Ingenieurbuero Samoticha
für Verfahrenstechnik

HS-Tropfen

Evaporation of atomized liquids

Version 3.2

User guide

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2 General information

When the liquid is being sprayed in the hot gas – it evaporates and the drops become smaller. The speed of decreasing the drops' diameter depends on the diameter itself, on the gas temperature and the thermal conductivity of the gas.

All of these parameters modify constantly. Evaporating of the drops of one size modifies the gas characteristics, and therefore influences the evaporation speed of the remaining drops. To calculate such process, it is necessary to apply the numerical methods, that is: using the computer to simulate these numerous parameters.

The aim of this program is to calculate the evaporation of the liquid drops in the hot gas. The drops' diameters and the fraction of drops of the various size classes in spectrum is different. Gas is based on the air, that means, it is composed of nitrogen, oxygen, carbon dioxide and water. It flows through the apparatus and carries the sprayed drops. The drops are so small, that its speed referring to the gas is very low.

As a result, the program gives the course of the drops' diameters in time, after the first contact with the hot gas, to the complete evaporation of the liquid. In the table, there were described: the distance travelled, gas temperature and its speed as a time function. It also shows the time to the complete evaporation, and also the range of the largest drops.

3 Process assumption data

To make the calculation possible, some facilities have been made. Some assumption data has been made, which enable creating the mathematical model of this process, and simultaneously, in the possibly slightest degree stand out of the reality. The following calculations and facility were placed at the basis of the calculation method:

- The drops' size is divided into classes. Each class contains one diameter, that means, there exist only the drops of this diameter, not the ranges from…to. The amount of 50 such classes can be given.
- The drops move together with the streams of gas, and they have constantly the same speed as the gas. Their relative speed referring to the gas amounts to zero.
- The gas flows in the apparatus with the flow of the flat profile, that is: the speed vector contains only one component (parallel to the axis) and it is the same in the full section. The speed changes only lengthwise the apparatus.
- The drops' arrangement in the gas in homogenous in the full section.

4 Evaporation of the drops

The drops' evaporation speed in the hot gas is limited by the heat transport from the gas to the drops. Therefore, it depends on the following parameters:

- Temperature difference between gas and liquid
- Thermal conductivity of the gas
- Heat of liquid evaporation

- Heat exchange surface

The heat transport in this process may at Re < 8000 be determined in the following way:

$$Nu = 2 + 0{,}303\ \mathrm{Re}^{0,6}\ Sc^{0,6}\left(\frac{\lambda_G}{\lambda_D}\right)^{0,5}$$

where λ_D – thermal conductivity of steam.

With the low relative speeds between drops and gas (small drops), the Nusselt number *Nu* is constant and it amounts to 2.
The time, when the drops' diameter decreases from d_1 to d_2 is described by the following equation:

$$\tau = \frac{\rho_c r_A}{8\lambda_G \Delta T_m}\left(d_1^2 - d_2^2\right)$$

when:

	r_A	- Liquid evaporation heat
	ρ_c	- Specific gravity of the liquid
	λ_G	- Thermal conductivity of the gas
	ΔT_m	- Average logarithmic temperature difference
	d_1	- Average before evaporation
	d_2	- Average after the time τ

If the class of drops *i* evaporates completely:

$$\tau_i = \frac{\rho_c r_A}{8\lambda_G \Delta T_m} d_i^2$$

In the time τ_i the other classes' drops decrease from D_1 to D_2. Because it is the same time interval, the result is:

$$\tau_i = C d_i^2 = C(D_1^2 - D_2^2)$$

and therefore:

$$D_2 = \sqrt{D_1^2 - d_i^2}$$

This is the way to calculate the averages of all the drops in time, when the smallest drops evaporate completely.

5 Program service

After starting the program, the main window is visible, on which upper edge, there is placed a row of buttons. The first three buttons enable the access to the pages, to enter and edition of the data. The button **Result** starts the calculations and it displays the page with the results. The button with the print symbol generates the dialogue for printing data and results. Next to it, there is visible the title of the currently evident page. In the right corner, there is a button for settings. The window does not contain menu.

5.1 Entering gas data

Gas data contain:

- Gas name
- Composition in Vol.-% of the wet gas
- Standard volumetric flow
- Temperature
- Absolute pressure
- Apparatus section
- Notes (Info)

To enter or change gas data, the button "Gas" shall be pressed.

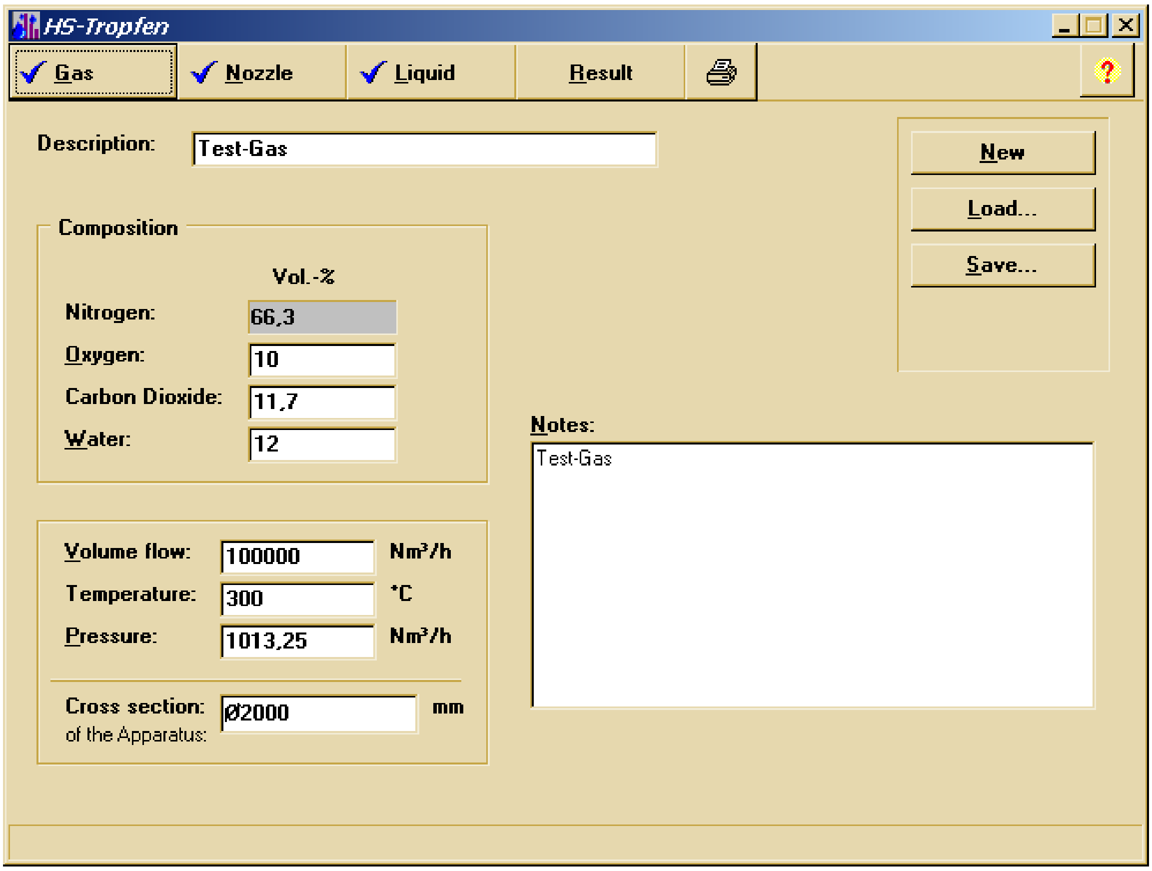


Illustration 1 Page to enter gas data

On the right, there is a panel with the buttons **Load** and **Save**, to operate on files with the gas data. The format of these files is compatible with the programs HS-SKLAD and HS-FIRE, so the

files coming from these programs can be read in. The button **New** deletes the data from the text fields.
On the left, there are the text fields to enter the gas data. Yellow background shows, that the data are wrong (e.g. out of the expires end) or its lack.

Description

Please name the gas. The name can be 32 characters long and it appears on the printouts.

Composition

The composition is given in the volumetric per cents. The nitrogen fraction fills the sum up automatically to 100%.

Volume Flow, Temperature, Pressure

The volumetric flow is given for the wet gas in the standard conditions. The temperature should be included in the range of 20° - 1200°, the pressure can amount from 20 to 8000 mbar.

Notes

Here, optional additional information about the gas can be entered. It appear on the printout..

Cross section

The apparatus section is entered into the light-blue text field.
It is given in the following way:

Section	**Keys**	**Presenta-tion as**	**Remarks**
Circular Diameter 1200 mm	D1200	ø1200	**D** for "Diameter"
Quadratic 2000 x 2000 mm	Q2000	□2000	**Q** for "Quadrat"
Rectangular 3000 x 4000	3000 x 4000	3000 x 4000	

5.2 Entering the drops' size spectrum

The drops data contain:

- Spectrum name
- List of classes and the cumulated fraction of liquid in classes
- Notes (Info)

The page with the drops' spectrum is generated with the button **Nozzle**.

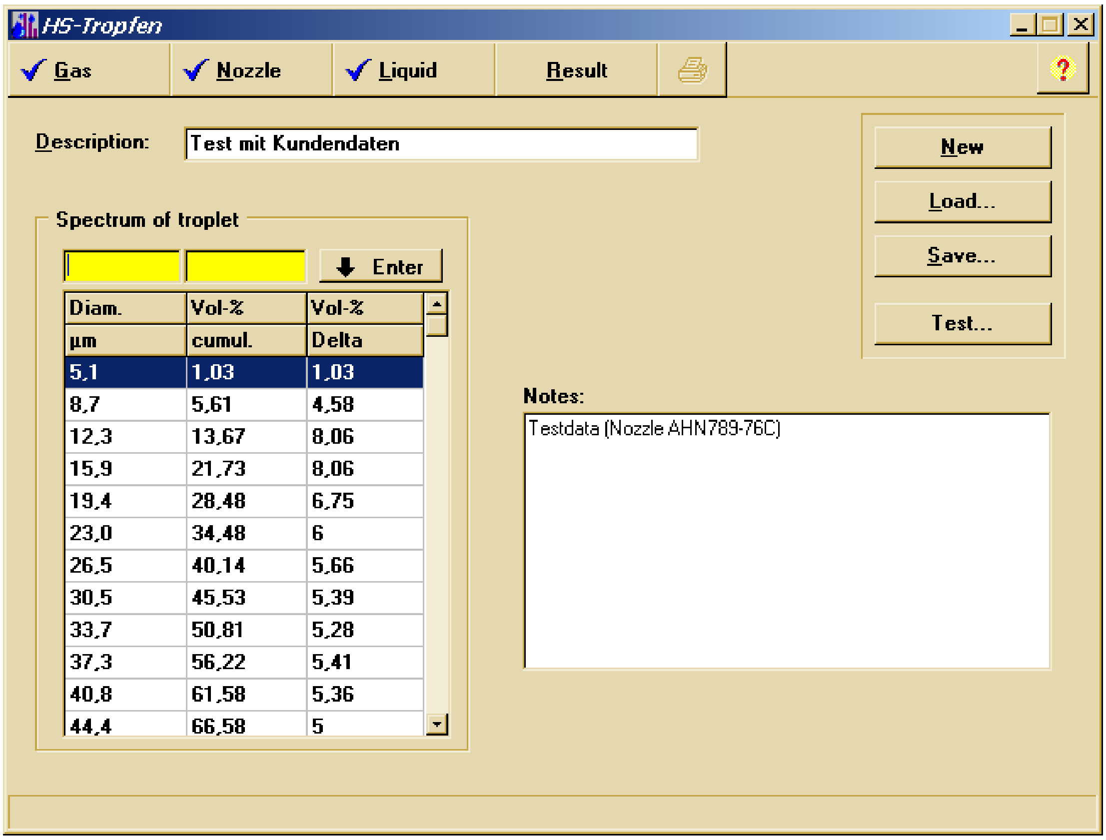


Illustration 2 Page to enter the nozzle data

On the right, there is a panel with the buttons **Load**, **Save** and **Test**. The button **New** deletes all the data.

To enter the drops' spectrum, there should be given in the text fields over the table adequately the diameter and the volumetric fraction of the given class in %. Then, with the button **Enter** or the key enter, they are transferred to the table. The data in the table is immediately classified according to the diameter.

After entering all the classes, the cumulated fraction of the last class shall be 100%. With the button **Test**, there is generated the window with the graphical presentation of the spectrum for the control.

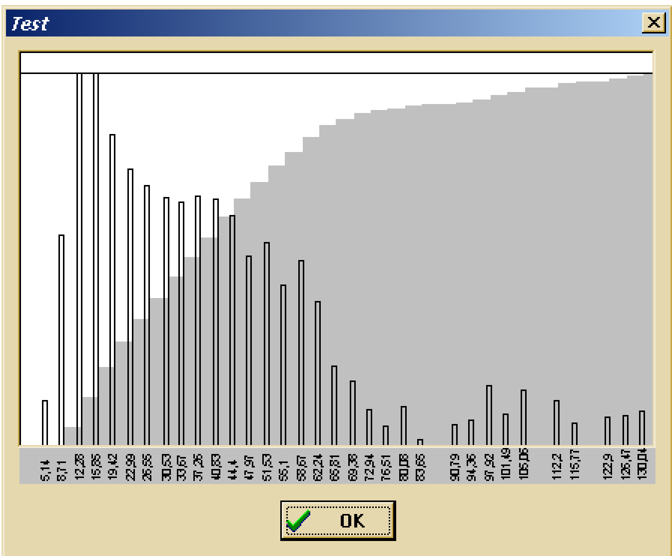


Illustration 3 Test of the drops' spectrum

If the data must be modified, the given row is marked, and the popup menu is generated. **Delete** removes the given class from the table. **Edit** transfers it back to the text fields, where it can be changed.

5.3 Entering liquid data

The program accepts as a liquid water, and the water solution of the gases (e.g. ammonia water). For all, there must be given the mass flux and the temperature. The kind of evaporated liquid is selected by marking the suitable option.

5.3.1 Data for water

In case of water, no further data is required.

5.3.2 Data for gas solution in water

Additionally to the mass flux and temperature, the program requires the following data:

- Specific gravity of the liquid
- Concentration of the gas dissolved in the solution
- The gas dissolution heat in water

The specific gravity is required in the equation for the time of evaporation. The concentration and the heat of solution is necessary for the correction of r_A in this pattern.

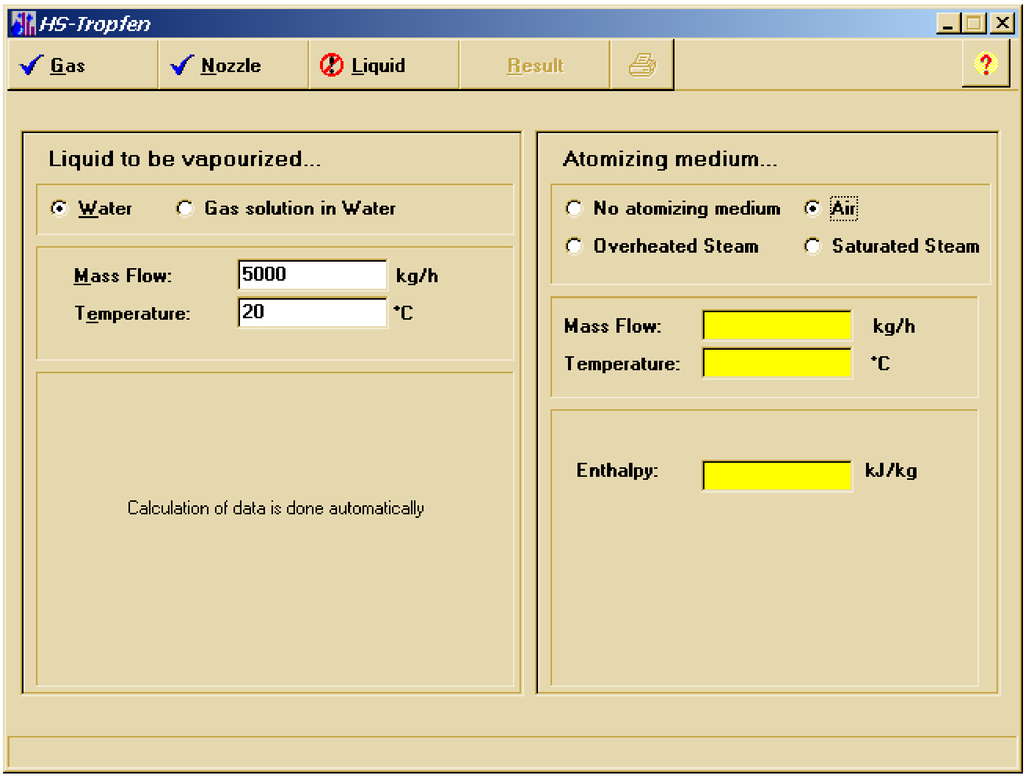


Illustration 4 Liquid data and operating medium page

5.3.3 Operating medium data

If the operating medium is used, its data is entered on the page “Liquid”. This medium will be at the beginning of the calculation, admixed to gas. With “Air”, there dry air is assumed, with “Overheated Steam” or “Saturated Steam”, the 100% of steam is assumed. To calculate the combination of such modified gas, the mass flux of the operating medium is required. Additionally, the temperature and the enthalpy is necessary to calculate the gas condition before the specific calculation of evaporation. In case of compressed air and the saturated steam, these data are calculated automatically by the program.

5.4 Results

When the data is entered, the calculation is started by generating the page “Result”. After calculation, there appears the table of results. At the bottom of the page “Result” there are overlaps, with the help of which it is possible to enter the graphics.

5.4.1 Table

Table contains columns:

1. Time
2. Track
3. Temperature
4. Velocity

The time starts from zero in the moment of the drops coming into contact with the hot gas. In some intervals, the time reaches the moment, when all the drops have evaporated. This time is placed in the last row of the table.

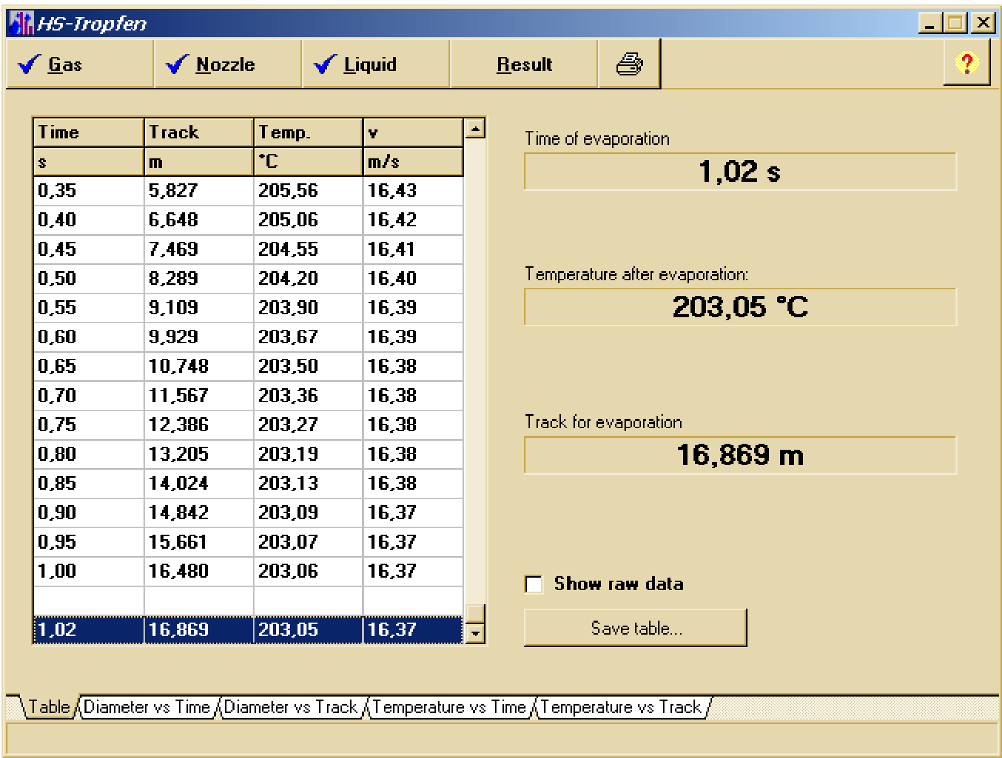


Illustration 5 Results in the table

The intervals are matched to the actual result. The option “Show row data” enables presenting all the results. They can be also recorded on the disc, for the further analysis.

5.4.2 Graphics

The results can be also presented in the diagrams shape. The diagrams present the modifications of the drops' diameter or relating to the traveled distance. There can also be presented the course of the temperature.

5.4.3 Diameter versus time diagram

Here, there were presented the drops' diameters during the evaporation, as a time function. Above the diagram, there is placed the combo-box which enables discrimination of the selected class. If the small drops are discriminated (which evaporate quickly) the time axis becomes dissected. The chosen class will also be discriminated on the printout..

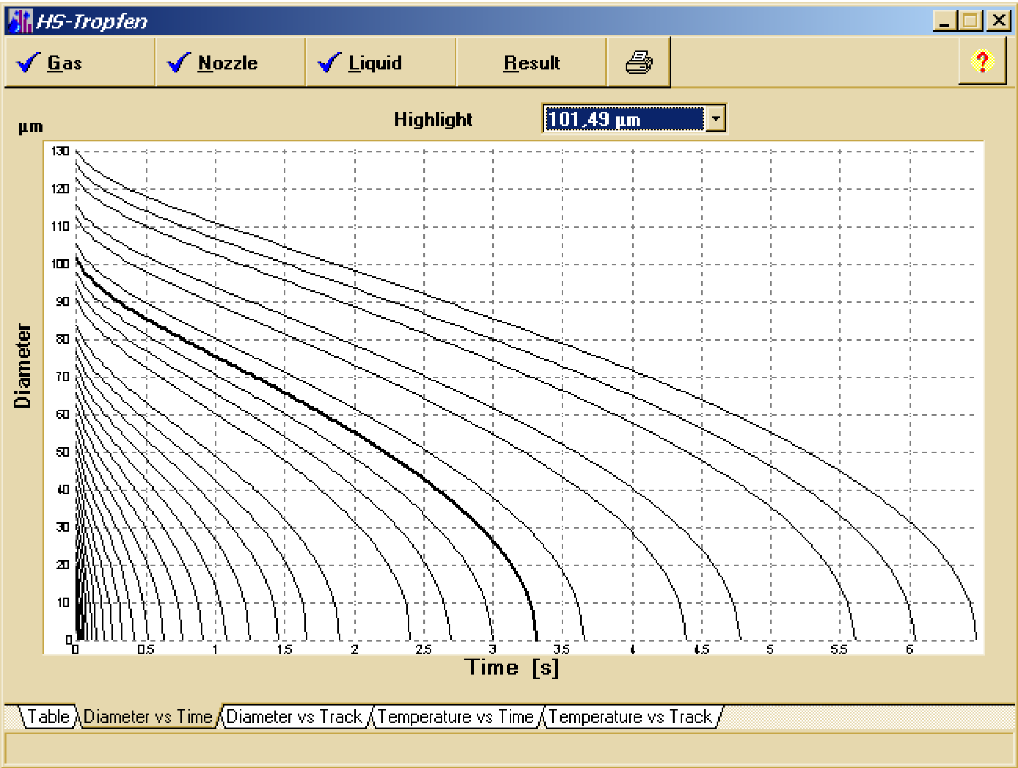


Illustration 6 Drops' diameter diagram as a time function

5.4.4 Results discussion

While testing the program, it was noticed, that the possibly precise definition of the diameters' spectrum has a great significance. The data should not be reduced by abandoning some classes. The more classes there are, the better it will be for the accuracy of the results. The results with the "reduced" data differ considerably from those, which consider the spectrum with many classes.

5.5 Printing

To print the results, there should be used the button with the printer symbol. It is only active, when the calculation has been done. The following dialogue appears:

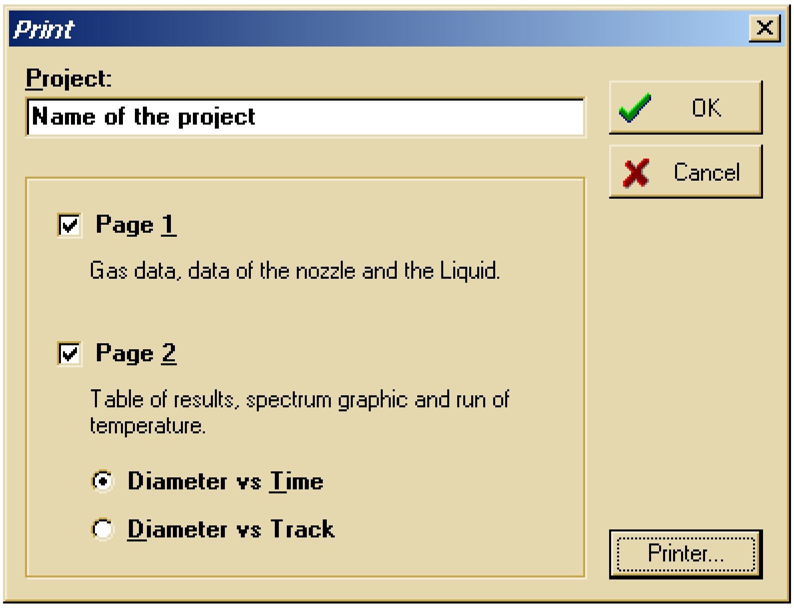


Illustration 7 Dialogue for printing

Project:
Optional text, which is the heading of the printout.

Page 1
Page with the entered data.

Page 2
Page with the results contain the table of results, the diagram with the temperature course and – dependent on the selected option – diagram of the drops' diameters as a time function or the traveled distance. The diameters marked in the program window are printed out in bold.

Printer...
This button leads to the system dialogue to the printer selection and to set the printing parameters. There can not be chosen the pages, which are to be printed – the dialogue "Printing" should be used for this aim.

6 Units system

This program enables working in the units of international SI system of measure, and also in the alternative, optionally defined by the user, system of units. It is possible to switch between these systems during work.

CAUTION !

The alternative system of measure units is defined by the user, therefore:

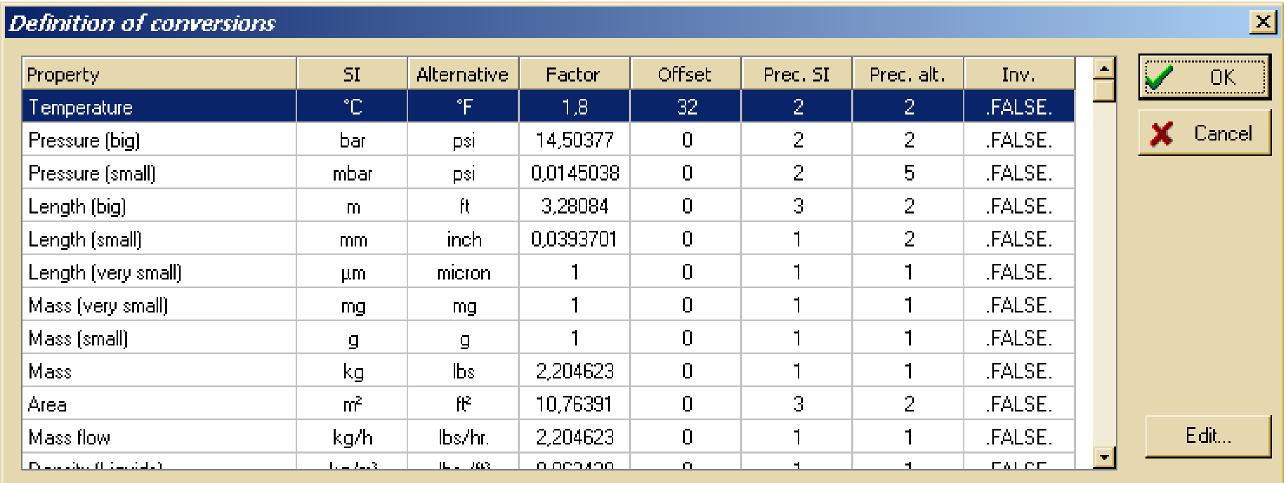
the user himself is responsible for the correctness of the recalculation definitions!

This refers also to the conversions already included in the newly installed programs. The user is obliged to check its correctness, before he starts using it!

Especially, the standard gas condition may be differently defined, therefore it recalculates into the standard in the SI system (0°C, sea level) can be different.

The recalculation definitions are used together by all the programs. The changes are made as follows:

The button with question mark generates the setting dialogue. Here the units system can be chosen. The changes are made after pressing **Edit…** button. Then, the window with the defined recalculations table appears:



Property	SI	Alternative	Factor	Offset	Prec. SI	Prec. alt.	Inv.
Temperature	°C	°F	1,8	32	2	2	.FALSE.
Pressure (big)	bar	psi	14,50377	0	2	2	.FALSE.
Pressure (small)	mbar	psi	0,0145038	0	2	5	.FALSE.
Length (big)	m	ft	3,28084	0	3	2	.FALSE.
Length (small)	mm	inch	0,0393701	0	1	2	.FALSE.
Length (very small)	µm	micron	1	0	1	1	.FALSE.
Mass (very small)	mg	mg	1	0	1	1	.FALSE.
Mass (small)	g	g	1	0	1	1	.FALSE.
Mass	kg	lbs	2,204623	0	1	1	.FALSE.
Area	m²	ft²	10,76391	0	3	2	.FALSE.
Mass flow	kg/h	lbs/hr.	2,204623	0	1	1	.FALSE.

Illustration 8 List of units recalculations

After marking the row and using the button **Edit...** the selected recalculation can be edited.

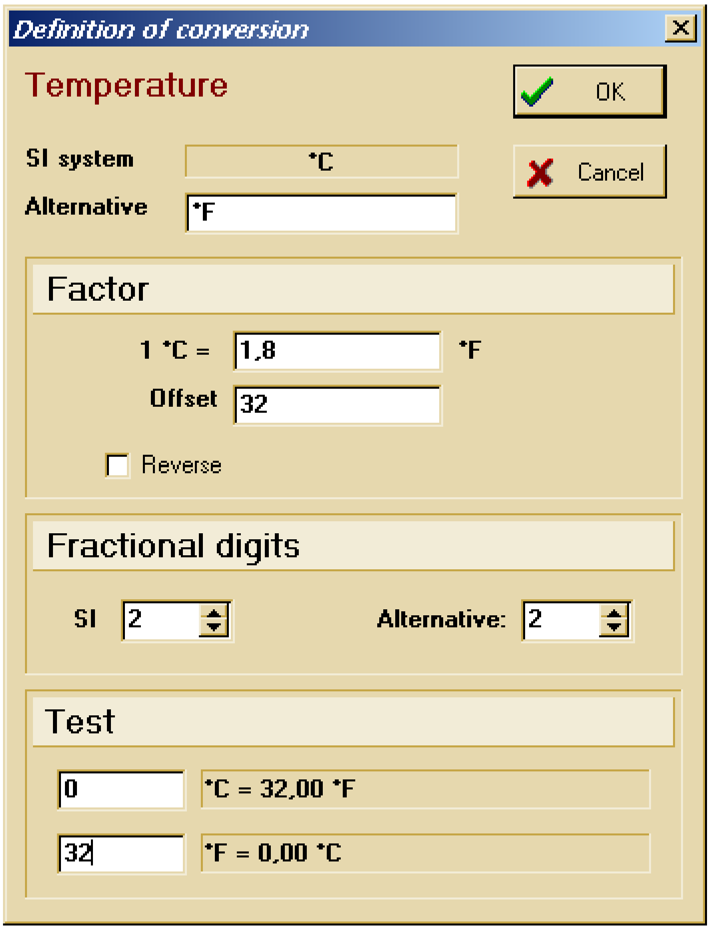


Illustration 9 Defining the recalculation

This example illustrates the definitions of temperature recalculations between "°C" and "°F". At the bottom of the dialogue, there can be tested the correctness of the entered data and set the number of digits after comma.

7 License agreement

Application range

This program can be used on the optional amount of computers within the company. Installation in the networks and the simultaneous installation on many computers of this company is allowed. The amount of simultaneously used licenses is regulated by the purchase of dongles or the hire contracts made.

The subject of the contract

This program is the work protected by law in the meaning of the intellectual property law. The rights to this program belong to "Ingenieurbuero Samoticha fuer Verfahrenstechnik". The indication of the author included in the program shall not be removed or changed. The subject of the contract is this program, its description and any other appendices written and the materials included in files. These are further called “software”.

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