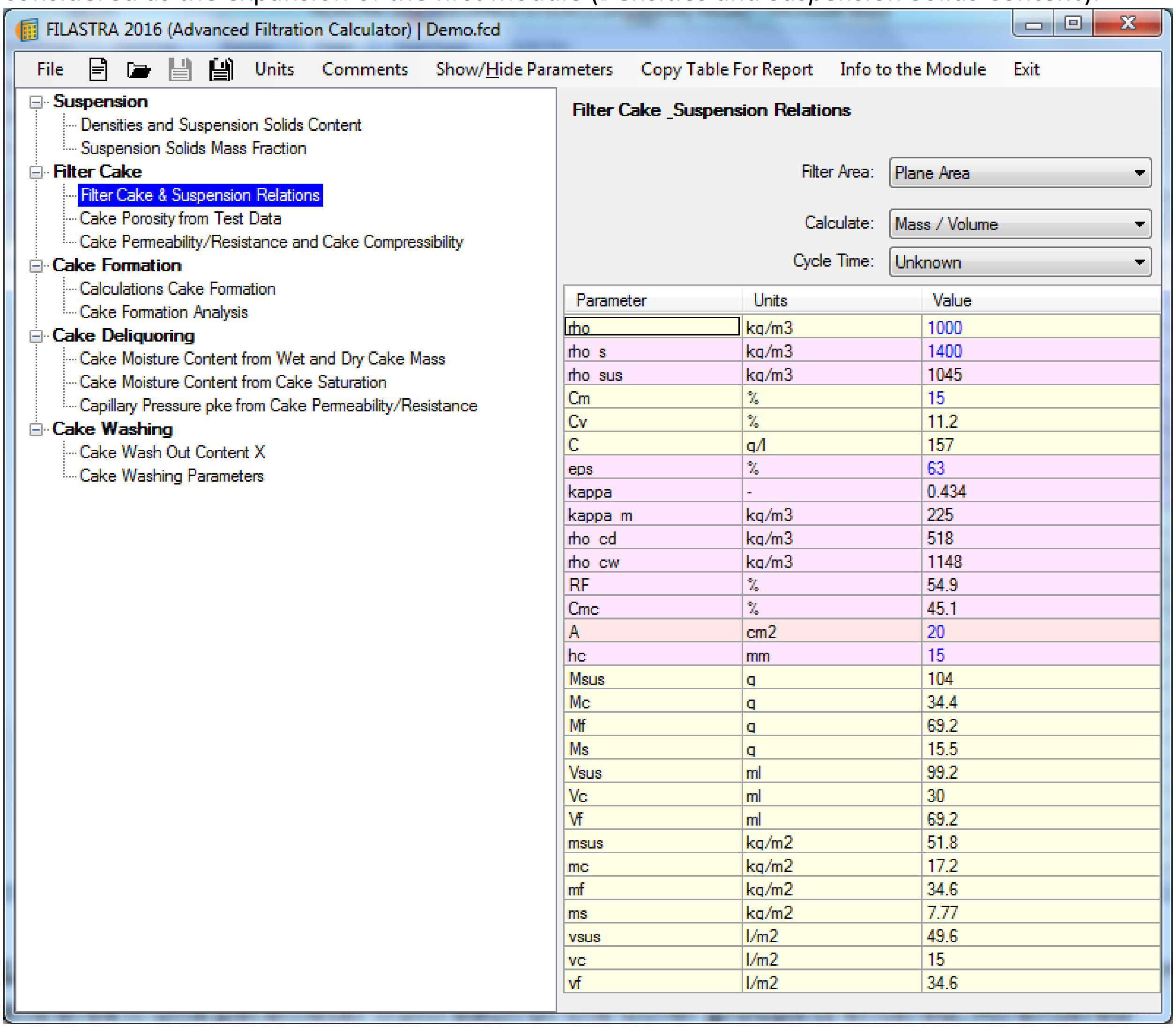


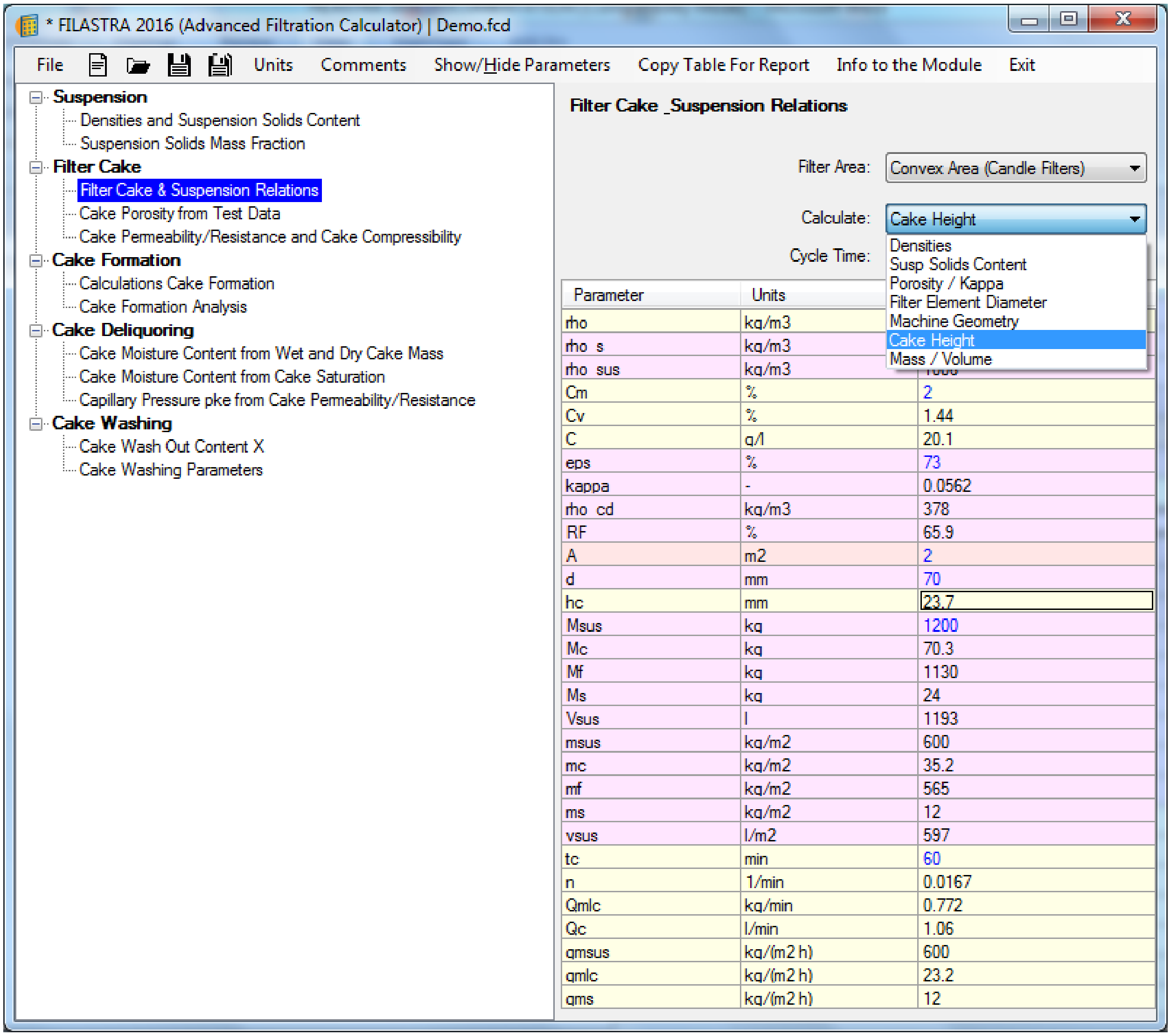
Fig. 3-1: Calculation of the parameters of the group *Suspension amount*: Msus, Vsus etc. for plane area if one parameter from each of the other groups is entered. All entered parameters are recognized by the blue color. In this example we have the option *Cycle time Unknown*.

As can be seen in Fig. 3-2 we have for all 3 filter area geometries a high flexibility regarding the calculated parameters. Please notice that for all *FILASTRA* modules we have the parameter grouping concept: Each group can have one or more parameters. All parameters of the same group have the same background color and for the parameters of the same group only one parameter can be entered and all others are calculated. But when a group is selected as calculated (see in this module the *Calculate* combo-box), then all parameters of this group are calculated (displayed in black color). Which are the groups in this module and which parameters belong to each group?

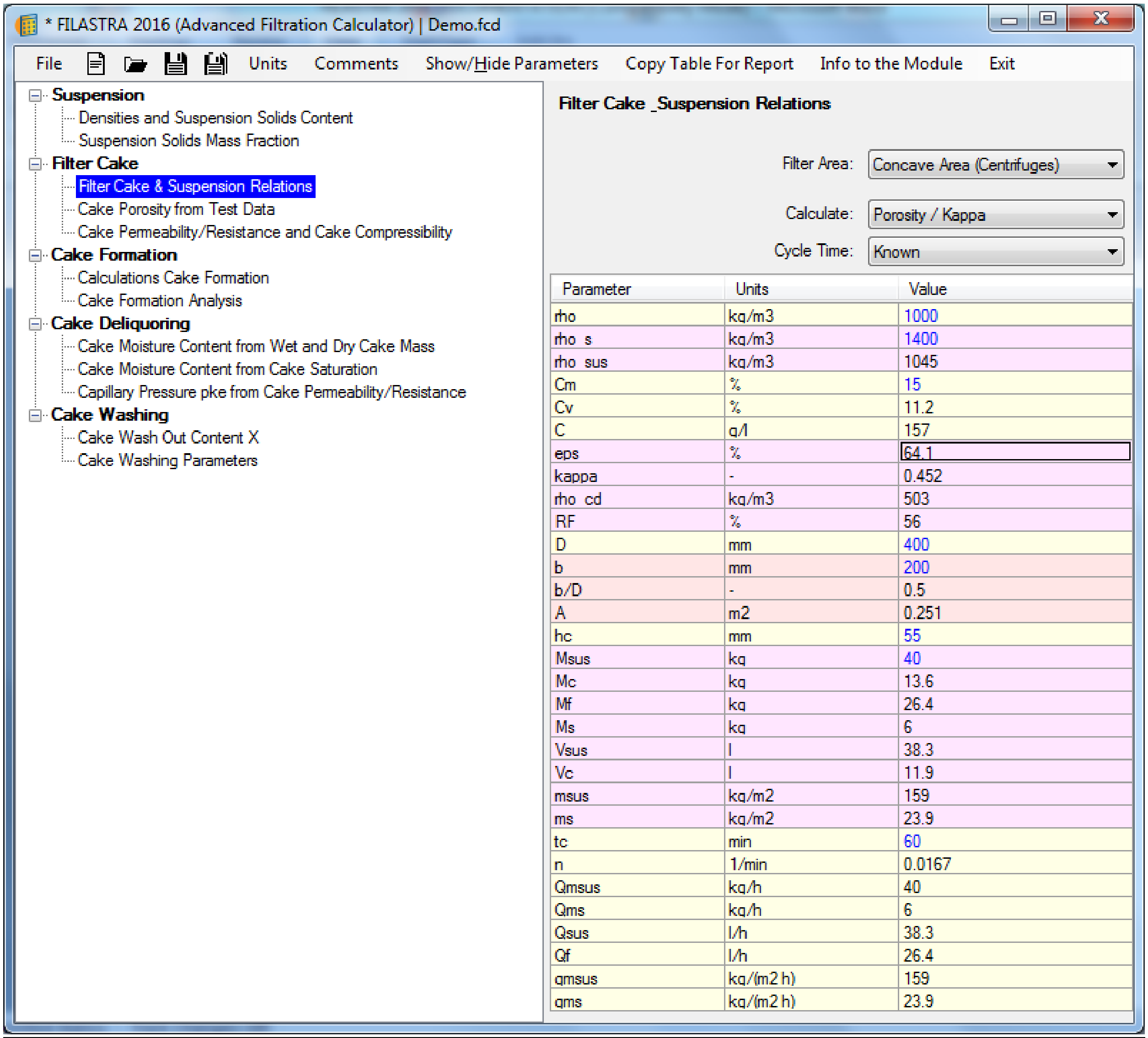
- Filtrate density
- Solids density/suspension density
- Suspension solids content as C_m, C_v and C
- Cake porosity, kappa (=cake volume related to filtrate volume) please notice that in this group in the *FILASTRA 2016* –version 5 more parameters are added: (kappa_m, rho_cd, rho_cw, Rf, Cmc). With the *Show hide parameters* menu the user has the flexibility to define which parameters in each group she/he wants to show
- Filter area A (for plane area) or filter area A and outer cylinder diameter d for convex area and for concave area cylinder inner diameter D and: cylinder width or height b or b/D or filter area A.
- Cake height hc
- Suspension volume, suspension mass. Please notice that in this group in the *FILASTRA 2016* –version 18 more parameters are added: (Mf, Mc, Ms, Mlc, Vf, Vc, Vs, Vlc, msus, mf, mc, ms, mlc, vsus, vf vc, vs, vlc).

- In the new program version by adding the option *Cycle time known* we have for this option additionally the tc-group with 22 parameters (tc, n, Qmsus, Qmc, Qmf, Qmlc, Qms, Qsus, Qc, Qf, Qlc, Qs, qmsus, qmc, qmf, qmlc, qms, qsus, qc, qf, qlc, qs).

The new added tc-group with 22 parameters as well as the additional parameters in the cake porosity (eps) and Suspension Mass (Msus)-groups makes this module very user friendly and powerful. As already mentioned, with the *Show hide parameters* menu the user has the flexibility to define which parameters in each group she/he wants to show.



<u>Fig. 3-2:</u> Example with Calculation of the cake height hc (see list of groups in the *Calculate*-combo box with at least one parameter which can be selected for calculation) for a candle filter (convex cylindrical area) if the filter geometry (A and d) and the amount of suspension (Msus) are given. Of course also one parameter for each of the other groups has to be entered. These parameters are in this example: Filtrate density, Solids density, Suspension solids mass fraction Cm and cake porosity.



Parameter	Units	Value
rho	kg/m3	1000
rho_s	kg/m3	1400
rho_sus	kg/m3	1045
Cm	%	15
Cv	%	11.2
C	g/l	157
eps	%	64.1
kappa	-	0.452
rho_cd	kg/m3	503
RF	%	56
D	mm	400
b	mm	200
b/D	-	0.5
A	m2	0.251
hc	mm	55
Msus	kg	40
Mc	kg	13.6
Mf	kg	26.4
Ms	kg	6
Vsus	l	38.3
Vc	l	11.9
msus	kg/m2	159
ms	kg/m2	23.9
tc	min	60
n	1/min	0.0167
Qmsus	kg/h	40
Qms	kg/h	6
Qsus	l/h	38.3
Qf	l/h	26.4
qmsus	kg/(m2 h)	159
qms	kg/(m2 h)	23.9

Fig. 3-3: Calculation of the cake porosity for a filtering centrifuge (concave filter area) if the centrifuge geometry (D and b), the amount of suspension (Msus) and the cake height hc are given. Of course also one parameter for each of the other groups has to be entered. These are in this example: Filtrate density, solids density and suspension solids mass fraction.

For all types of Filters it happens very often that somebody wants to calculate for example the expected cake height for a definite amount of suspension and vice/versa or even to determine the cake porosity for a given filter geometry, given suspension amount and given cake height. Also of practical importance is the determination of the size of the filter in order to get for a definite suspension amount a definite cake height.

The possibility to consider all three main forms of the filter area (plane, convex and concave) enables comparisons like for example: which amount of suspension for plane area, convex area and concave area has to be filtered in one cycle to have a definite cake height or for a given amount of suspension which cake heights are expected for each filter area form and constant filter area value.

The addition of 45 more parameters in the new program (*FILASTRA 2016*): 5 more parameters in the cake porosity group, 18 more parameters in the suspension mass (Msus) –group and 22 parameters in the new added cycle time (tc) group makes this module even more powerful and more user friendly.

4. Module: Cake Porosity from Test Data

The cake porosity (cake voids volume related to the cake volume) is one of the most important cake characterizing parameters and has to be determined experimentally. The cake porosity is needed to predict the cake height but also for predictions regarding the washing and deliquoring behavior of the filter cake.

This module enables the calculation of the cake porosity from tests with filters having plane or convex (candle filters) or concave (filter centrifuges) filter area under consideration of nonvolatile solutes in the cake liquid. Two options: Saturated cake (all voids filled with liquid) and non saturated cake are considered.

The easiest case is when the cake is saturated. In such a case the cake volume (that means the cake height) is not needed and that's why the porosity calculation doesn't need the knowledge of the cake geometry (that means of the filter type) (see fig. 4-1). For the saturated cake we have to know just the wet and dry cake mass of a representative cake sample and the densities of the liquid and the solids.

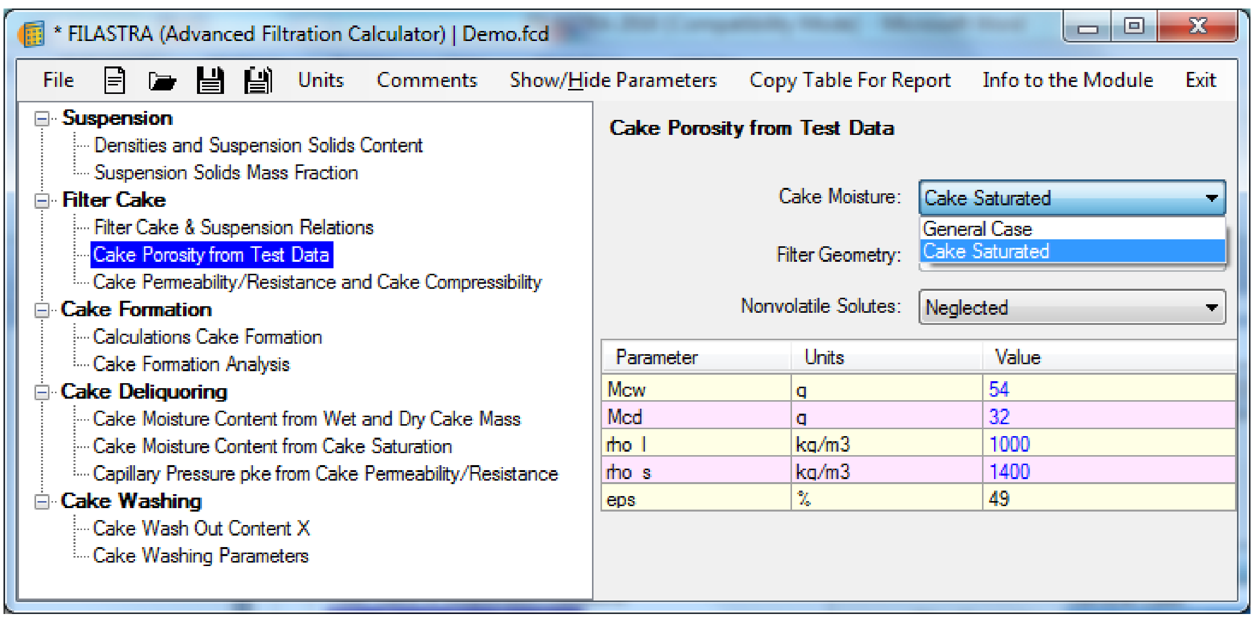


Fig. 4-1: Calculation of the cake porosity for the option *Cake Saturated* and neglected nonvolatile solutes in the cake liquid. In this case the measurement of the cake height is not needed (the cake height is usually the main error source for the calculation of the cake porosity when the cake is under saturated).

In the general case the cake can be under saturated (cake saturation S <100%). For this case the geometry of the filter cake which is related to the filter type is necessary. Besides the filter geometry (plane or convex or concave area), the cake height hc is necessary input parameter as well as the dry solids mass and the solids density.

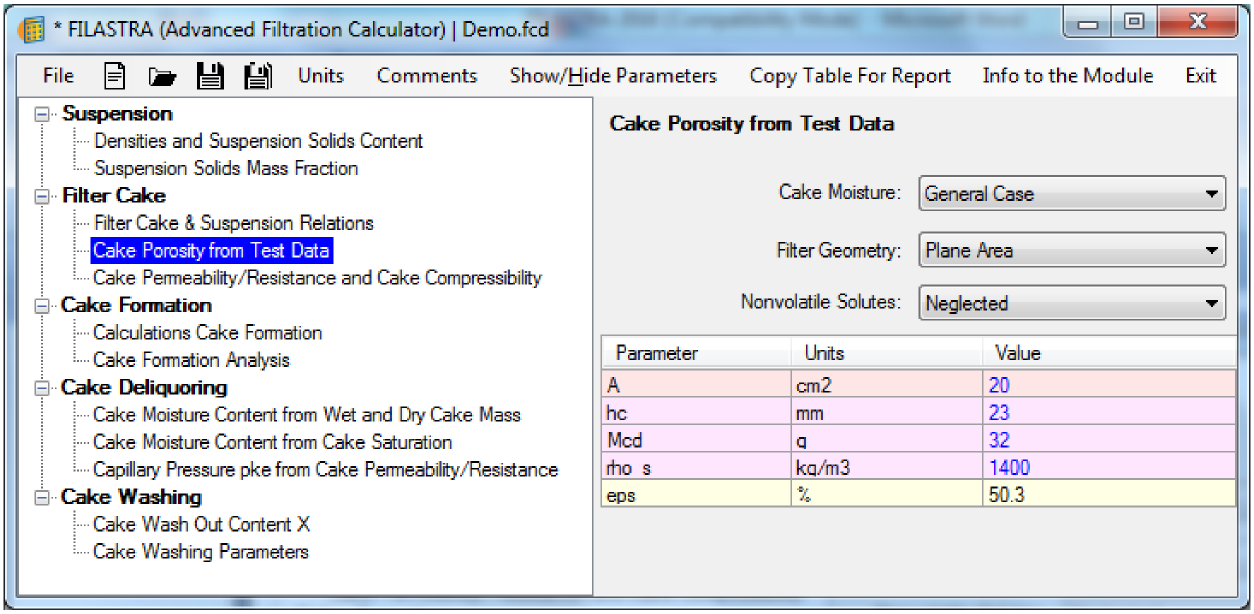


Fig. 4-2: Calculation of the cake porosity for the general case (cake under saturated) and neglected nonvolatile solutes in the cake liquid for a plane filter area. The knowledge of the filter area and the cake height (area and cake height gives the cake volume) is in this case necessary. Furthermore we need the dry solids mass of the cake with the volume Vc (Vc=A*hc) and the solids density.

When we have not negligible nonvolatile solutes in the wet cake, we have to select the option *Nonvolatile solutes: Considered*. In such a case the knowledge of the nonvolatile solutes content in the cake liquid (as non volatile mass fraction Cm_sol in % or concentration C_sol in g/l) is necessary. Besides the geometry parameters of the filter and the filter height (that gives us the filter cake volume), the wet and dry cake mass as well as the densities of liquid and solids are needed.

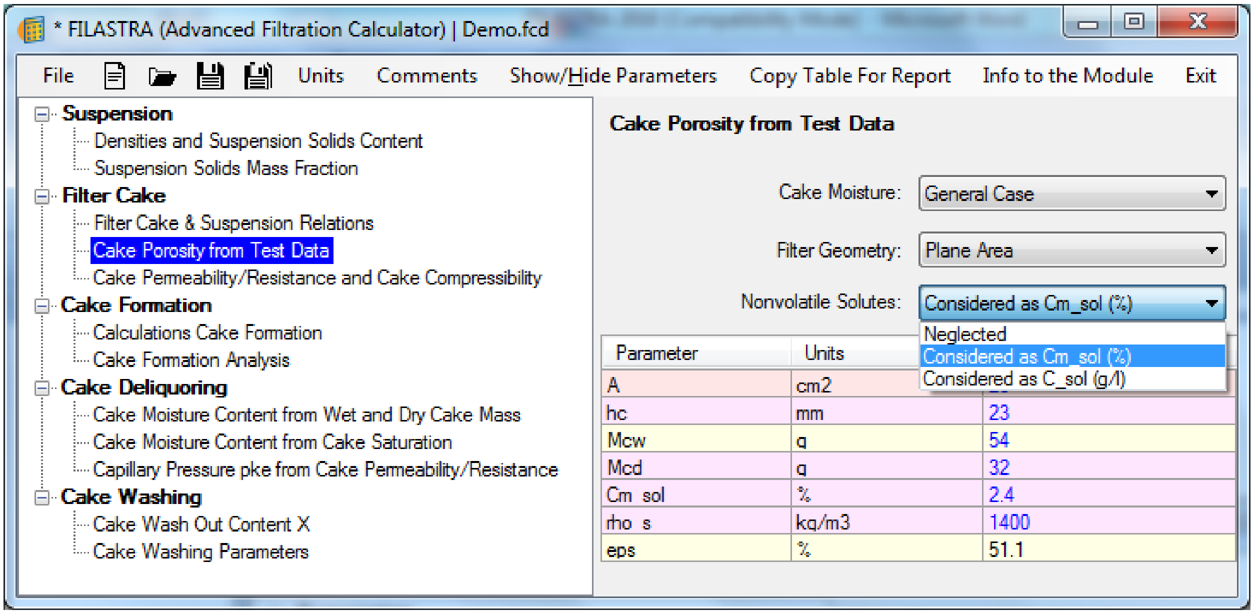


Fig. 4-3: Calculation of the cake porosity for the general case (cake under saturated) and consideration of nonvolatile solutes in the cake liquid for a plane filter area. Additional needed parameters (compared to the option for neglected nonvolatile solutes) are the solutes mass fraction in the cake liquid Cm_sol and the wet cake mass Mcw.

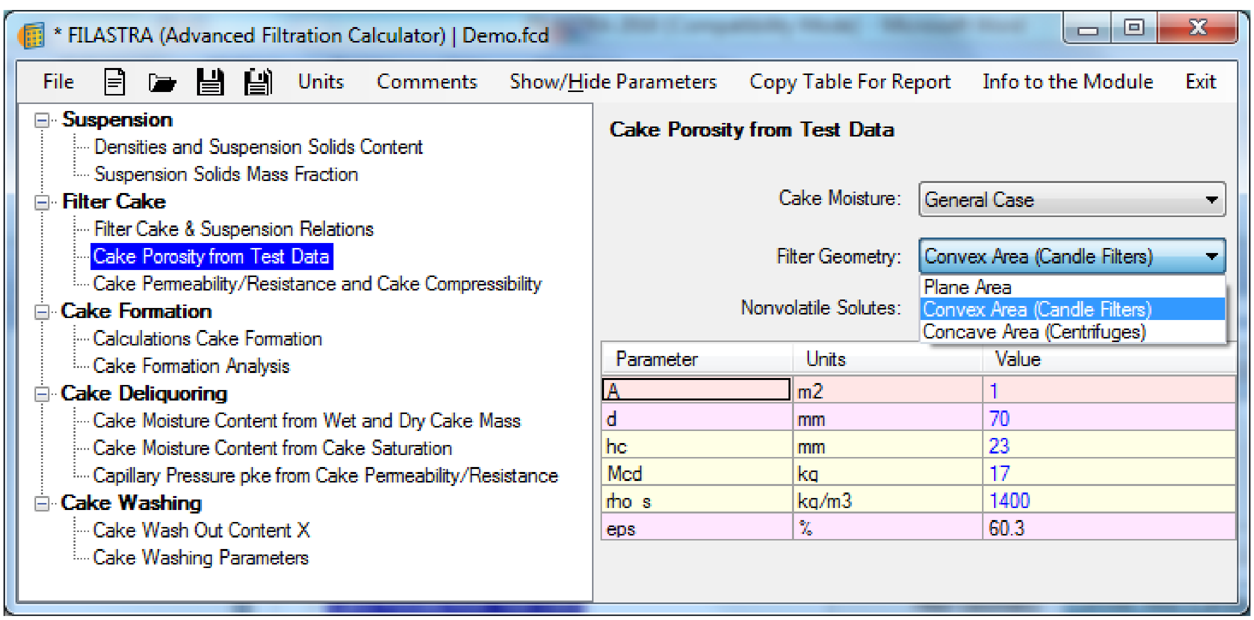


Fig. 4-4: Calculation of the cake porosity of an under saturated cake (general case) from a candle filter test (cylindrical convex area). Besides the filter area, the knowledge of the candle diameter d is necessary (option: *Nonvolatile solutes neglected*).

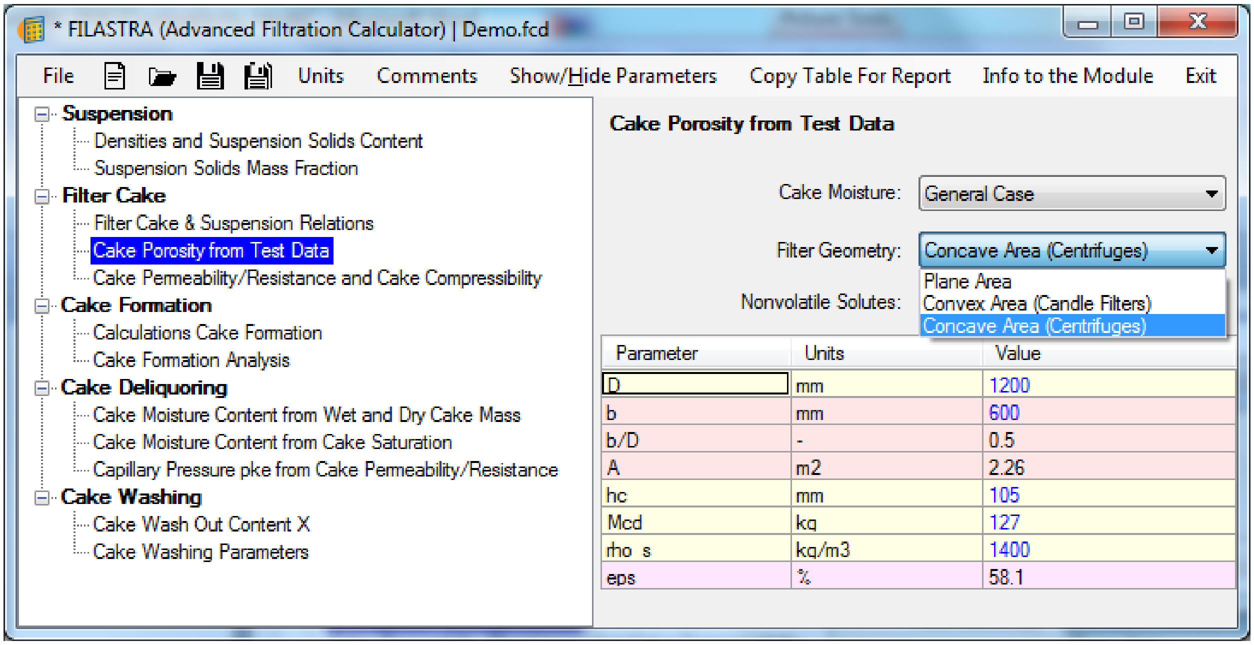


Fig. 4-5: Calculation of the cake porosity of an under saturated cake (General case) from a filtering centrifuge test (cylindrical concave area). Besides the centrifuge diameter D the knowledge of the: centrifuge height or width b or the ratio b/D or the filter area A is necessary (option: *Nonvolatile solutes neglected*).

5. Module: Cake Permeability / Resistance and Cake Compressibility

In the general case the filter cake is compressible. With compressible cake we mean a reduction of the cake permeability pc (or an increase of the cake resistance rc or alpha) with an increase of the cake formation pressure difference Dp. Please notice that pc=1/rc and for alpha we have: alpha = rc*/((1-porosity)*density_solids).

This module calculates as default the above parameters (pc, rc, alpha) if the value of one standard parameter is given (pc0 or rc0 or alpha0) as well as the cake compressibility nc and the pressure difference Dp. The standard values of the cake permeability and the cake resistance are characterized by the index "0" and are related to the pressure difference of Dp0=1 bar. The knowledge of the solids density and the cake porosity is only needed when calculating alpha from pc or rc and vice versa.

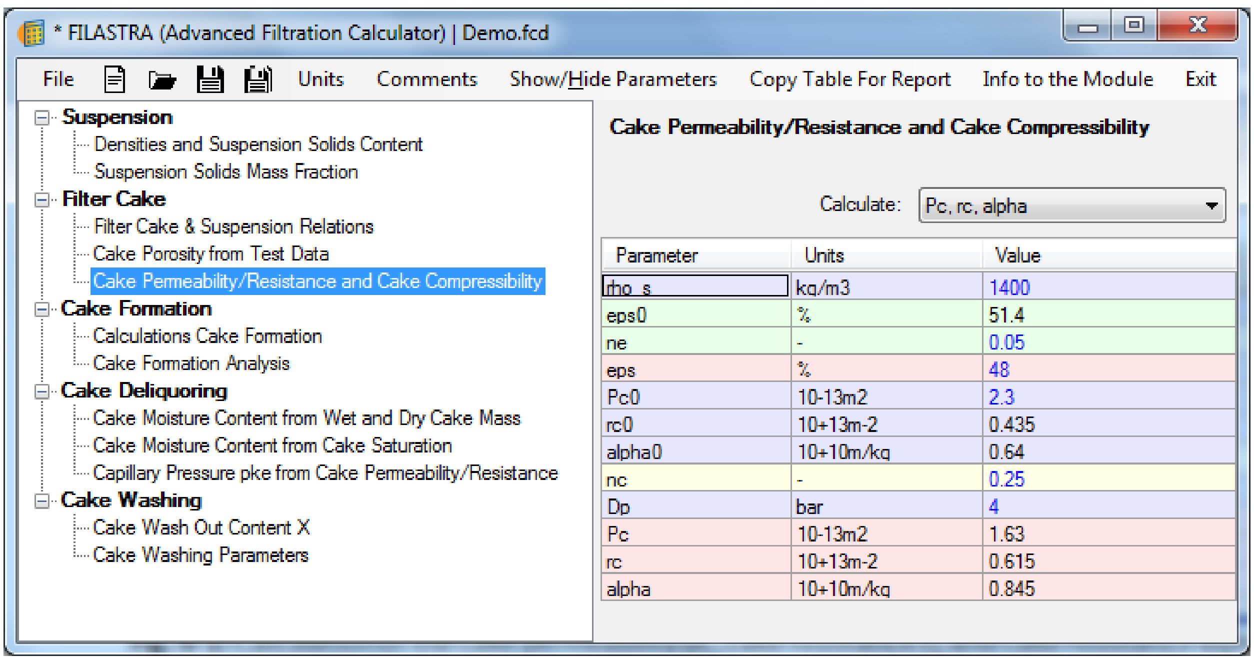


Fig. 5-1: Calculation of the cake permeability pc, cake resistance rc and cake resistance alpha (Option: *Calculate: Pc, rc, alpha*) by entering the value of one standard parameter (in this case of pc0)

This module has the flexibility that instead of the pressure depending cake permeability and cake resistance (pc, rc, alpha) the pressure difference Dp can be calculated if one parameter of the standard cake permeability or standard cake resistance (pc0 or rc0 or alpha0) and the real value (pc or rc or alpha) as well as the cake compressibility nc are given. Similar, the cake compressibility nc or the standard value of the cake permeability or cake resistance (pc0, rc0, alpha0) can be calculated if the other parameters are given.

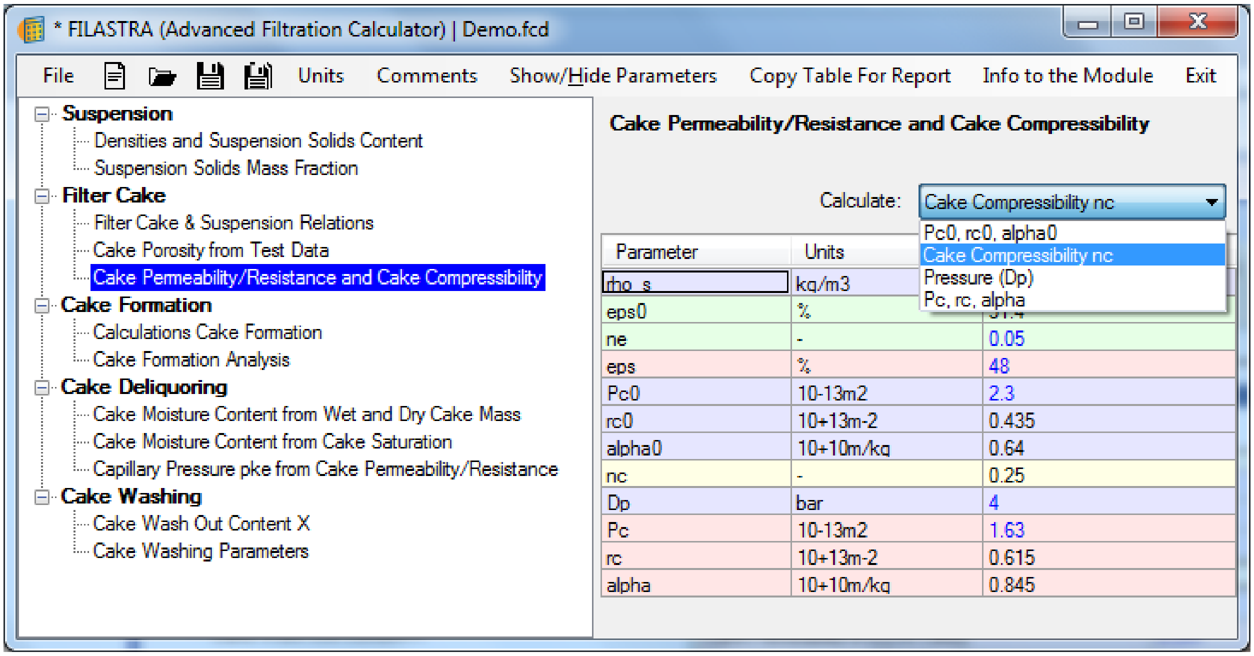


Fig. 5-2: The combo box "*Calculate*" makes the module flexible by enabling the calculation not only of the permeability / resistance values pc, rc, alpha (these are the values for the given cake formation pressure difference Dp) but also the calculation of the standard values (pc0, rc0, alpha0) or the calculation of the cake compressibility nc or the calculation of the pressure difference Dp.

In fig. 5-2 we see the 4 calculation options in the combo box "*Calculate*" that enables the selection of the parameter(s) which we want to calculate. Having this flexibility, questions like the following can be answered: For which pressure difference Dp for a given standard cake permeability pc0 and a given compressibility nc the value of the cake permeability is half of the standard value? Or what should be the standard cake permeability/cake resistance (pc0, rc0, alpha0) for a given pressure difference Dp and cake compressibility nc if a definite cake permeability/cake resistance (pc or rc or alpha) was measured. Or for definite standard values (pc0 or rc0 or alpha0) which cake compressibility nc we should have if for a given pressure difference Dp definite cake permeability/resistance values (pc or rc or alpha) are reported?

6 Module: Calculations Cake Formation

This module enables the calculation of the cake formation step in laboratory or pilot/industrial scale for a plane or approximately plane filter area and constant pressure difference Dp. Typical questions which can be answered: For a given suspension what is the expected filtration time tf to have a cake of for example hc=20 mm if the cake is formed with a constant pressure difference of Dp=4 bar? If we do a laboratory test with this suspension with a filter area for example A=20 cm^2 what is the necessary mass of suspension Msus to have this cake with the height 20 mm? And what are the masses of solids and liquid in the suspension Ms and Ml? The last question is useful also for laboratory purposes if we have to form first the suspension from dry solids and the liquid.

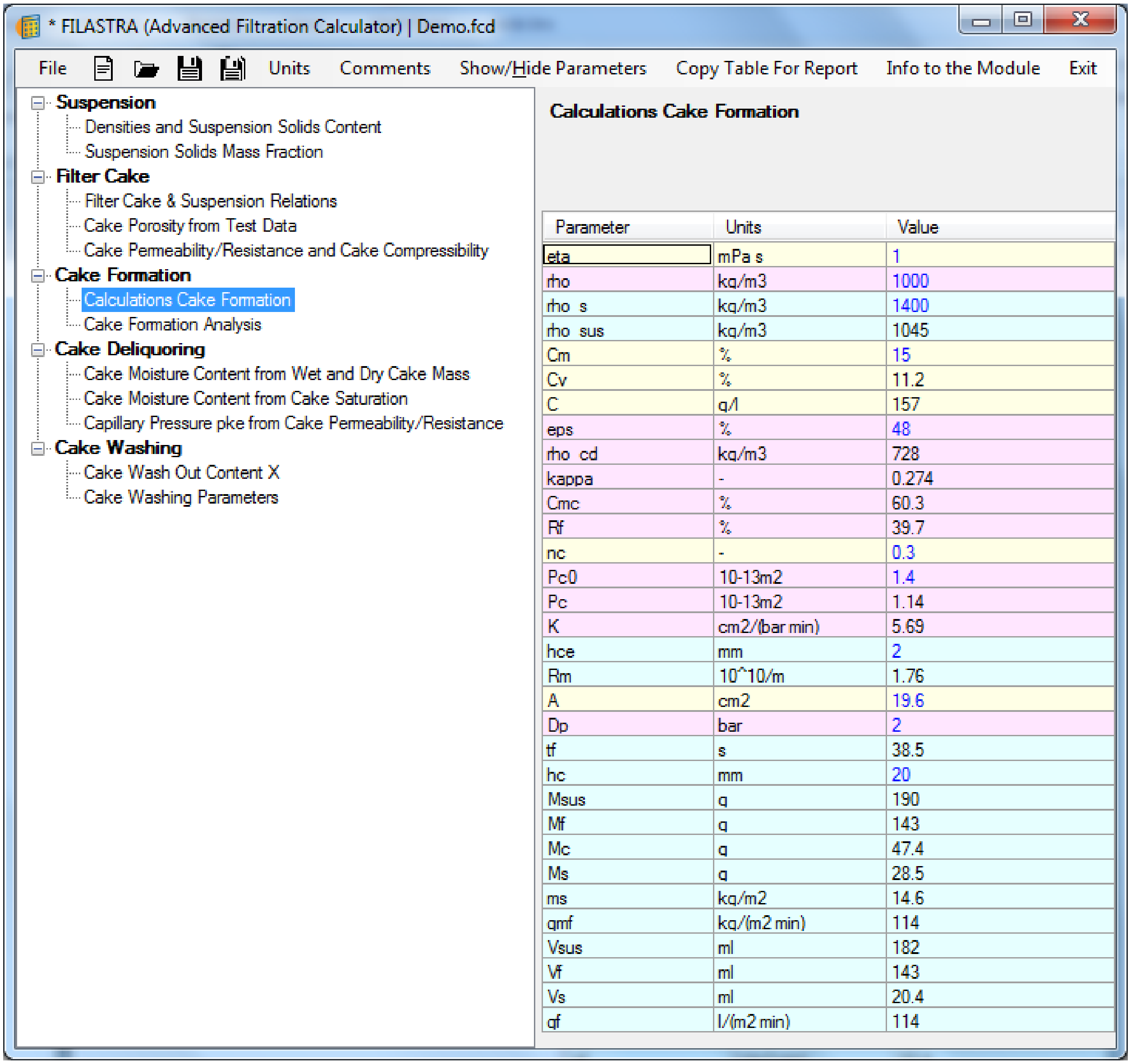
The program has the flexibility that instead of the cake height hc the filtration time tf or the suspension Mass Msus can be entered. In all program modules the values of the input parameters are in blue color and for the calculated parameters in black color. Entering the filtration time tf and calculating the cake height hc is more usual for continuous filters because for these filters by having the cycle frequency (rotational speed for drum, disc, pan filters or belt speed for belt filters) and the specific filter area the cake formation time tf is the given parameter and not the cake height.

Which are the suspension and cake characterizing parameters (both called as material parameters) necessary for the calculation of the cake formation step? We have the following parameters as input:

- Filtrate density
- Solids density or suspension density
- Suspension solids mass fraction (Cm) or volume fraction (Cv) or solids concentration (C)
- Cake porosity or dry cake density or kappa (kappa=cake volume / filtrate volume)
- Filtrate viscosity
- Standard cake permeability pc0 or resistance rc0 or alpha0
- Cake compressibility nc
- Filter medium resistance as Rm (absolute) or as hce (specific)

The possibility to enter any parameter belonging to the same group (parameters belonging to the same group are listed together with the same background color and only one parameter can be entered and the others are calculated) gives a high flexibility to the program, for example entering the solids density or the suspension density, the suspension solids mass fraction Cm or the volume fraction Cv or the solids concentration C, entering the standard cake permeability pc0 or the standard cake resistance rc0 or alpha0 etc.

For the experimental determination of the suspension solids mass fraction Cm see Module 2 (*Suspension Solids Mass Fraction*) and for the experimental determination of the cake porosity see module 4 (*Cake Porosity from Test Data*) or module 3 (*Filter Cake & Suspension Relations*).



Parameter	Units	Value
eta	mPa s	1
rho	kg/m3	1000
rho_s	kg/m3	1400
rho_sus	kg/m3	1045
Cm	%	15
Cv	%	11.2
C	g/l	157
eps	%	48
rho_cd	kg/m3	728
kappa	-	0.274
Cmc	%	60.3
Rf	%	39.7
nc	-	0.3
Pc0	10-13m2	1.4
Pc	10-13m2	1.14
K	cm2/(bar min)	5.69
hce	mm	2
Rm	10^10/m	1.76
A	cm2	19.6
Dp	bar	2
tf	s	38.5
hc	mm	20
Msus	g	190
Mf	g	143
Mc	g	47.4
Ms	g	28.5
ms	kg/m2	14.6
qmf	kg/(m2 min)	114
Vsus	ml	182
Vf	ml	143
Vs	ml	20.4
qf	l/(m2 min)	114

Fig. 6-1: Module window for the calculation of the cake formation step for a constant pressure difference and plane filter area. Parameters next to each other with the same background color belong to the same group, that means anyone of these parameters can be input and the others are calculated. For example the following 3 parameters: cake height hc, filtration time tf and suspension Mass Msus (=suspension mass for one filtration cycle) belong to the same group and we can enter tf or hc or Msus and all other parameters in this group are calculated.

7 Module: Cake Fomation Analysis

This is actually the most important module of the *FILASTRA* software and I am convinced that it will be a great help for the program users. Why? For the first time you have a tool that calculates at once both parameters: Cake porosity and cake permeability/cake resistance and not only from Batch filter test data (for example laboratory vacuum or pressure nutsche tests), see fig. 7.1, but also from data of continuous Pilot/Industrial filters (for example vacuum rotary filter performance data), see fig. 7.2.

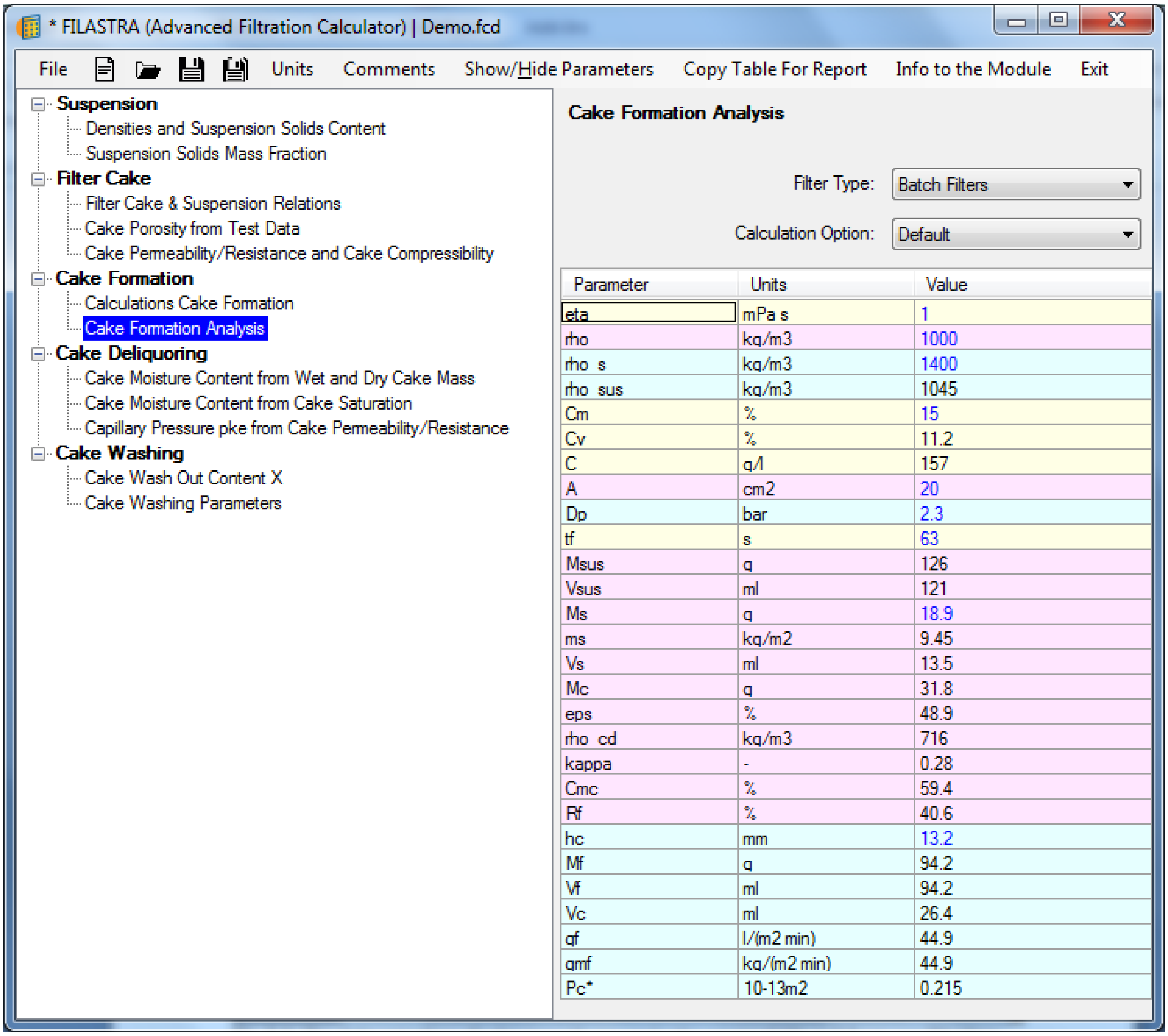
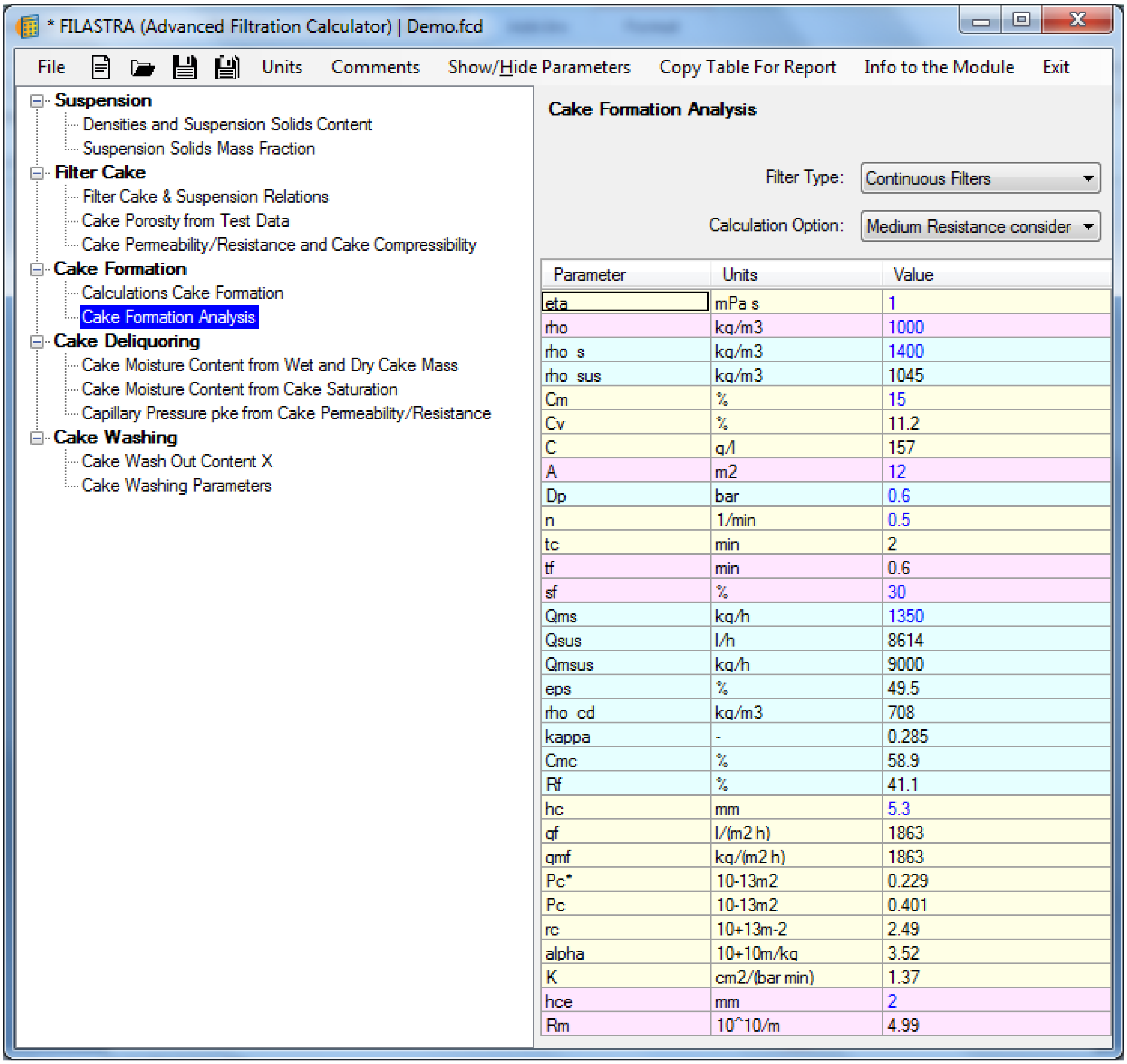


Fig. 7-1: The determination of cake porosity eps and cake permeability pc* from one filtration measurement with a Batch filter. Highest flexibility regarding the input parameters. All important parameters can be entered or calculated. The module can be used also as a simulation module if the porosity and permeability are entered instead of calculated.

There is a great flexibility regarding the last two input parameters (see last 2 groups of parameters in fig. 7-1). Default Inputs for the last two groups are the dry solids mass Ms (for continuous filters instead of Ms we have Qms as default Input) and the cake height hc but instead of them many other parameters can be entered (see fig. 7-1). Always Inputs should be the filter area A, the pressure difference Dp (constant during the filtration time) and the filtration time tf. Input material parameters are viscosity and density of the mother liquid, solids or suspension density and suspension solids content (Cm or Cv or C).



<u>Fig. 7-2</u>: Analysis of performance data of a Continuous Filter (for example rotary vacuum drum or pan filters or rotary pressure filters) to determine the cake porosity eps and the cake permeability pc. Default measured parameters (inputs) are the solids throughput Qms and the cake height hc.

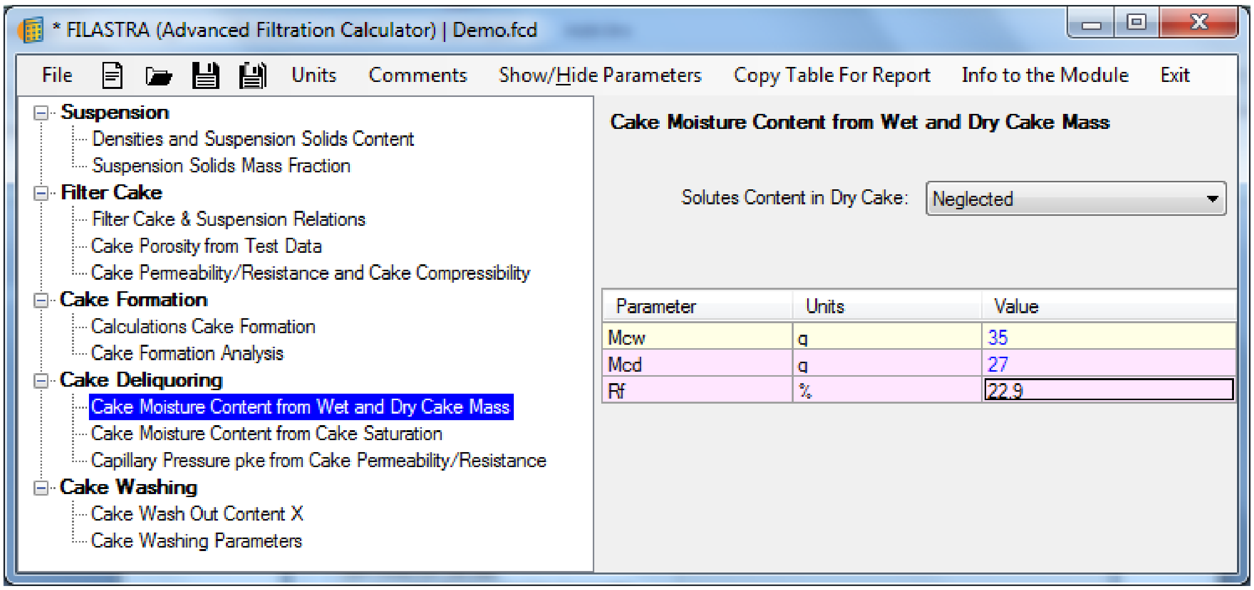
As default option, the filter medium resistance and the cake compressibility are neglected. That's why we use in this case the parameters pc*/rc*/alpha* instead of pc/rc/alpha. The "*" indicates for example that pc* is not the cake permeability (pc) but the permeability of the system cake-filter medium (from one measurement we can not get both parameters: cake permeability and filter medium resistance!). Only if Rm=0 we will have pc*=pc. In the combo box *Calculation Option* the user can select the consideration of the filter medium resistance (Rm or hce) or the consideration of both: filter medium resistance (Rm or hce) and cake compressibility nc. As last option we can additionally consider a cake porosity reduction with increasing pressure difference (see last option *Show also ne).* Default is ne=0, that means constant cake porosity. The *ne* value should normally not be higher than 0.05.

For the analysis of data from continuous filters we have to enter the filter area A, the pressure difference Dp, the cycle time tc or the frequency n (rotational speed) with n=1/tc and the specific area for cake formation sf or the cake formation time tf. For the last two inputs in the last 2 groups we can enter as default the solids throughput Qms and the cake height hc but instead of Qms the suspension rate as volume rate or mass rate (Qsus or Qmsus) and instead of the cake height hc the average filtrate flow rate as mass or volume (qmf or qf) can be entered. Same as with the analysis of Batch filter tests, input material parameters are viscosity and density of the mother liquid, solids or suspension density and suspension solids content (Cm or Cv or C).

The option *Cake Formation Analysis –Continuous Filters* can be used (similar to the option *Cake Formation Analysis –Batch Filters*) also for the simulation of the filter performance if the cake porosity eps and the cake permeability pc are entered instead of calculated.

8. Module: Cake Moisture Content from Wet and Dry Cake Mass

This module enables the calculation of the cake moisture content Rf, defined as liquid mass in the cake related to the total (=wet) cake mass from the measurement of the wet and dry cake mass. The correct determination of the cake moisture content is very important for the characterization of the deliquoring behavior of the filter cake and necessary input parameter for the analysis of the cake deliquoring data (see *FILOS* and *CENTRISTAR*). The analysis of the experimentally determined cake moisture content Rf enables the determination of the cake deliquoring specific adaptation parameters, which are necessary for Rf-predictions for any filter setting parameters (for any cake height, pressure difference and deliquoring time).



<u>Fig. 8-1:</u> Calculation of the cake moisture content Rf (defined as liquid mass in the cake related to the total wet cake mass) from the wet cake mass Mcw (=total cake mass) and the dry cake mass Mcd for the option that the nonvolatile solutes in the cake liquid are neglected.

For the calculation of the cake moisture content we have two options which can be selected in the combo box "*Solutes Content in Dry Cake*:" The first option is when the nonvolatile solutes in the cake liquid are negligible (see fig. 8-1) and the second option (which is the general case) is when nonvolatile solutes in the cake liquid are considered (see fig. 8-2).

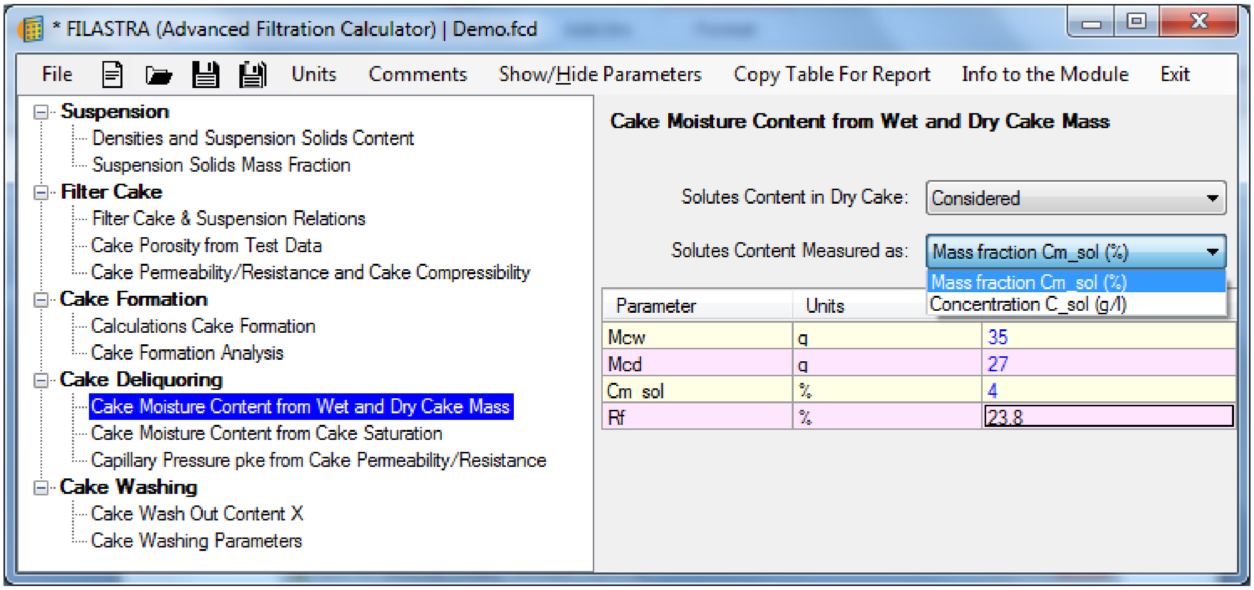


Fig. 8-2: Calculation of the cake moisture content Rf (defined as liquid mass in the cake related to the total cake mass) from the wet cake mass Mcw (=total cake mass) and the dry cake mass Mcd for the case that the nonvolatile solutes in the cake liquid are NOT neglected. For this option the solutes content in the cake liquid is an additional parameter (as solutes concentration C_sol (g/l) or solutes mass fraction Cm_sol (%))

The consideration of nonvolatile solutes in the cake enables the correct determination of the cake moisture content in all cases. For this general case we need besides the input of the wet and dry cake mass (Mcw and Mcd) the input of the nonvolatile solutes content in the cake liquid. This solutes content can be entered as solutes concentration C_sol in g/l or as solutes mass fraction Cm_sol in %. When the input parameter is the solutes concentration C_sol, then the input of the liquid density is also necessary.

By considering both cases: “*nonvolatile solutes neglected”* and “*nonvolatile solutes considered”* we can quantify the error in the cake moisture content calculation which we do if we do not consider existing nonvolatile solutes in the wet filter cake.

9. Module: Cake Moisture Content from Cake Saturation

The cake Saturation S defined as liquid volume in the cake related to the cake voids volume can have values between 100% (=saturated cake, that means all voids of the cake are filled with liquid) and 0% (=totally dry cake). By deliquoring a cake via a gas pressure difference or via a centrifugal pressure (as this happens in filtering centrifuges) or via a combination of centrifugal pressure and gas pressure difference, the cake Saturation decreases from S=100% (initial value) to a minimal value, which we call remanent Saturation Sr. This remanent Saturation has in most of the cases values between 7% and 15% and if thermal liquid removal from the cake is not considered.

The cake saturation S is for the calculation of the deliquoring step the most important parameter because it doesn't depend on the densities of the solids and of the liquid. When for example we give a cake Saturation value of 50% we know that no matter which material we have 50% of the liquid in the filter cake is removed and displaced by gas. But if for example we give a cake moisture value of Rf=25% we can not have any imagination about the deliquoring degree in the cake because depending on the solids and liquid densities and the cake porosity with Rf=25% the cake can be saturated (S=100%) or can have any other saturation 0<S<100 %.

That's why and although the cake moisture content Rf is for the praxis the used and thus the most interesting parameter, for analyzing and understanding the deliquoring behavior of the cake and for calculating the deliquoring step the cake saturation S is the parameter that has to be determined and used.

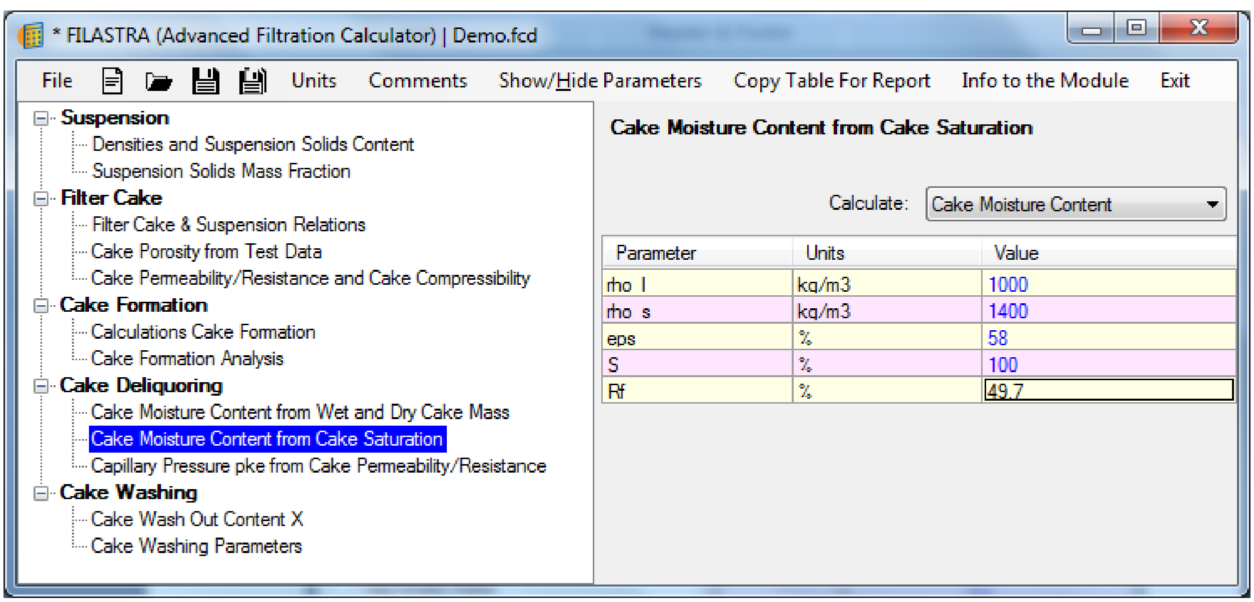
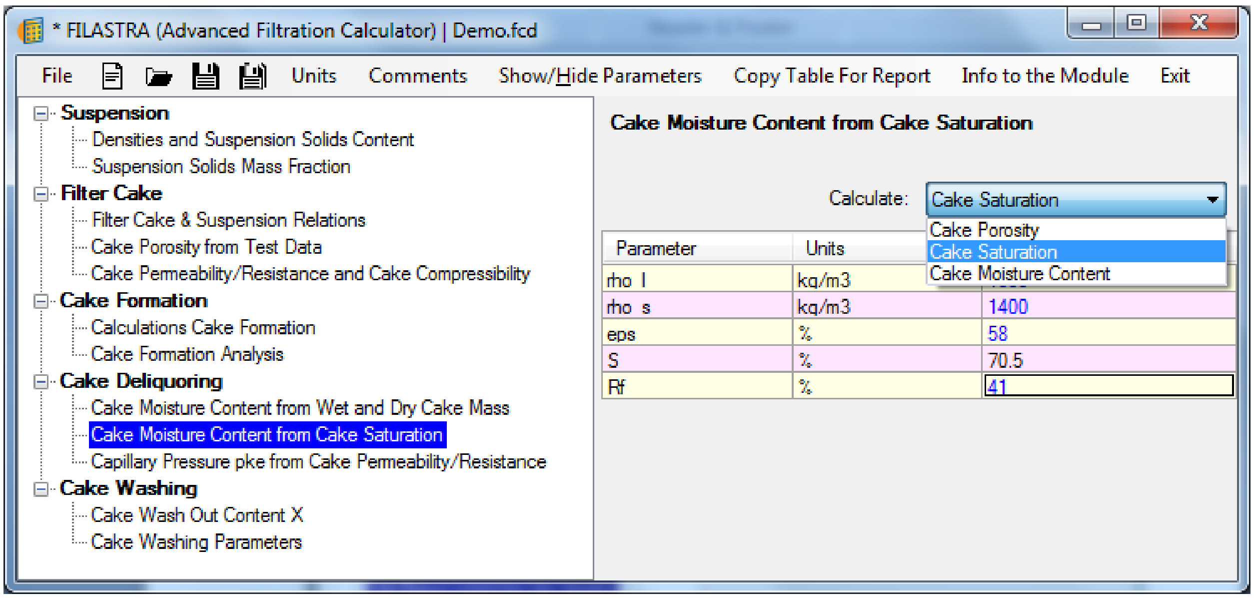


Fig. 9-1: Calculation of the cake moisture content for given densities of the liquid and the solids in the cake, for given cake porosity and cake saturation.

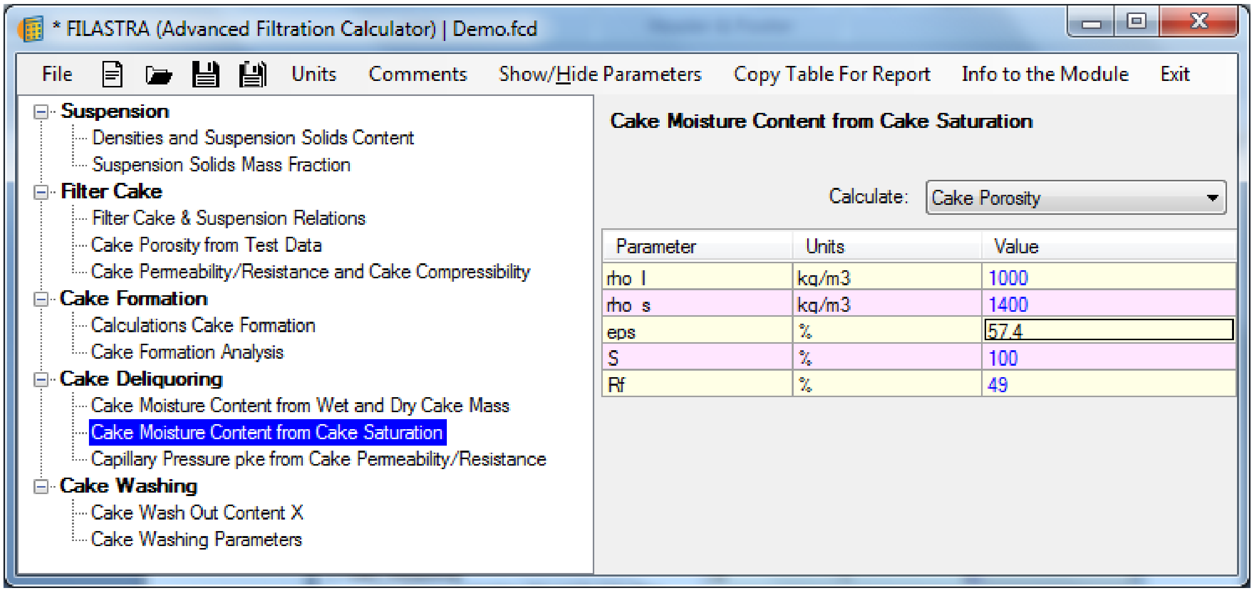
This module enables the calculation of the cake moisture content Rf when the cake saturation S is entered (see fig. 9-1) and vice versa (see calculation of cake saturation from the cake moisture content Rf in fig. 9-2). The practical way is that we experimentally determine the cake moisture content Rf (for that see module 8: *Cake Moisture Content from Wet and Dry Cake Mass*) and calculate the cake Saturation S (as we already said, the cake saturation is the parameter that gives us a correct imagination of the deliquoring degree of the cake). To calculate the cake saturation from the measured cake moisture content the densities of the cake liquid and the solids as well as the cake porosity are needed.



<u>Fig. 9-2:</u> Calculation of the cake saturation S for given densities for the liquid and the solids in the cake, for given cake porosity and cake moisture content. This option is also very useful because by getting the cake saturation we can judge the deliquoring degree of the cake and also we can judge the quality of the Rf-measurement.

This module can also be used to check the correctness of the Rf-values. It happens for example that one or more reported Rf –values are not correctly measured. Under the assumption of correct values for densities and cake porosity the moisture content Rf has a maximal possible value if the cake is saturated. Entering S=100% we calculate the maximal expected Rf-value. If for example the reported value is higher than the Rf-value that corresponds to S=100% then this is an evidence that the Rf-value is not correct.

Another example is the judgment if during the deliquoring step we had thermal effects (not negligible evaporation of the cake liquid) besides the mechanical liquid displacement from the cake: If the reported Rf-value gives us for example a cake saturation of S=3% and we know that the remanent saturation (=minimal Saturation that can be reached excluding any thermal effects) can not be, let say, less than S=7%, that means we had not negligible liquid evaporation during the cake deliquoring time.



<u>Fig. 9-3:</u> Calculation of the cake porosity from the cake moisture content Rf and the cake saturation S. This option is for example useful when we know that the cake is saturated (S=100%) but also to judge the correctness of reported cake porosity values. With this option we can also determine the minimal possible cake porosity (that is the value we get by entering the measured Rf-value and cake Saturation S=100%).

This module enables also the calculation of the cake porosity by entering both parameters: cake saturation S and cake moisture content Rf. Knowing for example that the cake is saturated (S=100%) and also the cake moisture content Rf (this parameter is measured) we can determine the cake porosity. We can also use this module option to determine the minimal possible value of the cake porosity in case that the cake saturation is not known because for a given cake moisture content Rf the minimal porosity value is given for the maximal cake saturation. Since we know that the maximal cake saturation is 100% by entering this value we calculate the minimal possible cake porosity for the given cake.

10. Module: Capillary Pressure pke from Cake Permeability/Resistance

This module enables the calculation of the capillary threshold pressure pke for given cake permeability pc and for given surface tension of the liquid in the cake during the deliquoring step (instead of pc the cake resistance rc in m^{-2} or alpha in m/kg can be entered). Another input parameter is the standard capillary threshold pressure pke_st, defined as the capillary pressure for the standard cake permeability Pc_st ($P_{c\_st}=10^{-13}$ m^2). It is recommended to use for pke_st the value 0.25 bar.

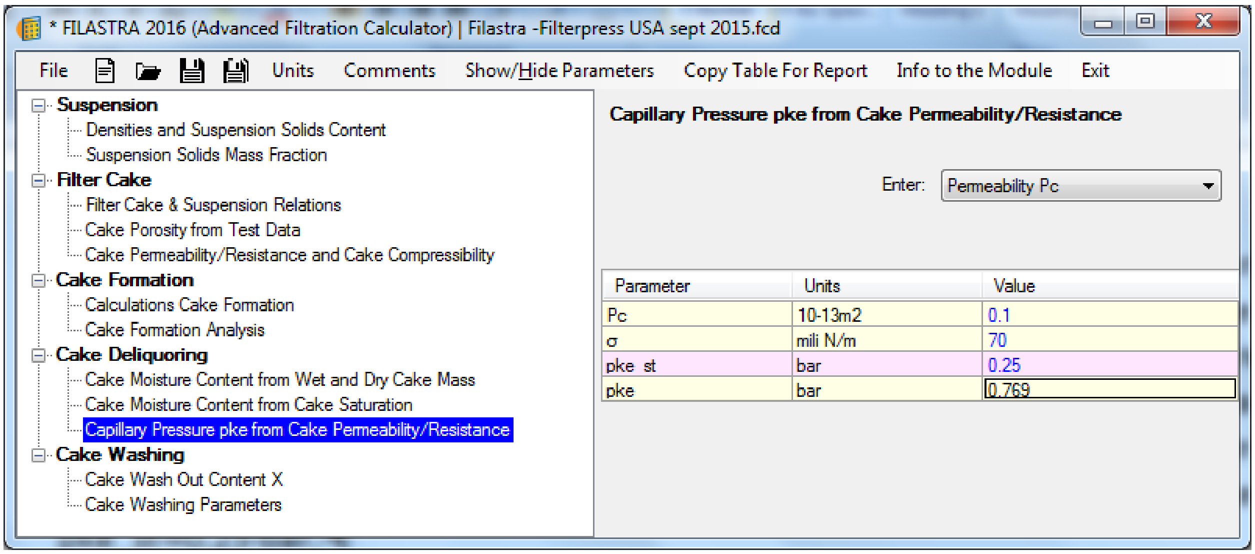


Fig. 10-1: Calculation of the capillary threshold pressure pke (=minimal pressure difference needed for the cake deliquoring) from the cake permeability pc (instead of the cake permeability the cake resistance as rc (m^{-2}) or alpha (m/kg)-value can be entered). Besides the cake permeability/resistance the surface tension of the liquid in the cake and the so called standard capillary pressure (pke_st) are needed. The pke_st is the value for pc=10^{-13} m^2 and according to experience with many materials it varies between 0.2 and 0.3 bar. It is recommended to use as default pke_st =0.25 bar.

It has to be noticed that in FILOS the pke-value is a material input parameter for the cake deliquoring step and this program doesn't consider automatically the relation of the pke with the cake permeability/resistance. It is recommended to use this module to calculate the pke from the p_c or r_c or alpha-value and then enter in FILOS this calculated value in the pke-field.

The possibility to calculate the capillary threshold pressure from the cake permeability / resistance is not only important for the input of correct pke-values in FILOS but also for judging the deliquoring behavior of the cake in dependence to the cake permeability. If for example we have a cake permeability value of pc=0.1 ("0.1" is the number in front of "10^{-13} m^2") then we calculate for water 25 °C a pke-value of 0.769 bar (see fig. 10-1) and we know immediately that this cake can not be deliquored in a vacuum filter.

11 Module: Cake Wash Out Content X

This module enables the calculation of the wash out content in the cake X (= mass of wash out substance related to the dry solids mass) by entering the wash out content of the liquid in the cake or by entering the wash out content of the liquid of the suspension, which we get after re suspending the wet cake with a definite amount of pure wash liquid Ml.

The experimental procedure for getting the wash out content in the liquid of the re suspended cake is the following: The washed and maybe deliquored cake sample with the wet cake mass Mcw is re suspended with a definite amount of pure wash liquid Ml and then this suspension is filtered. From the measurement of the content of the wash out substance in the filtrate Cw and the dry mass of the filter cake Mcd we calculate the wash out content in the cake X and also the cake moisture content of the wet cake sample Rf (Rf= mass of liquid in the wet cake related to the mass of wet cake).

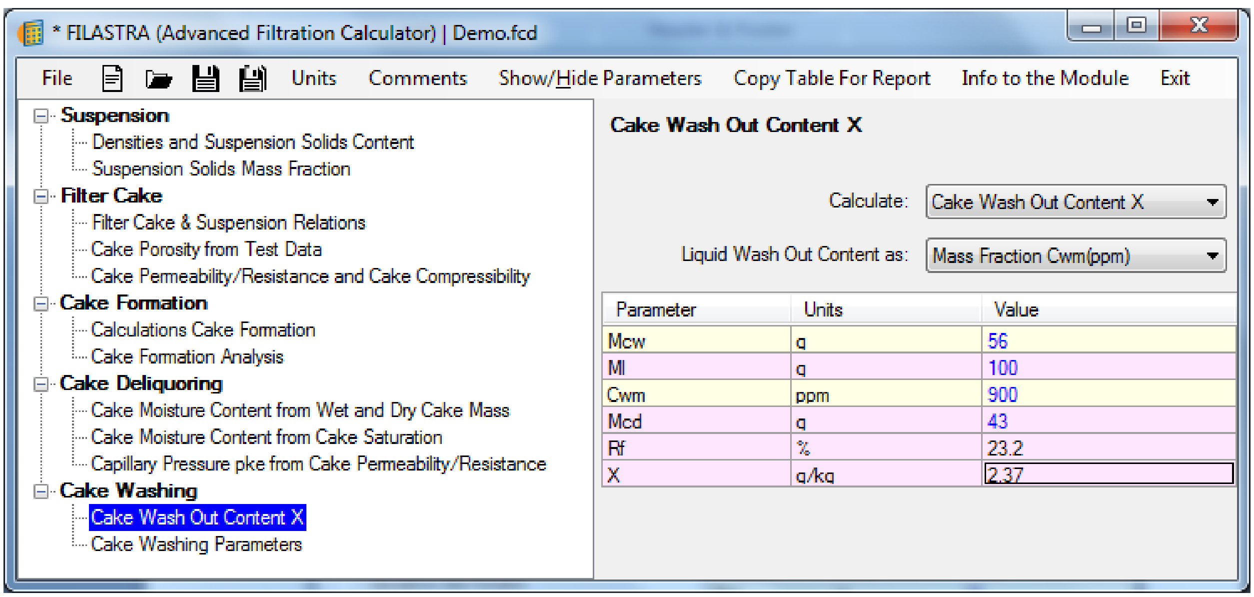


Fig. 11-1: Calculation of the wash out content in the filter cake X (=mass of wash out substance related to the dry solids mass) and of the cake moisture content Rf (=mass of liquid in the cake related to the mass of the wet cake) after re suspending the wet filter cake with a definite amount of wash liquid Ml and filtering this suspension. The wash out content X is then calculated from the value of the measured wash out content of the wash filtrate and the dry solids mass of the filter cake.

The Units for X can be selected in the Units window (see field: Cake Wash out Content X). The selection of the following units is possible: *g_wash out substance/kg_dry solids*, %, *mg_wash out substance/kg_dry solids* or *ppm*.

This module is very useful when using *FILOS* and *CENTRISTAR* and especially for the analysis of cake washing data to get the necessary adaptation parameters for the washing step. These adaptation parameters are necessary for the prediction of the washing performance of filters and filtering centrifuges for any setting parameters. The cake washing modules in *FILOS* and *CENTRISTAR* need the input of the wash out content X and of the cake moisture content Rf. Both of these parameters can be determined in this module.

In case that the wash out content of the liquid in the filter cake is known, then no re suspension of the wet cake is needed. This module calculates the wash out content in the cake X also for this case by entering Liquid Mass for resuspension Ml=0 and as wash out content (Cmw or Cw) the wash out content of the liquid in the wet cake.

For the case that the pH-value of the liquid in the cake is important, this module has the option to calculate the pH of the cake liquid (pH_c) by measuring the pH of the wash filtrate, which we get after re-suspension of the wet cake with a definite amount of water (pH=7) and filtering the suspension. The default unit for the calculated parameter X is for this option the mass of H^+-ions per kg dry solids (see fig. 10-2).

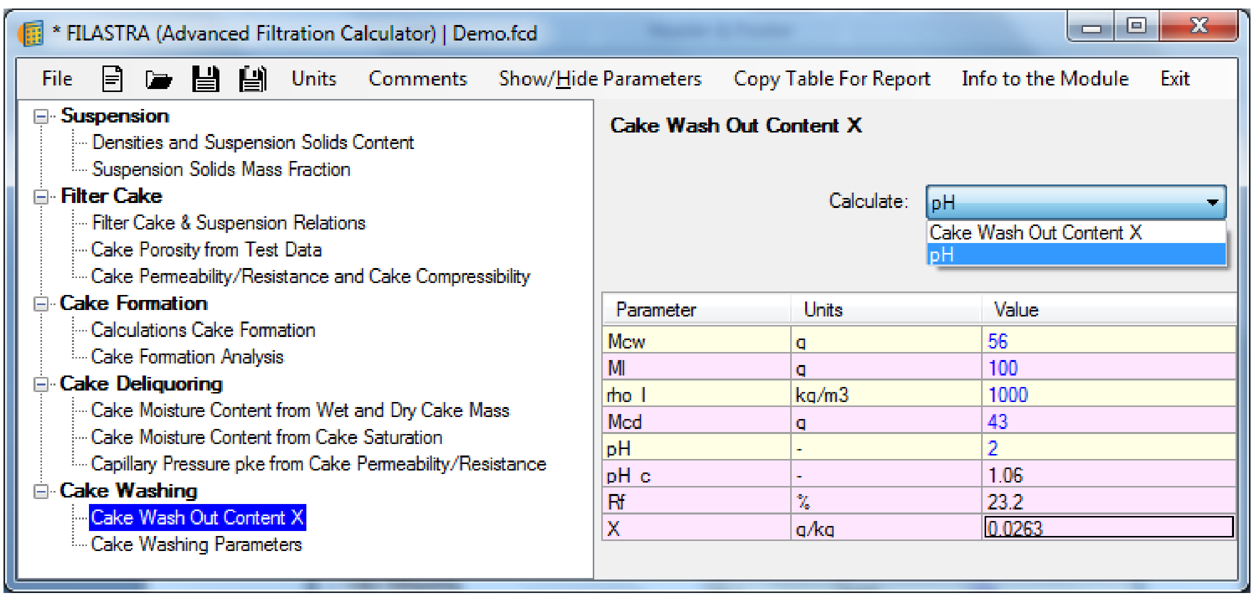


Fig. 10-2: Calculation of the pH of the liquid in the wet filter cake from the pH-value of the wash filtrate which we get after filtration of the re-suspended wet cake. Besides the pH of the liquid in the cake we calculate also the H^+-ions content in the cake X and the cake moisture content Rf.

12 Module: Cake Washing Parameters

For Filters and Filter Centrifuges (plane, concave and convex filter area) this module determines the needed washing liquid amount (specific and absolute) and when the cycle time is known additionally the average wash liquid flow rate (absolute and area specific). Needed inputs are filter geometry parameters, wash liquid and solids density, cake porosity and cake height. Instead of the cake height the absolute or the specific solids mass or (when cycle time is known) the solids throughput can be given.

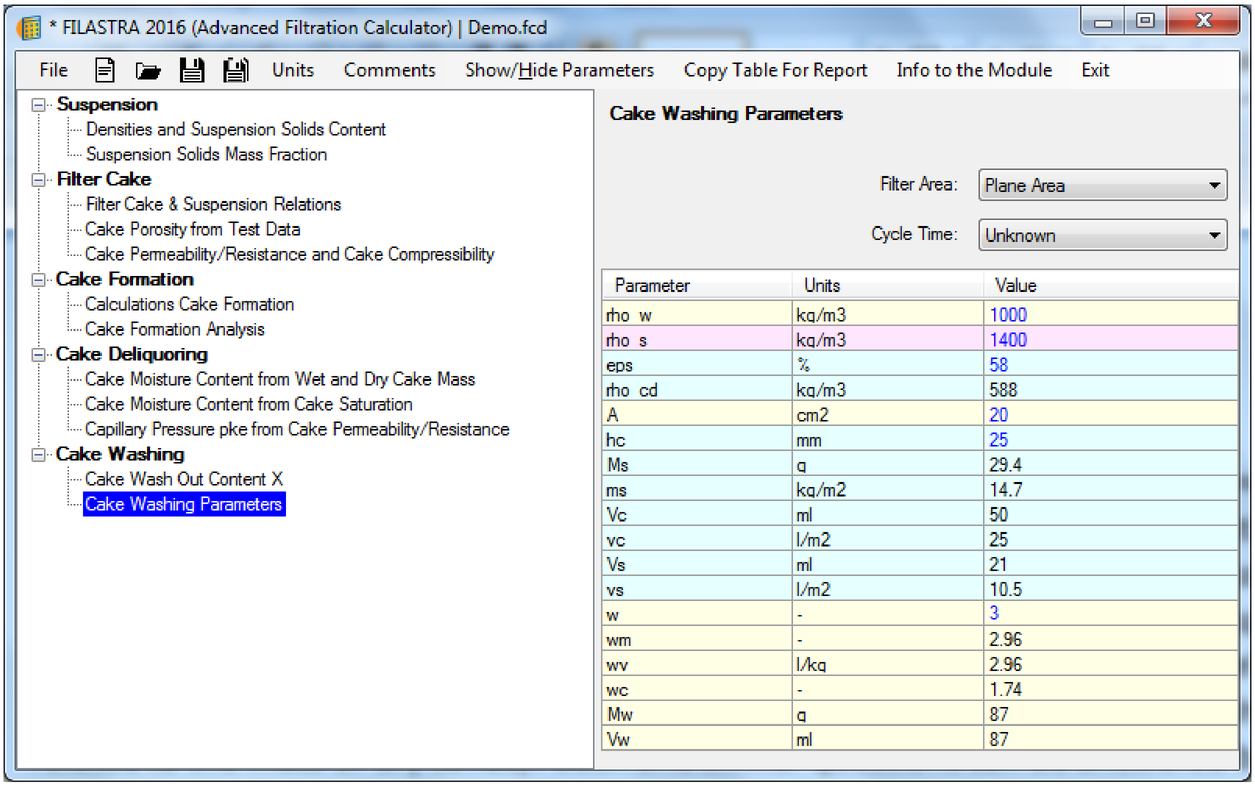


Fig. 12.1: Calculation of the needed absolute wash liquid amount (Mw, Vw) to have for a filter nutsche laboratory test a definite specific wash liquid consumption, as for example a washing ratio of w=3. Given parameters are the densities of wash liquid and solids, the cake porosity, the filter area and the cake height (see parameters with blue values). Beside the calculated wash liquid mass and volume (Mw, Vw), the specific liquid consumption as wm (=mass wash liquid per mass of dry solids) and wv (=volume of wash liquid per mass of dry solids) are calculated.

A typical question which can be answered by this new module is among others the following (see also fig. 12.1): We do a laboratory test with a vacuum or a pressure nutsche with a given filter area A. We form a filter cake of the height hc and we want to test the washing step. We want to use such a wash liquid amount which will give us a good washing result. From the theory and the experience we know that a washing ration of w=3 normally should be enough (washing ratio is defined as the specific wash liquid consumption =

volume of wash liquid related to the voids volume of the cake). What is the mass and volume of the wash liquid Mw, Vw needed for the experiment and which corresponds to w=3? What is the specific wash liquid consumption wm (=mass of wash liquid related to mass of the dry solids) and the specific liquid consumption wv (= volume of wash liquid related to the mass of dry solids)? Such and similar questions can be answered by this module not only for laboratory filters but for pilot or industrial filters and filter centrifuges.

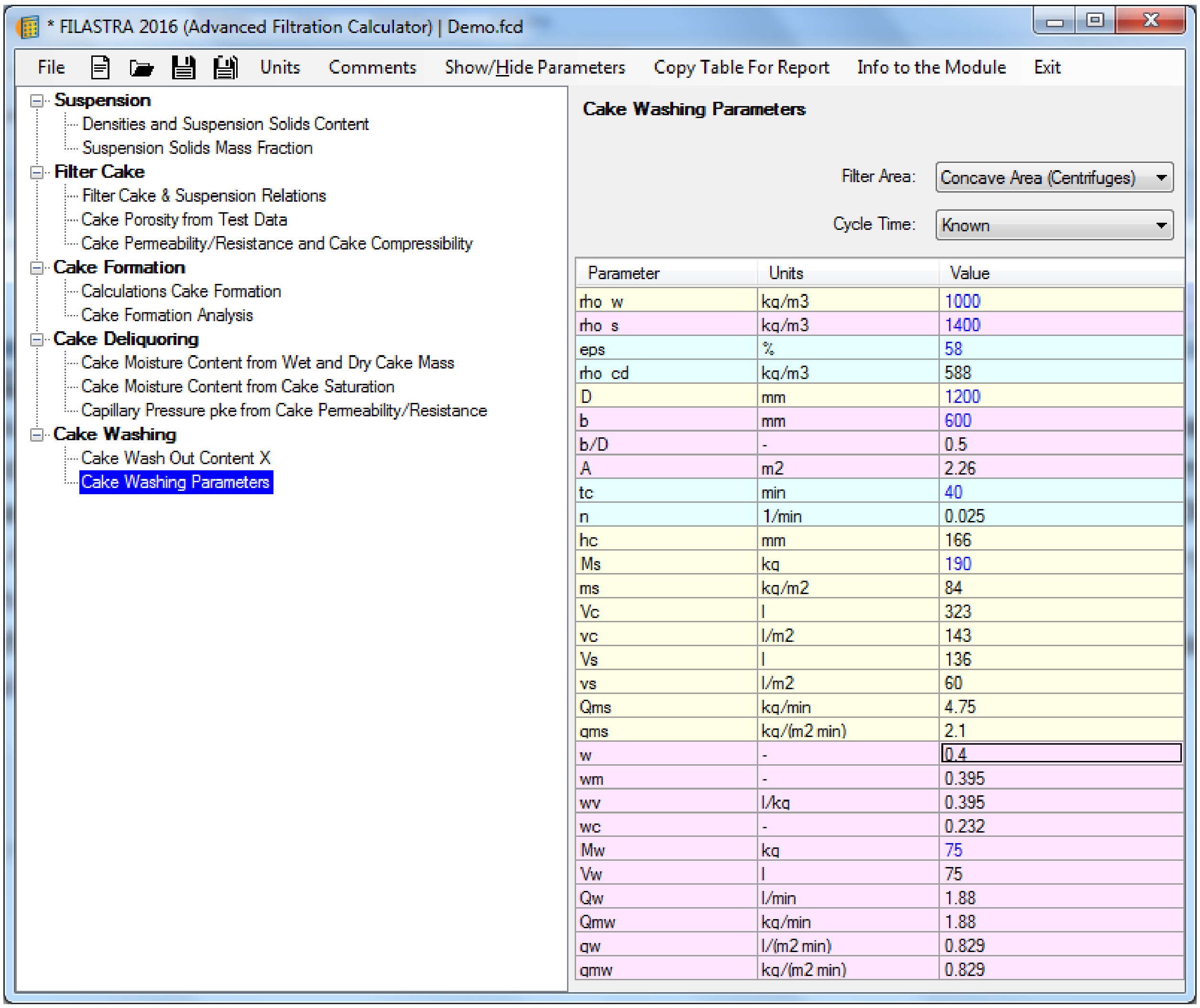
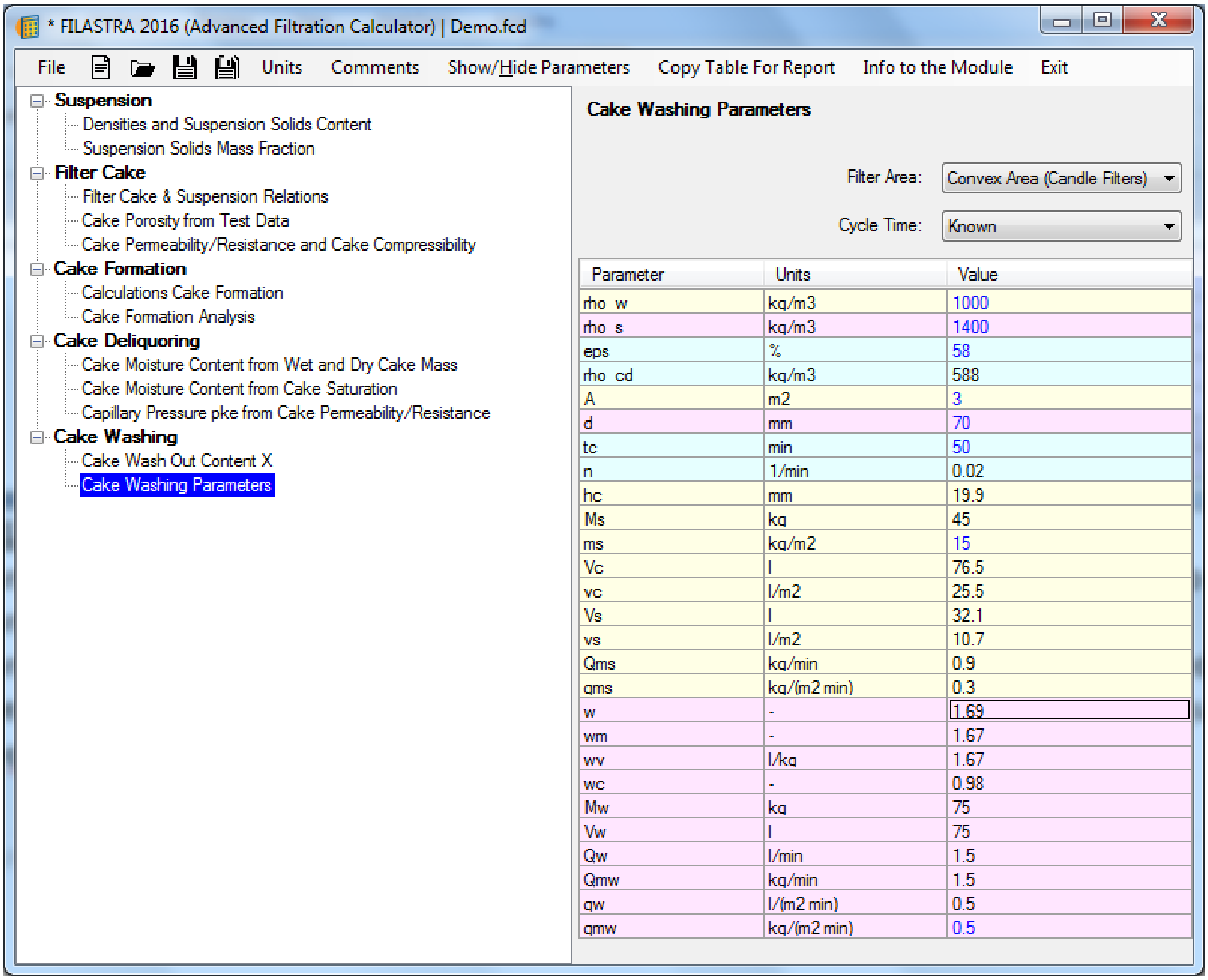


Fig. 12.2: Calculation of the cake height hc and the absolute and specific wash liquid consumption in a filter centrifuge as well as the mass solids rate (Qms) and average wash liquid rate (Qw, Qmw). The main question in this example was to prove if a definite amount of wash liquid Mw (Mw=75 kg) in an industrial Centrifuge with given geometry (D=1200 mm, b=600 mm) and with a dry solids per cycle of Ms=190 kg can be satisfactory for a good washing result. By calculating a washing ration of w=0.4 can be concluded that not a satisfactory wash out content in the discharged cake can be expected because of too small w-value.

Another typical question which can be easily answered by this module: We have an industrial filter centrifuge with cake washing and it is reported that for one cycle a definite mass of wash liquid was used. Knowing the centrifuge geometry, densities of dry solids and of washing liquid, the cake porosity and the dry solids mass in the centrifuge we ask: Is the used wash liquid amount enough in order to achieve a satisfactory result regarding the wash out content in the discharged cake? What cake height corresponds to the given dry solids mass for one cycle. What is the dry solids throughput of the centrifuge (Qms) and the average wash liquid consumption rate as mass rate and volume rate (Qmw, Qw) if the cycle time tc is known? The answer of this question is given in fig. 12.2.



Parameter	Units	Value
rho w	kg/m3	1000
rho s	kg/m3	1400
eps	%	58
rho cd	kg/m3	588
A	m2	3
d	mm	70
tc	min	50
n	1/min	0.02
hc	mm	19.9
Ms	kg	45
ms	kg/m2	15
Vc	l	76.5
vc	l/m2	25.5
Vs	l	32.1
vs	l/m2	10.7
Qms	kg/min	0.9
qms	kg/(m2 min)	0.3
w	-	1.69
wm	-	1.67
wv	l/kg	1.67
wc	-	0.98
Mw	kg	75
Vw	l	75
Qw	l/min	1.5
Qmw	kg/min	1.5
qw	l/(m2 min)	0.5
qmw	kg/(m2 min)	0.5

Fig. 12.3: Calculation of all important washing liquid and filter cake parameters (see parameters with values in black color) for a candle filter (Option: Convex Area). Due to the parameters grouping concept any parameter which belongs to a definite group (see parameters with the same background color) can be input and all others are calculated. In this example we enter the specific dry cake mass ms and the specific average wash liquid rate qmw and all other parameters in the last 2 groups are calculated.

In this module we can calculate the washing parameters for all three main filter geometries: plane area (as we have it in almost all filter apparatuses), concave cylindrical area (as we have it in filter centrifuges and in tube filters), convex cylindrical area (as we have it in candle filters). By selecting “Cycle time *known*” we enter the cycle time tc or the cycle frequency n and we calculate additionally the solids mass rate as absolute and specific values (Qms, qms)) as well as the average wash liquid consumption as absolute and specific mass and volume rate (Qmw, Qw, qmw, qw).

The grouping parameters concept makes this program user friendly and powerful. It gives the highest flexibility regarding the input parameters. Combined with the new applied Show-Hide Parameters concept the user has the additional flexibility to define which parameters he wants to display. Only for the input parameters is not allowed to be hidden. An example of the user friendliness of the grouping parameter concept is given in Fig. 12.3: For a candle filter (convex area) of given geometry we want to know the cake height hc and the needed wash liquid amount if the cycle time is known and the specific solids mass ms as well as the specific average wash rate qmw are given. As in all other modules of the program, all parameters with values in black are calculated parameters and only the parameters in blue color are inputs.