Manual for 20-l-Apparatus 7.1

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Symbols

	Please read this note!
	Question Answer
	Attention: Please read this safety instruction carefully!

1. Fundamentals

1.1 The field of applications of the 20-l-apparatus

1.1.1 Combustible dusts

Due to the less favorable surface to volume ratio, the explosion pressure Pmax measured in the 20-l-apparatus is in general slightly lower than the one measured in the 1m³ vessel. This is caused by cooling effects. Comparisons of pressure/time recordings also show that the pressure drop after the explosion is much faster in the 20-l-apparatus. Therefore a correction has to be made. In addition the pressure effect caused by the chemical igniters must be taken into account. With both (automatic) corrections, the Pmax value measured in the 20-l-apparatus agrees excellent with those measured in the 1m³ vessel.

The Kmax values calculated from the rate of pressure rise correlate exactly with the Kmax values obtained in the 1 m³ vessel - within the accuracy of measurements - up to aluminum dusts (Kmax > 700 m•bar/s)

1.1.2 Flammable gases and solvent vapors

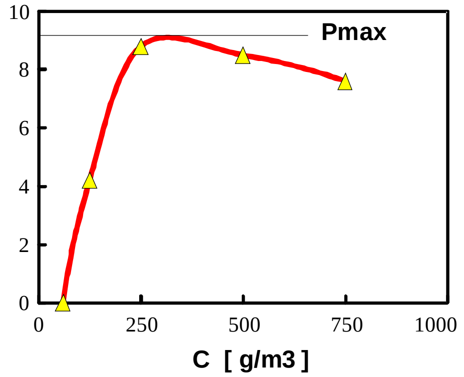
The minimum volume for the explosion testing of gas or solvent vapor / air mixtures is: V = 1 liters. Therefore, the 20-l-apparatus is also suitable for the explosion testing of gases and vapors.

1.1.3 Hybrid mixtures

"Hybrid mixtures" are dust/air mixtures containing flammable gases or flammable vapors in the combustible atmosphere. They are mixtures of two fold origin. These investigations of the explosion characteristics which are describing the explosion- and ignition behavior of such hybrid mixtures can also be determined with sufficient accuracy in the 20-l-apparatus; if the results are compared with the standard 1 m³ vessel.

1.2 Determination of the explosion indices

The explosion overpressure Pm and the rate of pressure rise dP/dt describe the violence of reaction of dust/air mixtures of random concentration after ignition in a closed vessel. The maximum explosion pressure Pmax and the maximum rate of pressure rise (dP/dt)max of combustible dusts are determined in closed standard equipment (e.g. 1-m³-vessel or 20-l-apparatus) by means of tests over a wide range of concentrations:



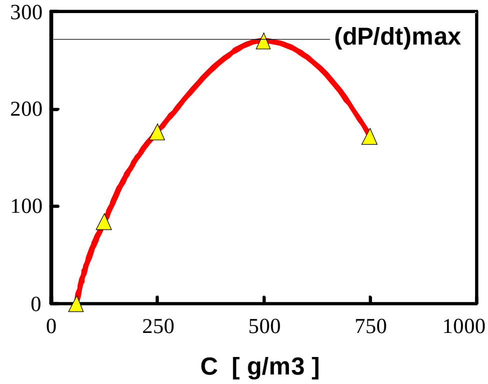


Fig. 1.2: Determination of the explosion indices and the lower explosible limit

With this test procedure, the lower explosible limit LEL can also be determined for dusts being tested. This LEL is important for risk evaluation in the chemical industry.
The maximum explosion pressure, when determined in closed, spherical or cubic vessels of sufficient size ($V \geq 20$ l) with central ignition source, is practically independent of the volume of the vessel.
But the maximum rate of pressure rise depends on the volume. It decreases with increasing volume. The Kmax-value is dust and test method specific but independent of volume.
For the 20-l-apparatus the following equation applies:

$$\mathbf{0.02}\ [m^3]^{\mathbf{1/3}} \times \mathbf{(dP/dt)max}\ [bar/s] = \mathbf{Kmax}\ [m \cdot bar/s]$$

The large number of dusts produced and handled in industry led to a classification of dusts, according to their Kmax-values, into dust explosion classes:

Dust explosion class	Kmax [m•bar/s]
St 1	> 0 - 200
St 2	201 - 300
St 3	> 300

1.3 Pressure course: Definitions

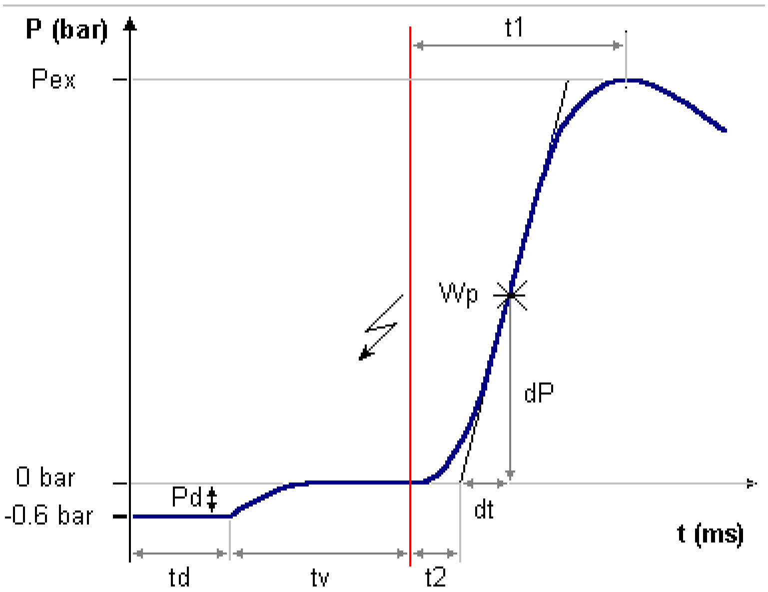


Fig. 1.3: Pressure/time-diagram of a fuel explosion

Pex	**Explosion overpressure:** the difference between the pressure at ignition time (normal pressure) and the pressure at the culmination point is the maximum explosion overpressure Pex measured in the 20-l-apparatus at nominal fuel concentration.
Pm	**Corrected explosion overpressure:** Due to cooling and pressure effects caused by the chemical igniters in the 20-l-apparatus, the measured explosion overpressure Pex has to be corrected.
Pmax	**Maximum explosion overpressure:** Maximum value of Pm determined by tests over a wide range of fuel concentrations.
(dP/dt)m	**Rate of pressure rise with time** at nominal fuel concentration. It is defined as the maximum slope of a tangent through the point of inflexion (Wp) in the rising portion of the pressure vs. time curve.
$(dP/dt)_{max}$	**Maximum rate of pressure with time**: Maximum value of (dP/dt)m determined by tests over a wide range of fuel concentrations.
Kmax	**Product specific constant =** 0.27144 x (dP/dt)max.
t1	**Duration of combustion:** time difference between the activation of the ignition and the culmination point.
t2	**Induction time**: time difference between the activation of the ignition and the intersection of the inflexion tangent with the 0 bar line.

Beside the actual explosion values Pm (dP/dt)m, t1 and t2, control values for correct operation are determined:

Pd — **Expansion pressure** of storage container: Difference between "pre-vacuum" and normal pressure. The standard value is 0.6 bar. (0.55 ... 0.7 bar are acceptable).

td — **Time-delay of the outlet valve:** Time between electrically activating the valve and beginning of pressure rise in the 20-l-apparatus. This time-delay has to be in the range of 30 to 50 ms; otherwise the valve and/or the dispersion device are probably dirty.

tv — **Ignition delay time:** tv influences the degree of turbulence. This is the most important control parameter.

1.4 Pressure course: Evaluation

1.4.1 Correction of the explosion overpressure at Pex > 5.5 bar

Due to the less favorable surface to volume ratio, the explosion pressure measured in the 20-l-apparatus is in general slightly lower than the one measured in the 1m³ vessel. This is caused by cooling effects. Comparisons of pressure/time recordings also show that the pressure drop after the explosion is much faster in the 20-l-apparatus. Therefore a correction has to be made according to the following equation:

$$\mathbf{Pm = 0.775 \cdot Pex^{1.15}}$$

With this correction, the Pm in the 20-l-apparatus then agrees with those measured in the 1m³ vessel.

1.4.2 Correction of the explosion overpressure at Pex < 5.5 bar

Due to the small volume of the 20-l-apparatus, below 5.5 bar the pressure effect caused by the chemical igniters must be taken into account. A blind test i.e. with IE = 10'000 J chemical igniters alone, will give a maximum overpressure of 1.6 bar. But during a dust explosion with rising Pex the influence of the igniters will be more and more displaced by the pressure effect of the explosion itself. The influence of igniters with less than IE = 1000 J can be neglected entirely. Correction values can be taken from the following equations:

$$\mathbf{Pm = 5.5 \cdot (Pex - Pci) / (5.5 - Pci)\ bar}$$

where Pci = pressure due to chemical igniters
= 1.6 bar • IE / 10'000

1.5 Influential parameters

1.5.1 Turbulence

The degree of turbulence is mainly a function of the ignition delay time, tv, i.e. the time between the onset of dust dispersion and the activation of the ignition of the dust/air mixture. It affects in particular the maximum rate of pressure rise, i.e. the Kmax value. Therefore, for dust testing, the ignition delay time has been standardized:

20-l-apparatus:	tv = 60 ms
1m³ vessel:	tv = 0.6 s

Normally, an increase of turbulence (tv < 0.6 s or tv < 60 ms) will also increase the explosion violence, and vice versa.

1.5.2 Particle size

Particle size distribution has an important influence on the explosion data. Particle size is characterized by the median M. The median is the 50% value of the particle size distribution curve.

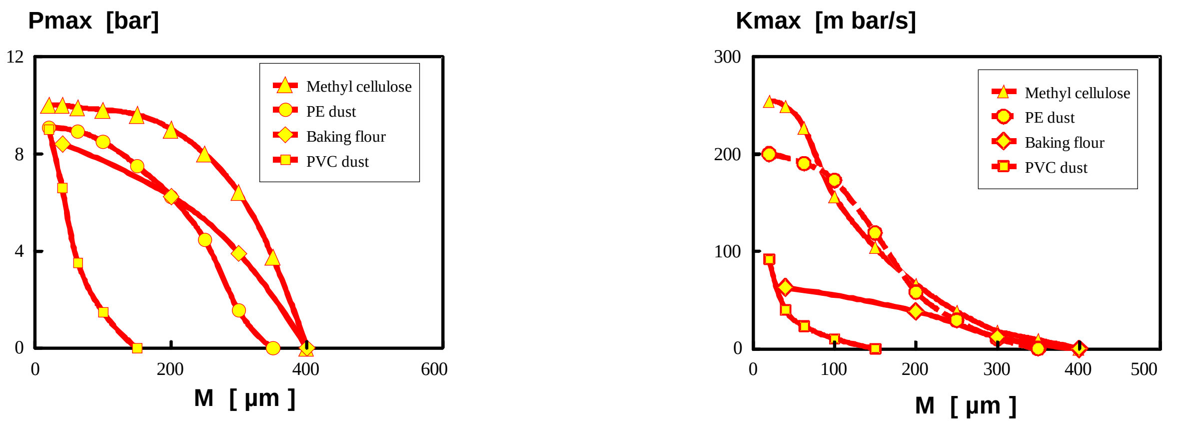


Fig. 1.5.2: Median vs. explosion data

It can be seen from fig. 1.5.2 that finer dusts will react more violently than coarser ones. Therefore, to obtain optimum values for the explosion data, the samples used for testing should have a median **M ≤ 63 µm**.

Experience has shown that the dispersion device and the outlet valve may have a grinding effect on the dust being tested, i.e. the size of the dust particles may be reduced by the dispersion process ! In cases where this effect is important, its magnitude can be evaluated by taking a dust sample after dispersion (without ignition).

1.5.3 Product humidity

The relative product humidity „H“ i.e. the ratio of water to dry substance, is an other influential parameter:

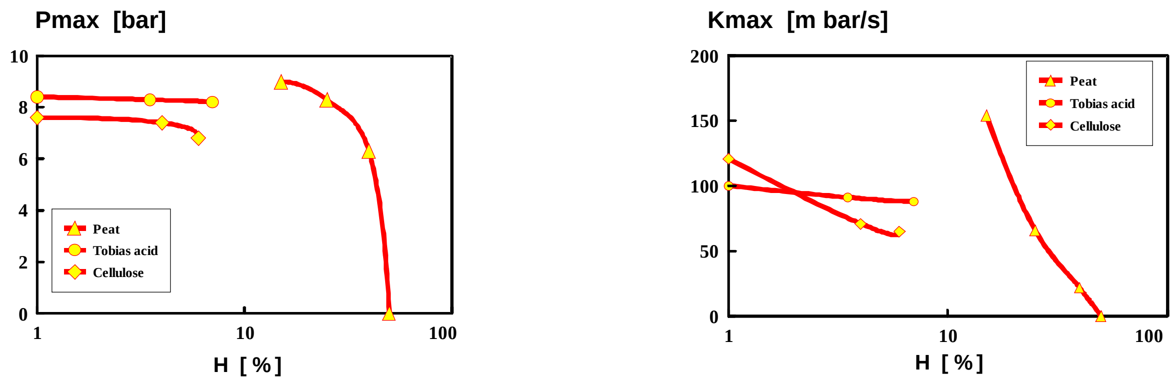


Fig. 1.5.3: Product humidity vs. explosion data

Often the statement can be heard that dusts containing a few % of water can no longer form explosive dust/air mixtures. Fig. 1.5.3 contradicts this assumption. Although comparatively few test results are available, it seems that a product humidity of at least 50% would be required to cause this effect. But fig. 1.5.3 demonstrates that product humidity should be clearly below 10% to avoid an important influence on the explosion data.

1.5.4 Temperature

Temperature is a very important parameter in industrial operations. An increase of temperature will reduce the value of the lower explosion limit. This influence is more pronounced the higher the value is at room temperature. Furthermore, the influence of temperature on the Pmax must be taken into account:

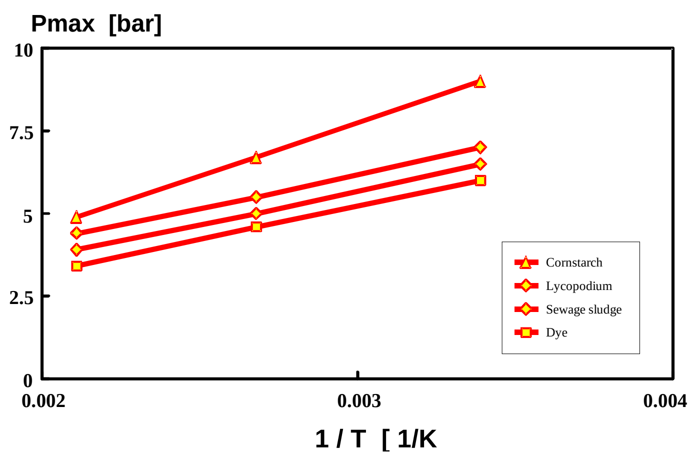
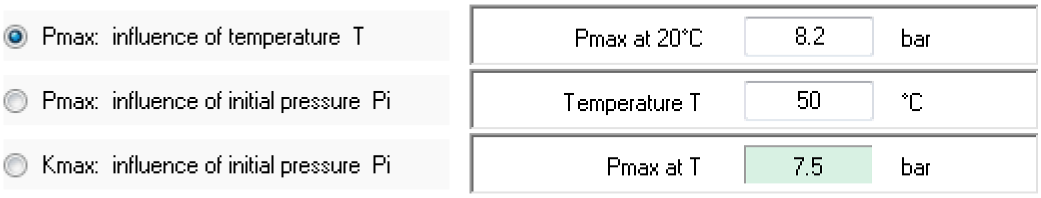


Fig. 1.5.4: Influence of temperature on Pmax

The figure shows a practically linear reduction of the maximum explosion pressure **Pmax** with increasing temperature. This is caused by the reduced oxygen content.

The **Kmax** value is also influenced by temperature. With the more violently reacting dusts, higher temperature will cause a linear reduction of the Kmax value. With the dusts reacting more slowly, the Kmax value will increase. For the practice the influence of the temperature on the Kmax values can be neglected.

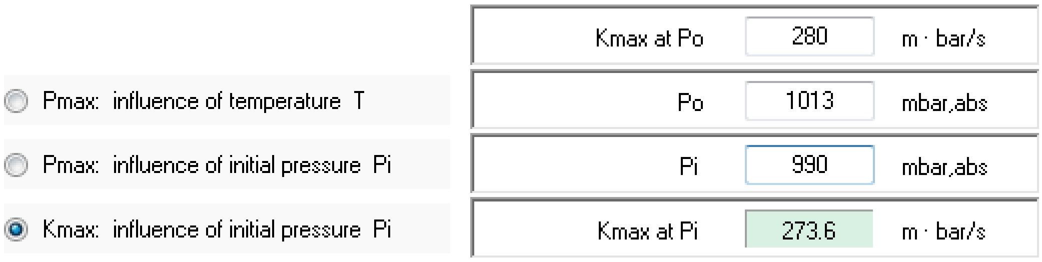
Calculations in *"Tools / Calculator"*



1.5.5 Initial pressure

The explosion indices Pmax and Kmax are direct proportional to the initial pressure Pi, the pressure in the sphere at the moment of ignition. This relation is linear up to an initial pressure of approx. 3 bar.

Calculations in *"Tools / Calculator"*



1.6 Mode of ignition and ignition energy

From a large number of test results obtained in the 1m³ vessel and in the 20-l-apparatus for the minimum ignition energy, it appears that dusts can be ranged into 2 groups with regard to the influence of the mode of ignition and the ignition energy on the explosion data.

1.6.1 Energy independent dusts

Fig. 1.6.1 shows that the measured explosion data are, within the accuracy of measurements, independent of the mode of ignition and the ignition energy (chemical igniters for IE = 250 ... 10,000 J, condenser discharge for IE > MIE).

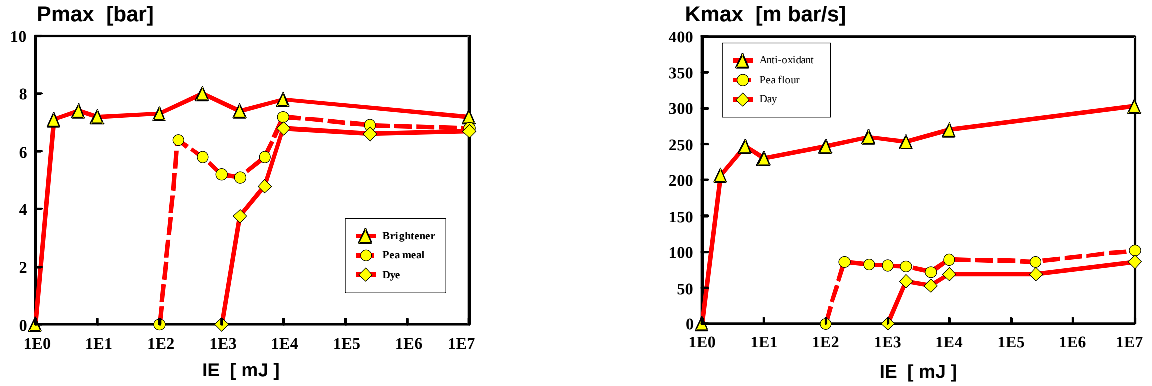


Fig. 1.6.1: definition of energy - **in**dependent dusts

From these findings it can be concluded that with these "energy independent dusts" the nature of the ignition source is not important. Weak condenser discharges or strong chemical igniters, such as specified for dust testing, give the same results.
In general, such dusts have a minimum ignition energy of less than 1 J.

1.6.2 Energy dependent dusts

With this group of dusts, a decrease of the ignition energy will cause a linear reduction of the Kmax value.

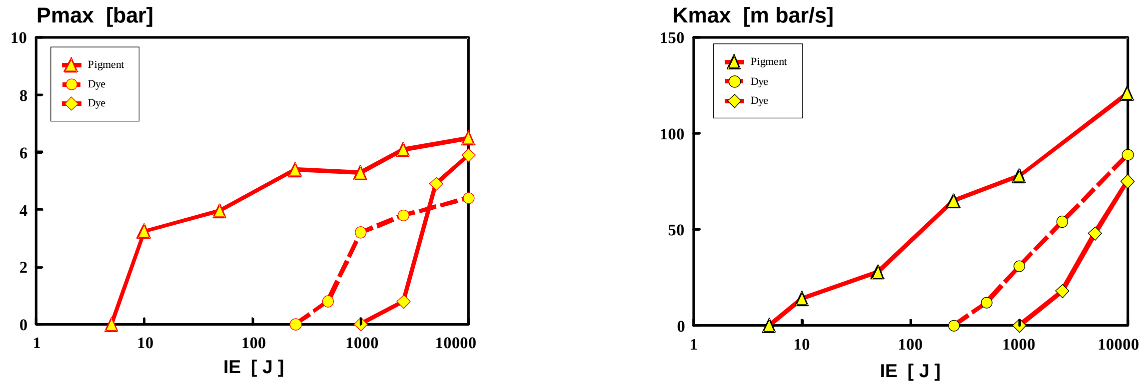


Fig. 1.6.2: Definition of energy **dependent** dusts

The explosion pressure is practically not subject to this influence; only with very few dusts a tendency to decrease can be observed.
In general, dusts in this group have a minimum ignition energy of more than 1 J.

1.6.3 Chemical igniters

Explosion indices must be determined using an ignition source of sufficient energy. For the time being, there is only one mode of ignition for reliable determination of explosion indices (Pmax, Kmax) in industrial practice:

2 chemical igniters of 5000 J each, with a total energy of **E = 10'000 J**

For the determination of lower explosible limit LEL and the limiting oxygen concentration LOC:

2 chemical igniters of 1000 J each, with a total energy of **E = 2'000 J**

It is emphasized that the application of this ignition source for dust testing is of dominating importance, not only to ensure that test results can be compared among different laboratories, but also in order to provide a reliable base for the design of technical explosion safeguards.

For the safe handling of the chemical igniters wearing of safety glasses is mandatory.

If powder is visible on the surface of the igniters as well as in the baggage of the igniters itself an ignition risk due to static electricity exists. Therefore build up of static electricity must be avoided (earthing of the operator etc.).

The chemical igniters should be stored in a safe place in a cool and dry atmosphere.
In addition national guide-lines should be obeyed.

Manufacturer:
Fr. Sobbe GmbH
Beylingstr 59
D-44329 Dortmund
Germany
Tel: +49 231 230 560
info@sobbe-zuender.de
www.sobbe-zuender.de

Manufacturer:
Simex Control s.r.o.
Ul. 4. kvetna 175
Vsetín 755 01 CZ
Czech republic
Tel: +42 0571 498 711
sale@simexcontrol.cz

Distributor for USA and Canada:
Cesana Corporation
P.O. Box 182
Verona, NY 13478
U.S.A.
Tel: +1 315 337 9181
office@cesanacorp.com

1.6.4 Condenser discharge

It must be pointed out that with a condenser discharge spark as an ignition source, the same course of pressure of a dust explosion is obtained as with chemical igniters, provided that the energy of the condenser discharge is above the minimum ignition energy.
Exceptions are, of course, encountered with dusts which are not readily ignitable and therefore have energy-dependent Kmax values.

1.6.5 Permanent spark

If instead of chemical igniters a permanent spark with an approx. energy of IE = 10 J is used as an ignition source. Measured Kmax values can be up to 60% lower than the values obtained with the two other ignition sources already mentioned.
Thus, the permanent spark can underestimate to a considerable degree the effective course of the explosion and must not be used for the determination of the explosion data of combustible dusts.

1.6.6 Glowing wire coil

Numerous comparative tests with chemical igniters and glowing wire coil have shown no correlation.
Most dusts tested with the glowing wire coil have either not been identified as explosive dusts or the explosion violence was underestimated. Therefore, this ignition source is not suitable for an unambiguous identification of explosive dusts nor a reliable determination of dust explosion indices.

1.7 Nomenclature

(dP/dt)m	greatest rate of pressure rise at any desired fuel concentration
(dP/dt)max	maximum rate of pressure rise at optimum fuel concentration
IE	ignition energy
K	product specific constant
Kmax	maximum value of the explosion index K
LEL	lower explosion limit
LOC	limiting oxygen concentration
M	median
MIE	minimum ignition energy at the most easily ignitable fuel concentration
Pd	pressure difference
Pex	greatest explosion overpressure at any desired fuel concentration, measured in the 20-l-apparatus
Pm	corrected greatest explosion overpressure at any desired fuel concentration, measured in the 20-l-apparatus according to the ISO-Standard
Pmax	maximum value of the explosion index Pm at optimum fuel concentration, measured in the 20-l-apparatus according to the ISO-Standard
Pi	initial pressure
Pz	dispersion pressure
St	dust explosion class
t1	combustion time
t2	induction time
tv	ignition delay time
UEL	upper explosion limit

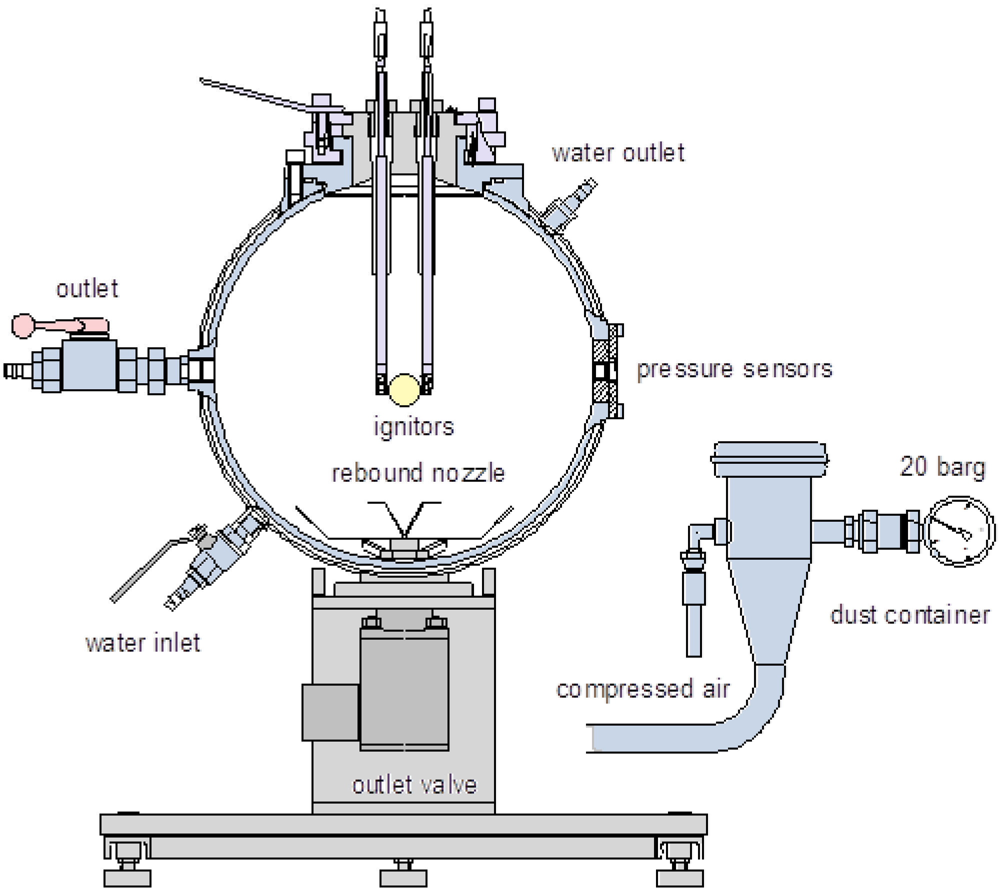
2. Apparatus

2.1 20-l-sphere

The test chamber is a hollow sphere made of stainless steel, with a volume of 20 liters. A water jacket serves to dissipate the heat of explosions or to maintain thermostatically controlled test temperatures.

For testing, the dust is dispersed into the sphere from a pressurized storage chamber via the outlet valve and a nozzle. The outlet valve is pneumatically opened and closed by means of an auxiliary piston. The valves for the compressed air are activated electrically.

The ignition source is located in the center of the sphere. On the measuring flange two "Kistler" piezoelectric pressure sensor’s are installed. The second flange can be used for additional measuring elements or for the installation of a sight glass.



For cleaning, the sphere can be opened on top by turning the bayonet ring. The diameter of the "hand hole" is 94 mm. A larger opening of 140 mm can be obtained by unscrewing the top flange. A safety switch controls the correct closing position of the bayonet ring.

Normally the 20-l-sphere and the gas control unit KSEP 310 are set up in a ventilated laboratory hood. The other units are installed outside of the hood.

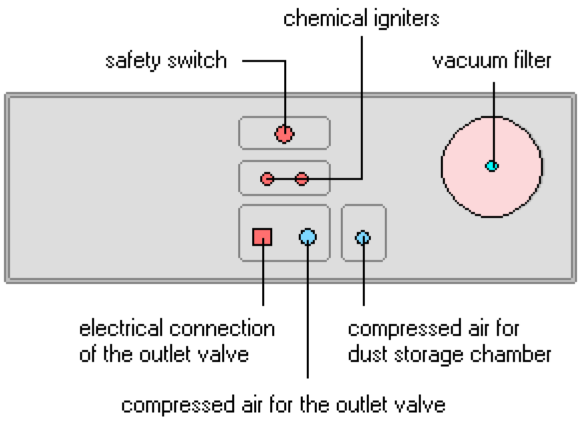
A high test frequency will necessitate keeping the operating temperature at approx. 20°C by means of water cooling, i.e. the operating temperature should correspond to room temperature. Thermostatic control of the cooling water is not necessary, but care should be taken that there is always some flow of water and that the outlet temperature of the cooling medium never exceeds 25°C.

After a test the pressure inside the 20-l-sphere will be relieved by means of the ball valve „outlet". The blast can contain glowing particles. This risk has to be considered.

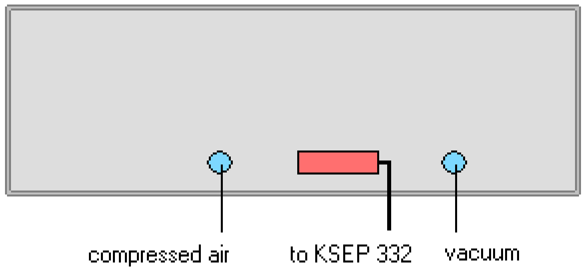
2.2 Control unit KSEP 310

The control unit KSEP 310 is installed as an auxiliary unit behind the sphere on the same base plate.

Front side



Back side



Compressed air:

Compressed air is used to power the outlet valve and is also connected to the inlet valve of the dust storage chamber. The pressure in the storage chamber corresponds directly to that of the external compressed air system.
(standard = **20 bar overpressure = 21 bar absolute**).

The 20 bar compressed air connection must have an adequate cross section. It must be possible to pressurize the storage chamber (V = 0.6 l) within 5 seconds.

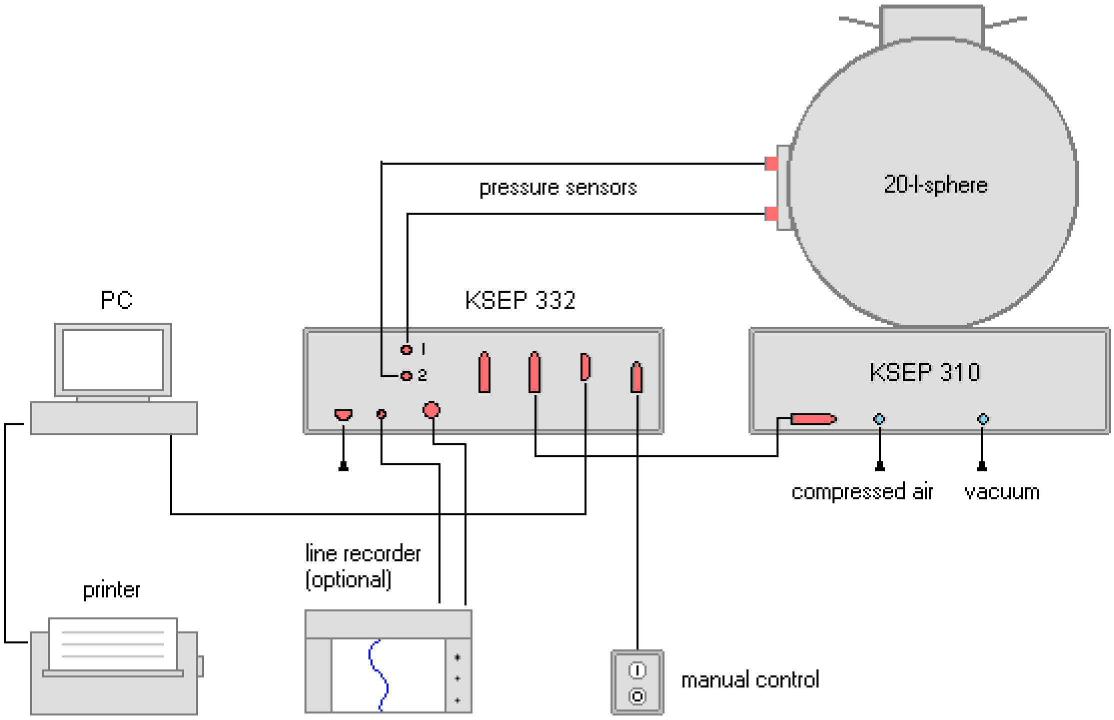
For the 20-l-apparatus only normal compressor compressed air may be used (in cylinders). With the use of, e.g. synthetic compressed air explosion indices which are clearly different were obtained.

Vacuum:

Prior to dispersing the dust, the sphere is evacuated to such a degree, that the remaining pressure, together with the air contained in the storage chamber, result in the desired starting pressure for the explosion test. For that purpose, the ball-valve on the vacuum connection of the sphere is opened and the sphere is evacuated via the vacuum filter until the vacuum meter shows the desired vacuum. The vacuum filter can easily be removed for cleaning.

2.3 Measurement and Control System KSEP 332

The KSEP 332 unit uses piezoelectric pressure sensor's to measure the pressure as a function of time and controls the valves as well as the ignition system of the 20-l-apparatus. The measured values to be processed by a personal computer are digitized at high resolution. The use of two completely independent measuring channels gives good security against erroneous measurements and allows for self checking.



Personal Computer:

Any standard personal computer running the operating system Microsoft-Windows in the versions: **7 … 10** is suitable.

Line recorder (optional):

The transducer output is digitized at high resolution and stored in the KSEP 332 memory (0.2ms / 10,000 measurements per channel). The Personal Computer only receives part of it (500 measurements / channel). For test purposes only, the complete record of the KSEP 332 can be shown with a Y/t-line recorder.

This feature is no longer state of the art, but still useful for testing the charge amplifiers.

Before installing the electrical connections to the KSEP 332 it is advisable to compare the information on the rating label with the data of your mains supply.

2.4 Pressure Measuring System

2.4.1 Pressure Sensors

The pressure sensor’s (manufactured by Kistler) are based on the piezoelectric principle: a quartz crystal is deformed by pressure. By this deformation, an electrical charge proportional to the differential pressure is generated on the surface.

Measuring unit: "Coulomb" **C** (10E-12 C = 1pC)

The piezoelectric system allows only the measurement of pressure differences. Thus, no indication of the absolute pressure within the 20-l-sphere is possible. Furthermore, the unavoidable insulation resistance in the connecting cables and plugs and stray currents of the following amplifier will cause a slow drift of the charge signal. This means that the electrical signal will change even when the sensor is exposed to static pressure. However, for the short duration of an explosion recording, this drift can be neglected.
It is recommended to flush the connectors with a cleaning spray (Kistler no. 1001) before plugging them together.

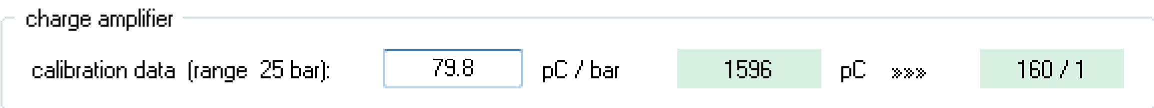
The membrane of the pressure sensor has to be protected against the flame front of the explosion by a layer of silicone rubber (e.g. Kistler no. 1043) of approx. 2 mm thickness. Too hard or too thick protective layers will have a "shunting" effect on the membrane and cause faulty measurements especially in the vacuum range. The protective silicone layer must be renewed periodically.

2.4.2 Adjustment of the Charge Amplifiers

The charge generated by the piezoelectric pressure sensor’s is transformed into proportional voltage by means of charge amplifiers. The different sensitivity of each sensor requires adjustment of the amplifying unit. The sensitivity of the sensor’s can be read from the calibration sheet (range 0 ... 25 bar): K pC. The measuring range of the system is 20 bar. From this, the adjustment of the amplifier is calculated as follows:

Amplification:	**A • 10^N [pC]**	**= 20 [bar] • K [pC/bar]**
Example:	K	= 79,8 pC/bar
	20 bar • 79,8 pC/bar	= 1596 pC
	1596 pC	= 160 • 10^{1}
	setting	= 160 / 1

calculation: ***System / Pressure Sensors***



3. Software

3.1 Installation

3.1.1 System requirements

Any standard personal computer running the operating system Microsoft-Windows 7 … 11 (32 or 64Bit)

Graphics, monitor:	resolution minimum 1024 x 768, colors minimum 16 bit
Interface:	USB (adapter USB - RS232 delivered with the 20-l-apparatus) or RS232 (COMx)

3.1.2 Installing the KSEP - Software

Please run the following setup-file: ***KSEP71_setup.msi***

3.2 Configuration

Start now the KSEP-software ...

3.2.1 User management

When first starting KSEP, the administrator has to define the users:

Users | § Rights

no	username	signature	authorization	expired	active	status
1	New	Cesana AG	Setup	never	✓	activated
2	AD	my Administrator	Administrator	never	✓	new
3	SE	my Service	Service	never	✓	new
4	SU	my Supervisor	Supervisor	never	✓	new
5	OP	my Operator	Operator	31.12.2023	✓	new

username A sensible short form.

signature: Full name. Will be inserted into the protocol.

authorization: *"Administrator"* for the administration of the users.
"Service" for calibration and maintenance.
"Supervisor" for supervision of processing.
"Operator" for all other users.
see: 3.2.2 Rights

expired: Expiry date of access right (authorization).

active: The administrator can also withdraw an access right ...

status: *"new"* or *"activated"*

The account of the administrator in row 2 never expires.

3.2.2 Rights

The administrator can freely define the rights for all accounts:

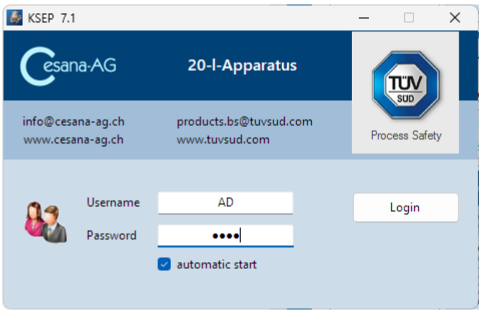
Users | Rights

no	can do ...	Administrator	Service	Supervisor	Operator
1	New tests	✓	✓	✓	✓
2	Filemanager (new, save)	✓	✓	✓	✓
3	Table modification	✓	✓	✓	✓
4	Test conditions	✓	✓	✓	
5	System - Settings	✓	✓		
6	Software Update	✓	✓		
7	User Management (see: Users)	✓			
8	Set Access Rights (this table)	✓			

Save all entries and exit *"Settings"*.

3.2.3 Choice of user

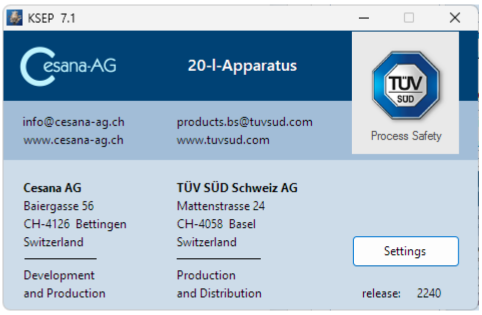
Insert user name and password. New users will be requested to confirm the password.
Note: KSEP doesn't distinguish between upper and lower case characters.



automatic start:
After a renewed start of KSEP, the last user will be displayed and with a delay of one minute the system will automatically change to the main program.

Login

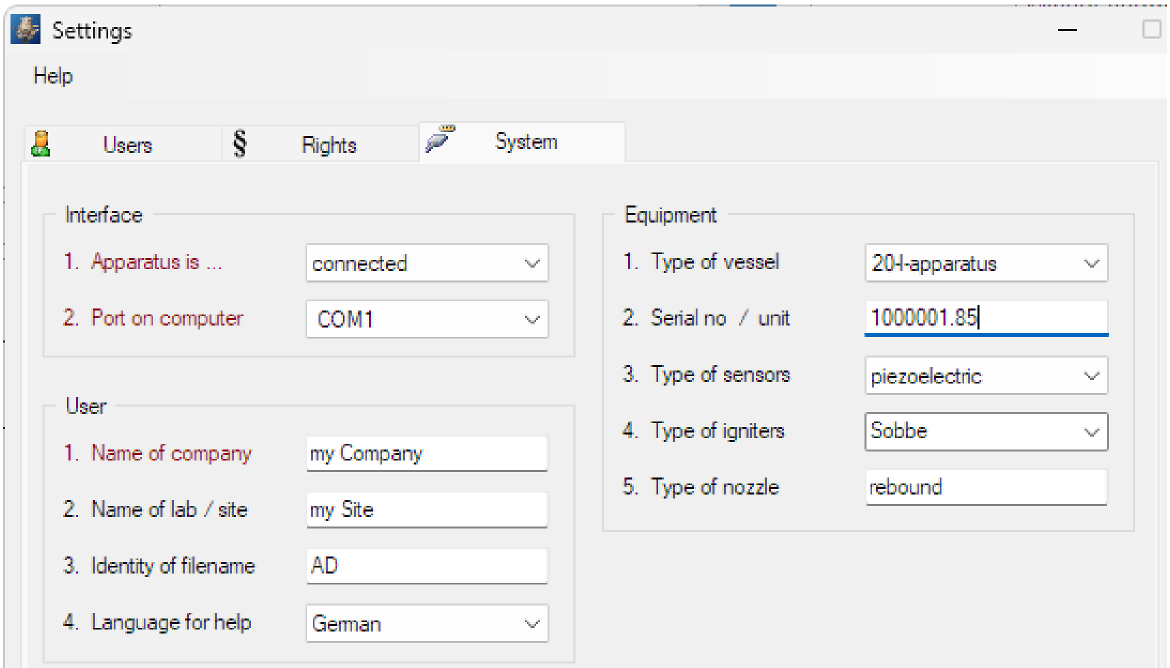
For further configuration of KSEP please log in with rights for *"System - Settings"* i.e. as *"Administrator"*.



Settings

... **further settings** (i.e. selection of interface)

3.2.4 Settings



Interface

1. The KSEP-apparatus is connected or will be simulated.
2. *RS-232 port on computer.* This setting is irrelevant if KSEP is simulated.

User

1. *Name of company:* will be used for the report
2. *Name of lab/site:* will be used for the report
3. *Identity:* automatic generated filenames starts always with the here defined identity. Thus, enter an abbreviation specific for your laboratory.
4. *Language for help:* The KSEP program always uses English. However, both English and German is available for the integral help.

Equipment

1. *Type of vessel:* 20-l-apparatus or 1m^3-vessel
2. *Serial no / unit:* see nameplate on vessel
3. *Type of sensor:* default = "piezoelectric"
4. *Type of igniters:* Sobbe / Simex / ...
5. *Type of nozzle:* rebound / annular / ...

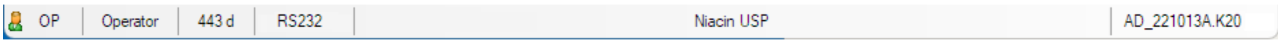
Directory

1. *KSEP-files:* The directory of the last KSEP-file is stored automatically. Therefore you can leave the preset directory.
2. *Report-files:* The directory of the last report mask is stored automatically. Therefore you can leave the preset directory.

Save all entries and exit *"Settings"*.

3.3 Operation

3.3.1 Status bar



1 2 3 4 5 6

1.	The actual user,	see: 3.2.4 choice of user
2.	The authorization of this user,	see: 3.2.3 rights
3.	Access is expired after ...,	see: 3.2.2 user management
4.	Interface,	see: 3.2.5 settings
5.	The actual product	
6.	Filename	

3.3.2 Files

New file

At the start of a test with new dust, a new file is opened. The file name is automatically allocated by the program (**A**) or given by you (**B**):

A: Automatic generated filenames starts always with identity (see: 3.2.4 settings), followed by the date when the file is opened. The subsequent letter distinguishes files which are generated on the same day.

example 1:	Identity_221013A.K20	(apparatus = 20-l-sphere)
example 2:	Identity_221013B.K20	(created on the same day as example 1)
example 3:	Identity_221013A.1M3	(apparatus = $1m^3$-vessel)

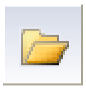
B:

example 4:	my_Product.K20	(apparatus = 20-l-sphere)
example 5:	my_Product.1M3	(apparatus = $1m^3$-vessel)

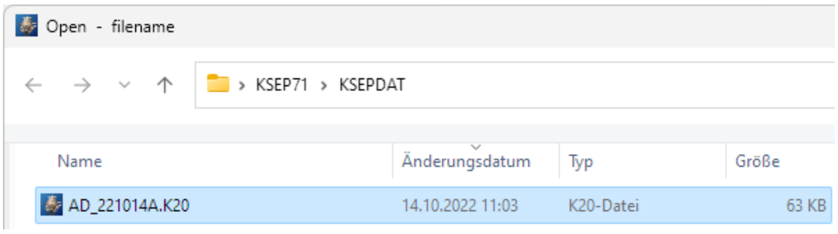
In the past the filename was limited by the operating system to only 8 characters. An assignment filename - product was difficult. Therefore the KSEP-program contains it's own file manager and also shows beside the filename the designation of the product. This has been very useful in the past so we decided to keep this feature in the actual software release.

With modern operating systems this restriction becomes unnecessary. The filename can be much longer and can also contain the designation of the product. For which version (A or B) you decide is up to you.
Our recommendation: **B** is state of the art.

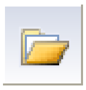
Open file - by filename



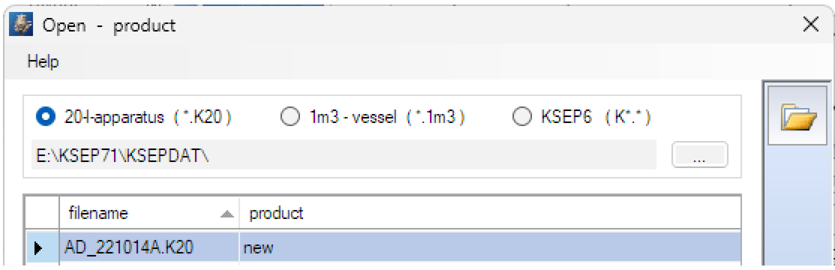
An index of KSEP-files is shown according to the Windows-Standard:



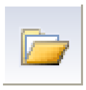
Open file - by product (.K20 - files)



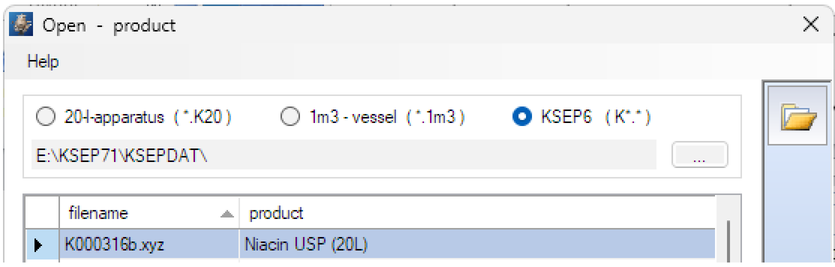
An index of KSEP-files is shown with filename and product. You can sort the fields (ascending or descending, "filename" or "product") by a click on the corresponding field.



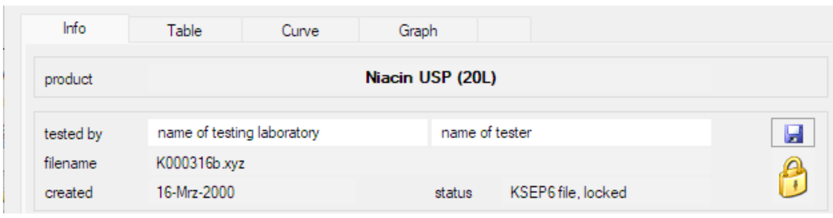
Open file - by product (KSEP 6 - files)



An index of old KSEP-files is shown with filename and product. You can sort the fields (ascending or descending, "filename" or "product") by a click on the corresponding field.



KSEP 6 - files are always **locked**. You cannot add test series, manipulate the table or add comments, except view and printout - as it is.
The name of testing site and tester was in the past not explicitly written to the file.
You can now get rid of this drawback:



Fill out the fields "tested by" and save the file.

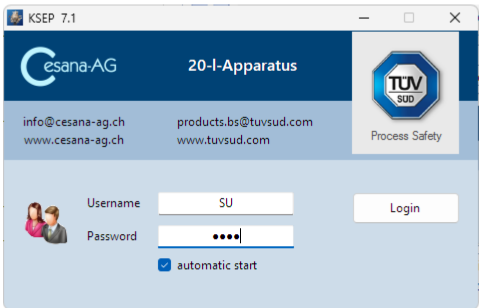
3.3.3 Authorization

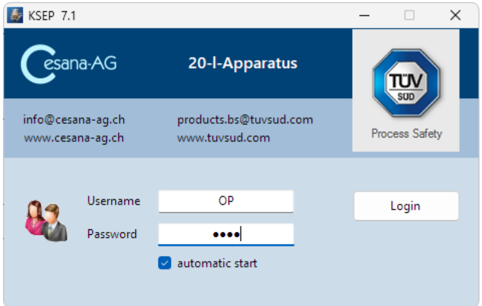
unlocked
You have full access: you can add series, manipulate data and add comments.

locked
All manipulations of data are locked, except view, export and printout.

When creating a new file, all **activated** users are transferred to the file. i.e. the supervisor can open this file on his workplace and manipulate the data and add comments. Provided that he is activated in the list of users on the KSEP-apparatus.

To activate an user enter username and password:





i.e. The users SU and OP are now activated (status = **activated**). For these the KSEP-file is unlocked on each PC with KSEP-Software, provided that username and password are the same.

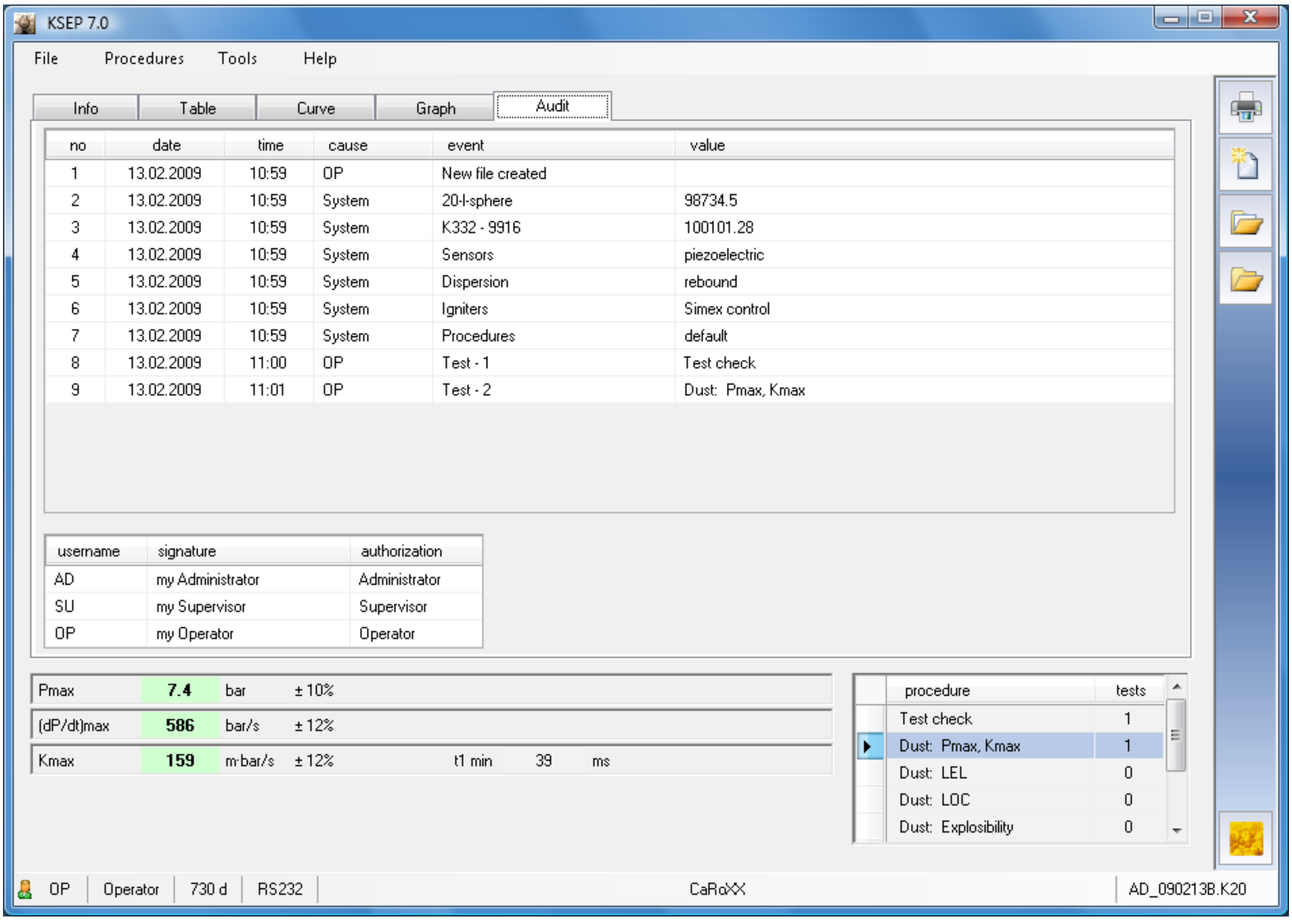
Users | § Rights | System

no	username	signature	authorization	expired	active	status
1	New	Cesana AG	Setup	never	✓	activated
2	AD	my Administrator	Administrator	never	✓	activated
3	SE	my Service	Service	never	✓	new
4	SU	my Supervisor	Supervisor	never	✓	activated
5	OP	my Operator	Operator	31.12.2023	✓	activated

You can also see the activated users on page "Audit":

username	signature	authorization
AD	my Administrator	Administrator
SU	my Supervisor	Supervisor
OP	my Operator	Operator

3.3.4 Audit



All activities are automatically recorded. An example:

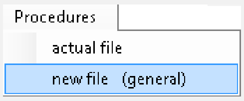
1	*OP* starts a new file and with it a new audit
2...7	Detailed data of apparatus and control equipment
8...9	Each added test will be recorded

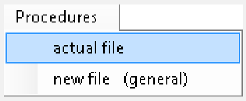
The data of the audit are stored manipulation proof in the KSEP-file.

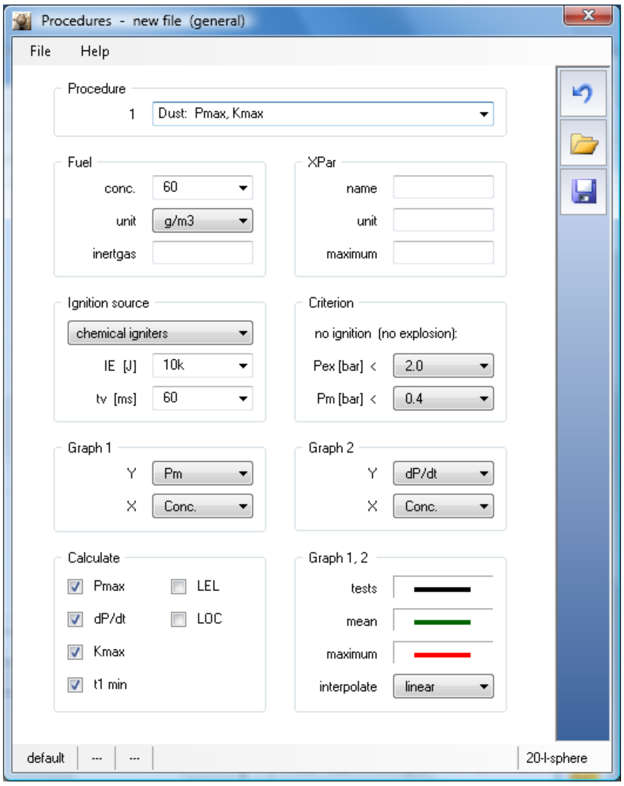
3.3.5 Procedures

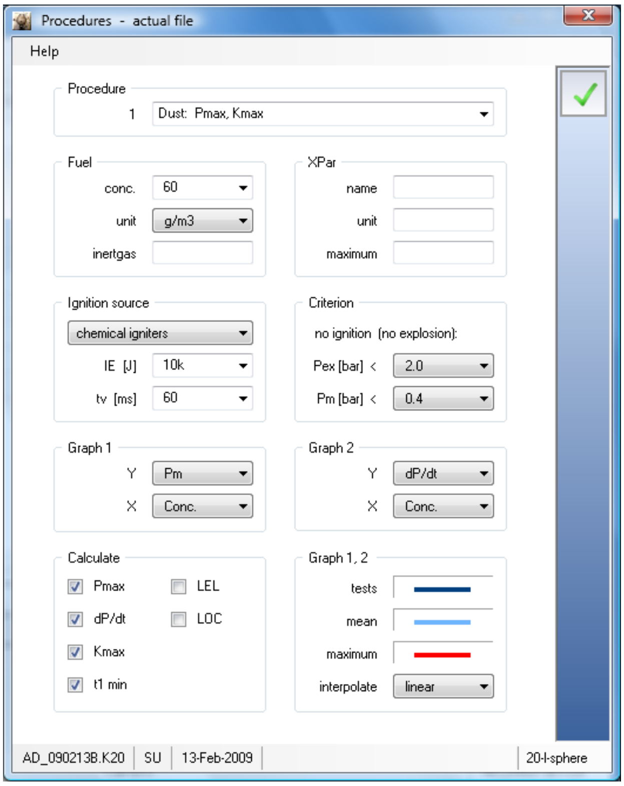
It is no longer necessary to change the test parameters each time another type of test is selected. Choose the procedure and the relevant pre-defined parameters will be activated. The procedure name, the size and designation of parameters and the coordinates of the graphic display can be pre-set using this tool.
We distinguish between:

General procedures for a new file	Procedures of the actual file





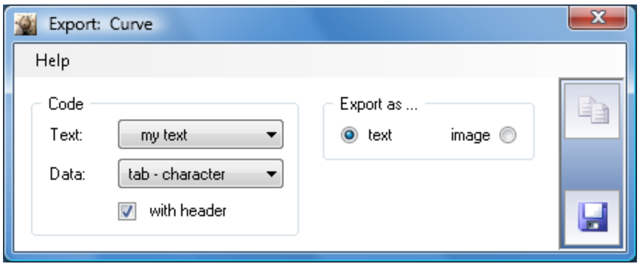




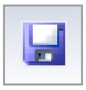
All procedures are an integral part of the respective KSEP-files.
New settings will only be active in a new KSEP-file.

3.3.6 Export

You can easily export data to other software.
Select first a page (*Info, Table, Graph, Curve, Audit*).
The Export-Menu is in "*File / Export*".



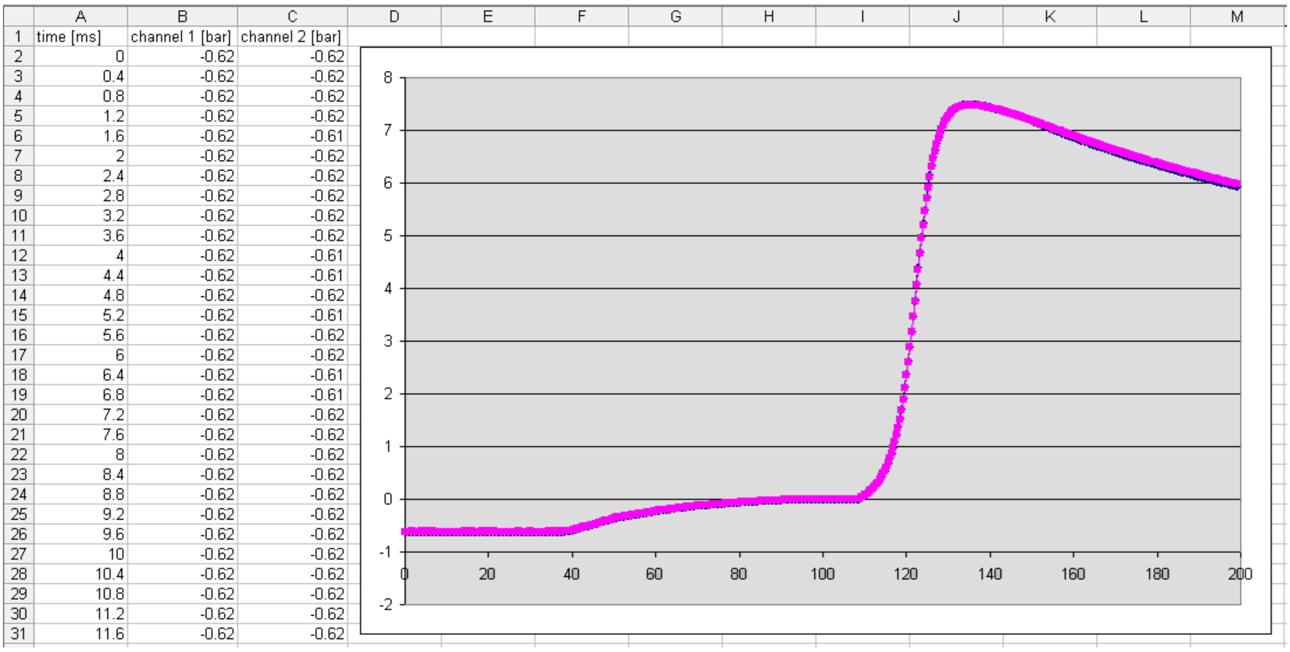
Text: Text with or without quotation marks.
Data: Define here the character which separates numbers.
with header: Shall a header be added to the columns ?



The data is written into a text file (*.txt).

The data are copied according to your instructions directly in the Windows-clipboard. From there you can paste it into any other program i.e. Excel, Word.

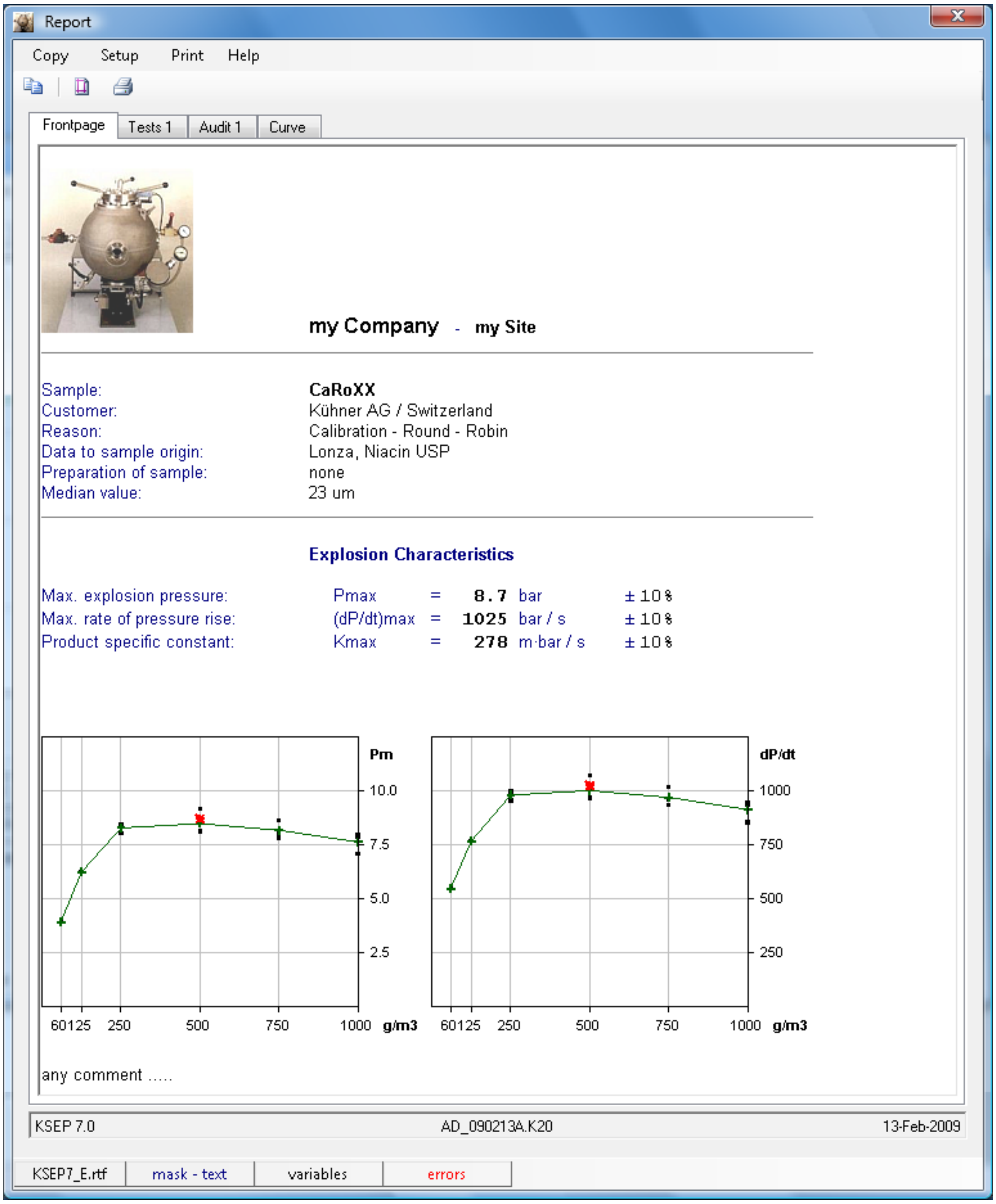
In the following example the values of the curve are sent to the clipboard and then directly inserted into an Excel-sheet:



	A	B	C
1	time [ms]	channel 1 [bar]	channel 2 [bar]
2	0	-0.62	-0.62
3	0.4	-0.62	-0.62
4	0.8	-0.62	-0.62
5	1.2	-0.62	-0.62
6	1.6	-0.62	-0.61
7	2	-0.62	-0.62
8	2.4	-0.62	-0.62
9	2.8	-0.62	-0.62
10	3.2	-0.62	-0.62
11	3.6	-0.62	-0.62
12	4	-0.62	-0.61
13	4.4	-0.62	-0.61
14	4.8	-0.62	-0.62
15	5.2	-0.62	-0.61
16	5.6	-0.62	-0.62
17	6	-0.62	-0.62
18	6.4	-0.62	-0.61
19	6.8	-0.62	-0.61
20	7.2	-0.62	-0.62
21	7.6	-0.62	-0.62
22	8	-0.62	-0.62
23	8.4	-0.62	-0.62
24	8.8	-0.62	-0.62
25	9.2	-0.62	-0.62
26	9.6	-0.62	-0.62
27	10	-0.62	-0.62
28	10.4	-0.62	-0.62
29	10.8	-0.62	-0.62
30	11.2	-0.62	-0.62
31	11.6	-0.62	-0.62

3.3.7 Test report

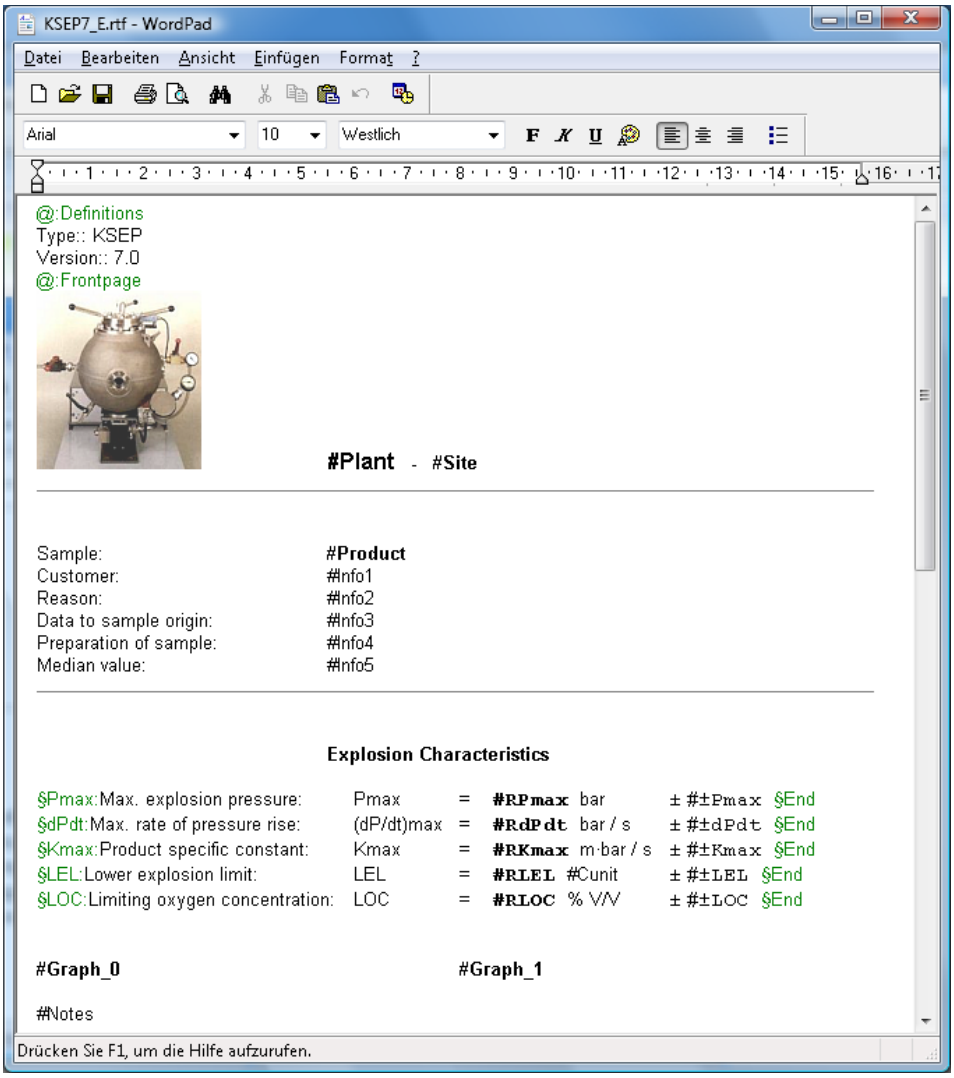
Select a mask. The test results and graphics are then inserted automatically by the program in the mask and a report is produced. This can be edited as a whole and then printed out.



We recommend to enter all comments and other information's (customer, reason, sample preparation, median value etc.) in the corresponding fields in the window „info" rather than to edit the report. Changes in the report, e.g. added comment, would be lost !

3.3.8 Report-mask

Aim and object of the mask is to enter repetitive text and to define all those fields in which variables (e.g. test results) should be entered automatically for the report.



The KSEP-software contains sample masks in English and German. These masks can be easily adapted to your requirements. We recommend to use the Editor-program "**WordPad**" from Microsoft.

These masks are split into several sections. Each section starts with a "@:"-code. Please do never modify this codes. All fields for variables are marked by "#"-code.

While the use of fonts designed for proportional character spacing is possible, formatting of the results table will be difficult. Therefore we recommend to use fonts with fixed character spacing (e.g. Courier New) for tables.

sections ' @: ' / variables ' # '

@:definitions	section for contents and printout	
	Type::	KSEP
	Version::	7.0

@:frontpage	section for product, final results, graphs and notes
@:tests_header	section for header of tests-table
@:tests_table	section for contents of tests-table
@:tests_footer	section for footer of tests-table
@:audit_header	section for header of audit- table
@:audit_table	section for contents of audit -table
@:audit_footer	section for footer of audit -table
@:curve	section for header of curve
@:end	end of report

global data:	
#Plant	name of your company
#Site	your lab. / your name
#Proc	test procedure
#Product	product
#File	filename
#ADate	actual date
#Graph_X	graph 0 & 1
#Funct	selected function
#XName	XPar - name
#XUnit	XPar - units
#CUnit	conc. (g/m3 or vol%)
#Info1	customer
#Info2	reason
#Info3	data to sample origin
#Info4	preparation of sample
#Info5	median value
#Notes	comments

final results:	
#RPmax	max. explosion pressure
#RdPdt	max. rate of pressure rise
#RKmax	max. explosion index K
#RLEL	lower explosion limit
#RLOC	limiting oxygen concentration
#Rt1	min. combustion time
#±Pmax	% deviation Pmax
#±dPdt	% deviation dP/dt
#±Kmax	% deviation Kmax
#±LEL	% deviation LEL
#±LOC	% deviation LOC
#t1min	% deviation [t] combustion time
audit:	
#ANr	test number
#ADate	date
#ATime	time
#ACaus	reason
#AEVT	event
#AVAL	value

single tests:	
#TNr	test number
#TSer	test number (Series)
#TConc	dust / gas concentration
#TPex	pressure
#TPm	pressure, corrected
#TdPdt	rate of pressure rise
#TPd	pressure difference
#TPi	pressure at ignition
#Ttd	delay of outlet valve
#Ttvs	ignition delay, setvalue
#Ttve	ignition delay, effective
#Tt1	duration of combustion
#Tt2	induction time
#TIE	ignition energy
#TXPar	variable parameter
#TNote	comments on tests

curve:	
#Curve	Picture curve
#CResult	result
#CNr	test number
#CSer	test number (Series)
#CConc	dust / gas concentration
#CPex	pressure
#CPm	pressure, corrected
#CdPdt	rate of pressure rise
#CPd	pressure difference
#CPi	pressure at ignition
#Ctd	delay of outlet valve
#Ctvs	ignition delay, setvalue
#Ctve	ignition delay, effective
#Ct1	duration of combustion
#Ct2	induction time
#CIE	ignition energy
#CXPar	variable parameter
#CNOTE	comments on tests

4. Calibration

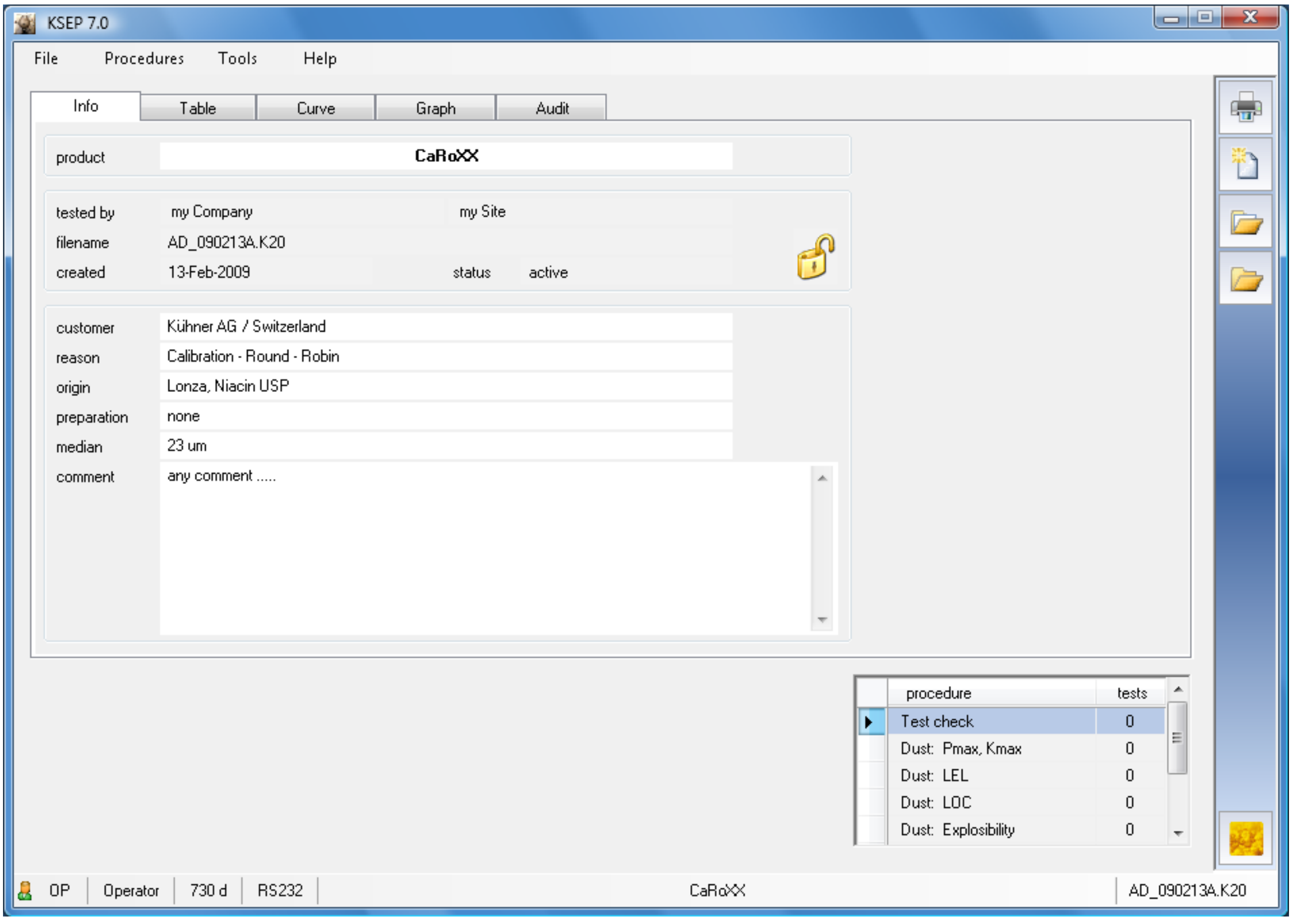
According to international standards (e.g. ISO 9000, GLP), test equipment must be calibrated at intervals by comparison with a standard or a calibrated testing apparatus. This calibration also applies to the 20-l-apparatus for the determination of Pmax and Kmax. Therefore we deliver with the equipment a test dust with reference results. We highly recommend to follow all the instructions step by step and to determine the explosion indices of the test dust.

4.1 Test check

A test check is a test sequence without dust and without chemical igniters. Thereby, the correct function of the entire system is checked in a simple way. It is recommended that the check be repeated at the onset of each test series !

4.1.1 New file

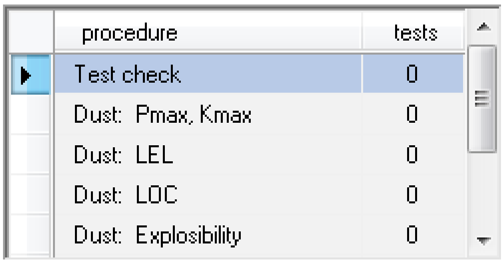
At the start of a test with a new dust, a new file is opened. The file name is automatically allocated by the program (Identity and date) or given by you. See: 3.3.2 Files.



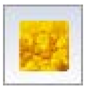
We recommend to enter all information's related to the product (customer, reason, sample preparation, median value etc.) in the corresponding fields. This text will be stored together with the test results in the KSEP-file.

4.1.2 Select procedure "test check"

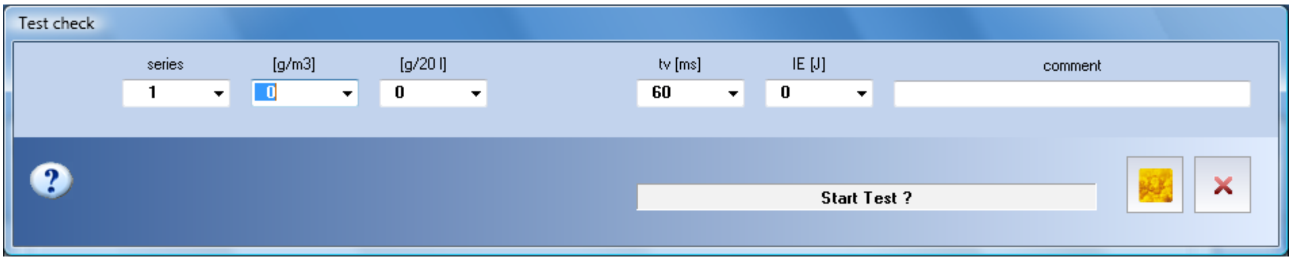
Working with the equipment is facilitated considerably by grouping the tests according to **procedures,** because the pre-adjustment of test-parameters and graphic display differ from task to task.

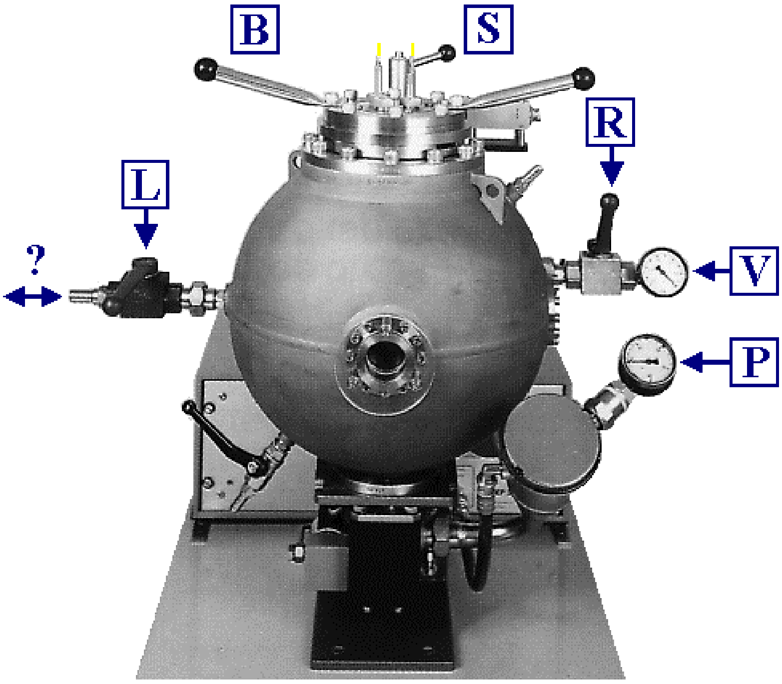


4.1.3 Procedure "test check"



Open the window „Next Test“ by a click on this button or push the „enter“-key. Under the procedure „Test Check“ all parameters are pre-set as follows:





Test check

1. Open the ball valve (**L**) - venting.
2. Close the ball valve(**R**) - vacuum.
3. Turn the bayonet-ring (**B**) in the final position.
4. The safety switch (**S**) can be closed now.
5. Pressurize the dust storage container. (button „**I**“ on the manual control)
6. Adjust air pressure (**P**) to 20 bar with the regulator on the air cylinder.
7. Relieve the pressure into the sphere. (button „**O**“ on the manual control)
8. Close the ball valve (**L**) - venting.
9. Open the ball valve (**R**) to the vacuum pump.
10. Evacuate the sphere to 0.4 bar absolute. Indication (**V**) = **-0,6** bar.
11. Close the ball valve (**R**) to the vacuum pump.
12. Start an automatic test run.
13. Open vent valve (**L**) slowly: just a little air should flow in or out.

i.e. there should be ambient pressure within the sphere !

A comparison with the ambient pressure is only permissible if it does not deviate significantly from 1013 mbar. Otherwise, an absolute pressure gauge must be connected to the outlet ball valve for this test.

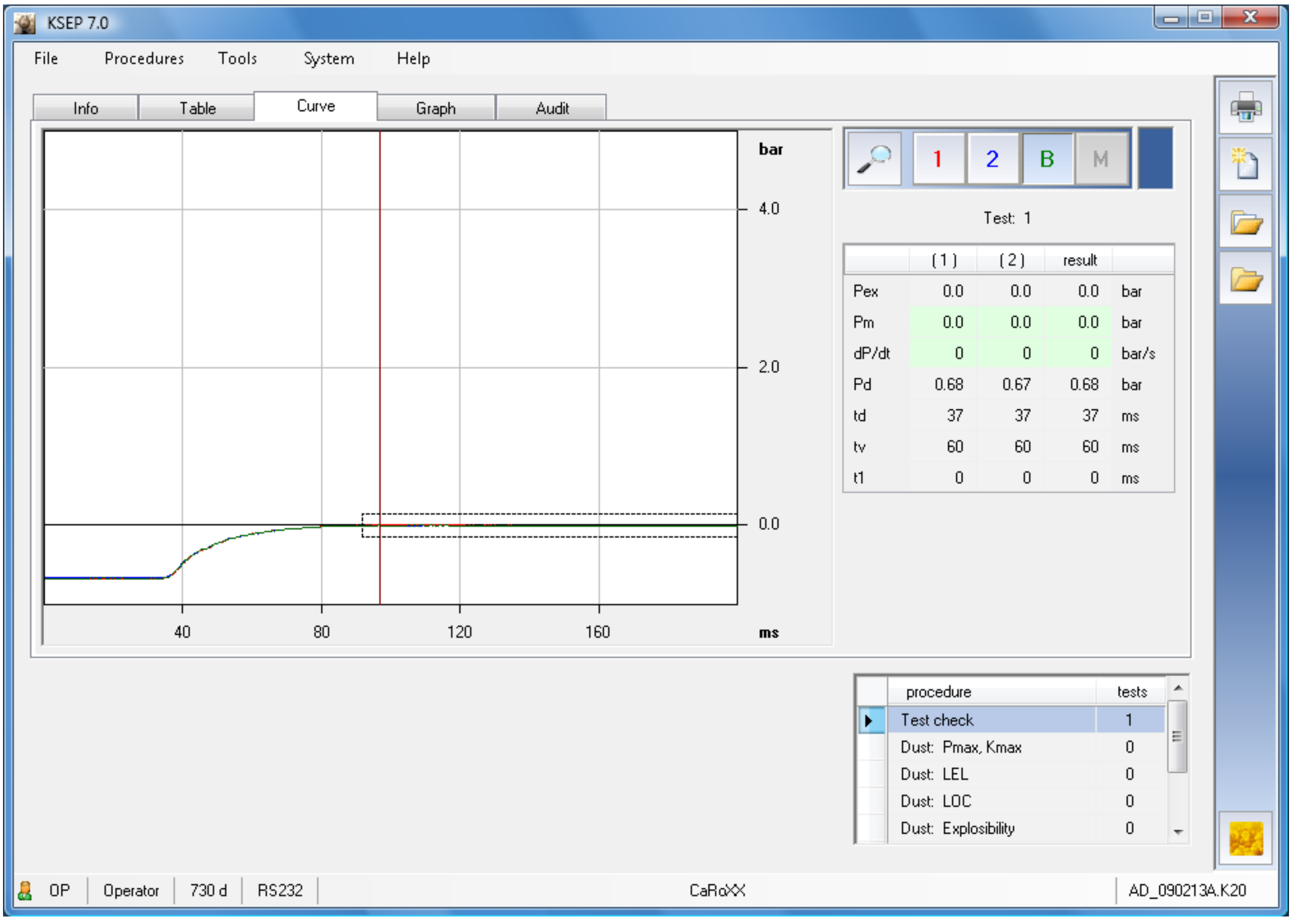
The following conditions must be met very accurately:

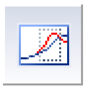
Dispersion overpressure Pz = 20 bar (21 bar absolute)
The propellant pressure Pz is the compressed air pressure in the dust storage container. This pressure must be 20 bar.

Initial pressure Pi = 1013 mbar = atmospheric pressure.
The explosion indices Pmax and Kmax are directly proportional to the initial pressure Pi. This is the most common source for faulty results !

4.1.4 Pressure curve "test check"

After a test, the pressure curves of channel 1 (red) and channel 2 (blue) and their mean value (green) are displayed:





Change back to overall view.

Zooming: with help of the mouse, pull a window around the area to be enlarged.
With this key the chosen sector will be shown.

Error messages:

The entire evaluation is generally done automatically. The following explosion- and control-parameters are assessed and unacceptable discrepancies are highlighted in red color:

Pd The expansion pressure Pd is outside the acceptable range of 0.55 to 0.7 bar.
Please check the initial pressure of the storage container. Check also the settings of the charge amplifiers, the thickness and the hardness of the protective Silicon-layer on the pressure transducers.

td the time lag of the outlet-valve is outside the acceptable range of 30 to 50 ms. The outlet valve may be dirty or the dust dispersion device plugged.

tv the measured ignition delay time deviates more than ± 5 ms from the entered time tv.

4.2 Explosion indices

4.2.1 Test Conditions

Procedure		=	**Dust: Pmax, Kmax**
Ignition source		=	Chemical igniters
Ignition energy	IE	=	**2 x 5 kJ**
Ignition delay time	tv	=	60 ms

4.2.2 Principle

In a first test series, the maximum explosion overpressure and the maximum rate of pressure rise are determined over a wide range of concentrations. Starting with a low dust concentration of 60g/m³ (1.2g / 20-l), the concentration is increased in steps, until the maximum values for the explosion pressure and the rate of pressure rise have clearly been determined. The following steps must be used:

60; 125; 250; 500; 750; 1000; 1250; 1500 g/m³

After the first test series, the concentration range close to the observed maxima (Pmax, (dP/dt)max) is twice checked, i.e. the tests are repeated at the optimum concentration, the next higher and the next lower concentration. An example:
(Assuming, the maxima of Pm and (dP/dt) are at 250 resp. 500 g/m³)

1. series:	60,	125,	250,	500,	750,	1000 g/m³
2. series:		125,	250,	500,	750	
3. series:		125,	250,	500,	750	

4.2.3 Sample preparation

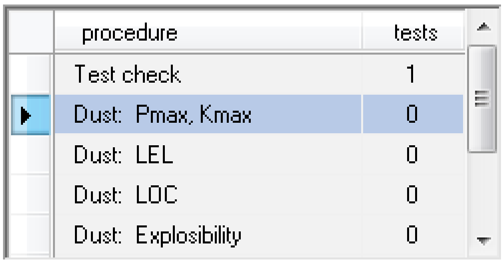
The results can only be compared, when the sample preparation is the same. Therefore the test dust has been milled, homogenized and tightly packed. Please keep the container closed whenever possible.

Please test the sample **„as delivered“.**
By no means, prepare the sample additionally.

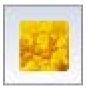
4.2.4 Water cooling

A high test frequency will necessitate keeping the operating temperature at approx. 20°C by means of water cooling, i.e. the operating temperature should correspond to room temperature. Thermostatic control of the cooling water is not necessary, but care should be taken that there is always some flow of water and that the outlet temperature of the cooling medium not exceeds 25°C.

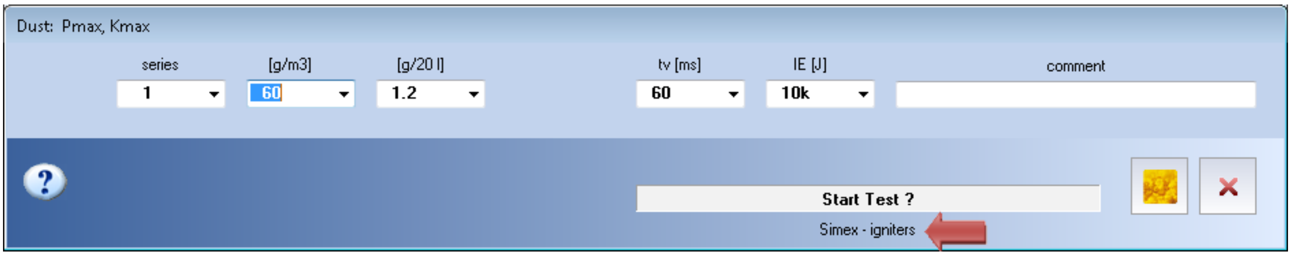
4.2.5 Select procedure "Dust: Pmax, Kmax"



4.2.6 Procedure "Dust: Pmax, Kmax"



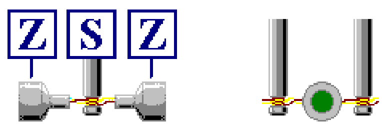
Open the window „Next Test“ by a click on this button or push the „enter“-key. With procedure „Dust: Pmax, Kmax“ all parameters are pre-set as follows:



The ignition delay time of Simex-igniters is 5ms shorter than with Sobbe.
It can happen that the outlet valve is not fully closed at the moment of ignition.
Therefore the KSEP-software corrects for Simex-igniters the time of ignition by 5ms.
See: 3.2.5 Settings

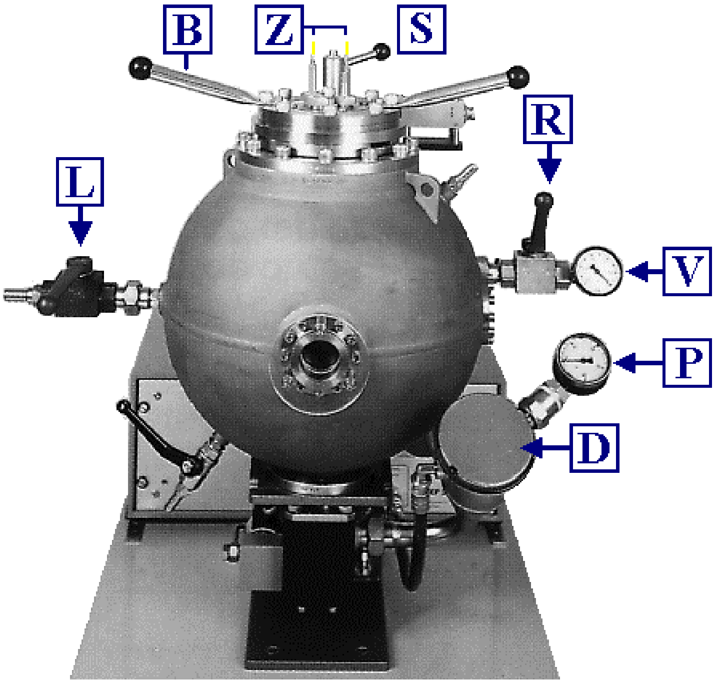
4.2.7 Fitting of igniters

Two chemical igniters (**Z**) each having an energy of 5kJ are connected to the electrode (**S**) as shown. The two igniters are firing horizontal and in opposite directions.



Sobbe-igniters are connected in parallel.

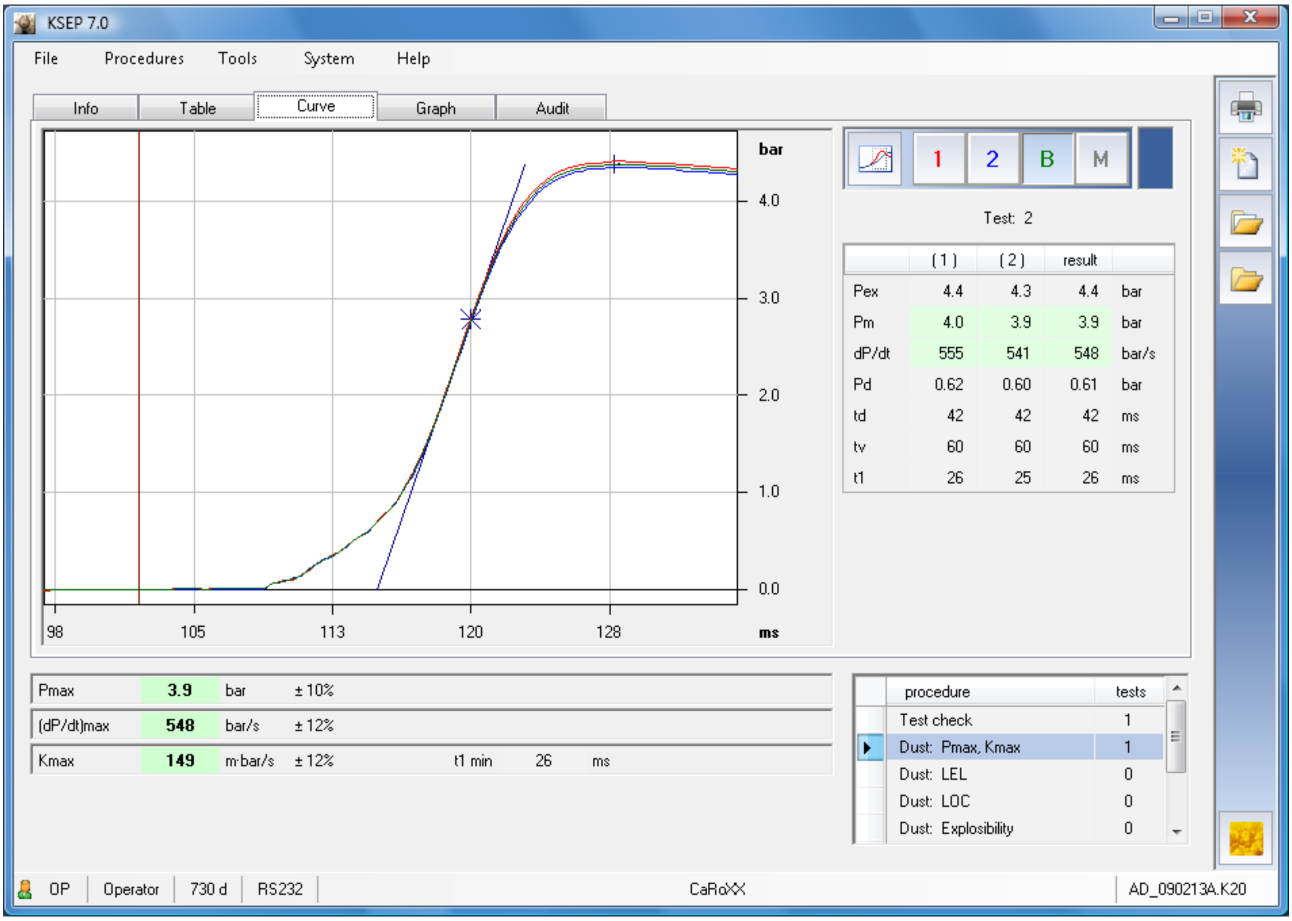
Simex-igniters are already pre-wired (serial connection).

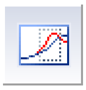


	before the test:
1.	Charge the dust to the storage container (**D**).
2.	Connect two chemical igniters (each 5 kJ) in parallel to the electrode rods.
3.	Put the cover on the sphere and turn the bayonet-ring (**B**) in the final position.
4.	Connect the ignition lines (**Z**).
5.	Close the safety switch (**S**).
6.	Close the ball valve (**L**).
7.	Open the ball valve (**R**) to the vacuum pump.
8.	Evacuate the sphere to 0.4 bar absolute. Indication (**V**) = **-0,6** bar.
9.	Close the ball valve (**R**) to the vacuum pump.
10.	Start an automatic test run.
	after the test:
11.	Open the ball valve (**L**) to vent the sphere.
12.	Rinse the apparatus with compressed air by alternately pushing the buttons (**I**) and (**O**) on the manual control (approx. 3 times).
13.	Open the sphere and remove residues with a vacuum cleaner.
14.	Remove the burned-out igniters and clean the electrode rods.
15.	Clean the rebound nozzle: all holes must be free.
16.	Clean the dust storage container, suck away remaining dust with a vacuum cleaner.
	before the next test:
17.	Enter the new dust concentration.
	before the next series:
18.	Perform a test check as described in section 4.1.
19.	Enter the next series number.

4.2.8 Pressure curve

After a test, the pressure curves of channel 1 (red) and channel 2 (blue) and their mean value (green) are displayed. The vertical line defines the moment of ignition. The tangent of max. rate of pressure rise, the point of inflexion and the cross for max. explosion pressure Pex are displayed in cobalt blue color.





Change back to overall view.

Zooming: with help of the mouse, pull a window around the area to be enlarged.
With this key the chosen sector will be shown.

4.2.9 Error messages:

The entire evaluation is generally done automatically. The following explosion- and control-parameters are assessed and unacceptable discrepancies are highlighted in red color:

Pex **Pm**	The difference between the pressures values of the two sensor's exceeds 0.3 bar. This usually means that either the adjustment of the charge amplifiers or the silicone protection on the pressure sensor's are faulty.
dP/dt	The difference of the rate of pressure rise of the two sensor's differs by more than 10% of the mean value.
Pd	The expansion pressure Pd is outside the acceptable range of 0.55 to 0.7 bar. Please check the initial pressure of the dust storage container.
td	The time lag of the outlet-valve is outside the acceptable range of 30 to 50 ms. The outlet valve may be dirty or the dust dispersion device plugged.
tv	The measured ignition delay time deviates more than ± 5 ms from the entered time tv.

4.2.10 Manual evaluation (especially for weak explosions)

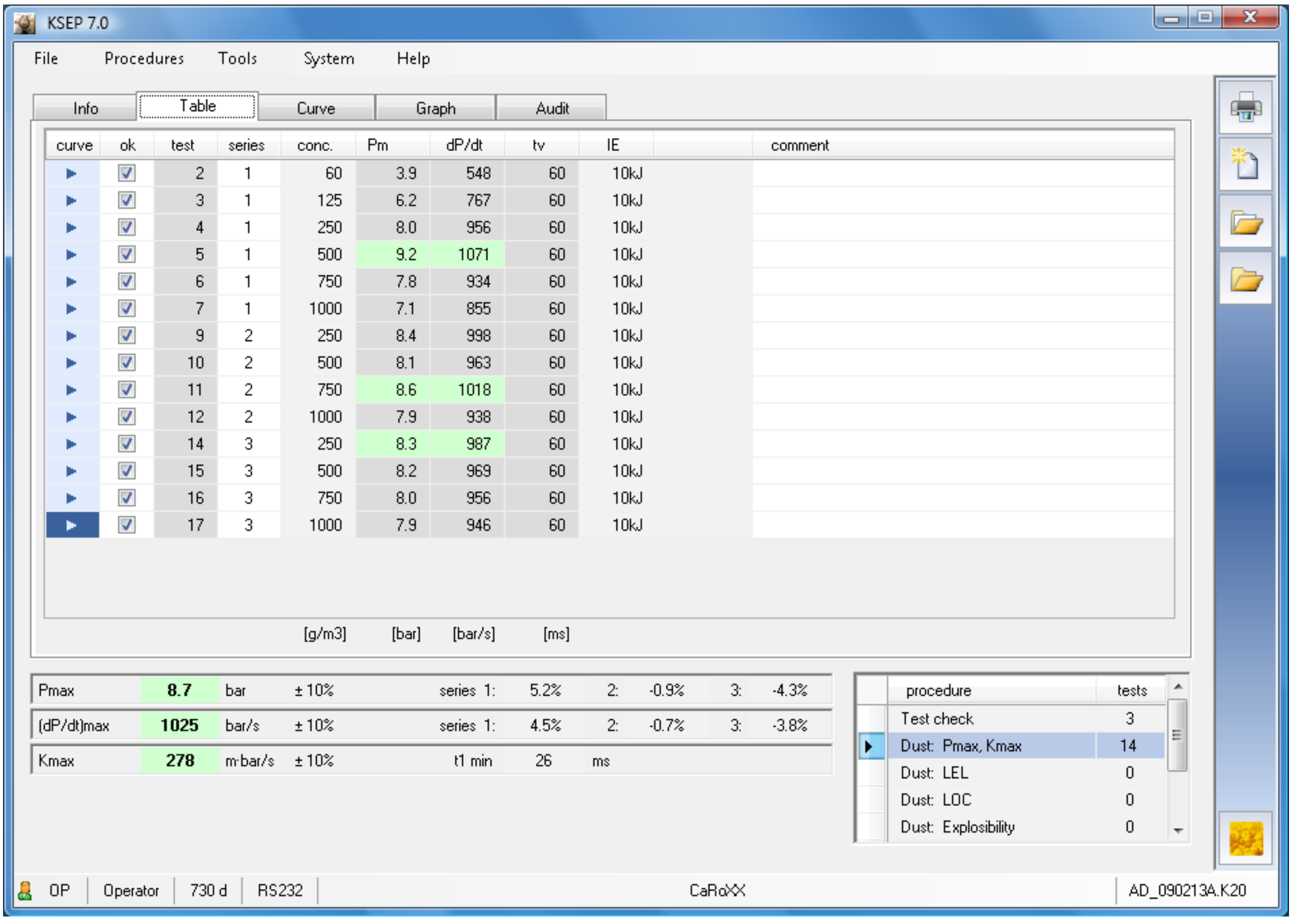
If a (dP/dt)m of less than 150 bar/s is obtained, it is possible that the rate of pressure rise of the chemical igniters is higher than that of the fuel explosion. It is therefore necessary to compare this explosion pressure curve with the pressure curve caused by the chemical igniters alone and under otherwise identical conditions. Typical values for chemical igniters of 10 kJ are approx. 100 bar/s. It can be assumed that the pressure rise caused by the chemical igniters is terminated after 50 ms. (Thus the tangent may only be drawn at least 50 ms after ignition).

The KSEP 332 automatically compensates for this effect. Of course this simple rule of thumb can not cover all practical cases, thus a manual evaluation has to be done from time to time:

Observe how and where the computer sets the tangent after an explosion test. Weak explosions or oscillations superimposed on the pressure course may lead to wrong results. If you do not agree, it's best to do a manual evaluation.

4.2.11 Results - table

Subdivided by procedure, all tests are shown:



curve	ok	test	series	conc.	Pm	dP/dt	tv	IE	comment
▶	☑	2	1	60	3.9	548	60	10kJ	
▶	☑	3	1	125	6.2	767	60	10kJ	
▶	☑	4	1	250	8.0	956	60	10kJ	
▶	☑	5	1	500	9.2	1071	60	10kJ	
▶	☑	6	1	750	7.8	934	60	10kJ	
▶	☑	7	1	1000	7.1	855	60	10kJ	
▶	☑	9	2	250	8.4	998	60	10kJ	
▶	☑	10	2	500	8.1	963	60	10kJ	
▶	☑	11	2	750	8.6	1018	60	10kJ	
▶	☑	12	2	1000	7.9	938	60	10kJ	
▶	☑	14	3	250	8.3	987	60	10kJ	
▶	☑	15	3	500	8.2	969	60	10kJ	
▶	☑	16	3	750	8.0	956	60	10kJ	
▶	☑	17	3	1000	7.9	946	60	10kJ	
				[g/m3]	[bar]	[bar/s]	[ms]		

Pmax	8.7	bar	± 10%	series 1:	5.2%	2:	-0.9%	3:	-4.3%
(dP/dt)max	1025	bar/s	± 10%	series 1:	4.5%	2:	-0.7%	3:	-3.8%
Kmax	278	m·bar/s	± 10%	t1 min	26	ms			

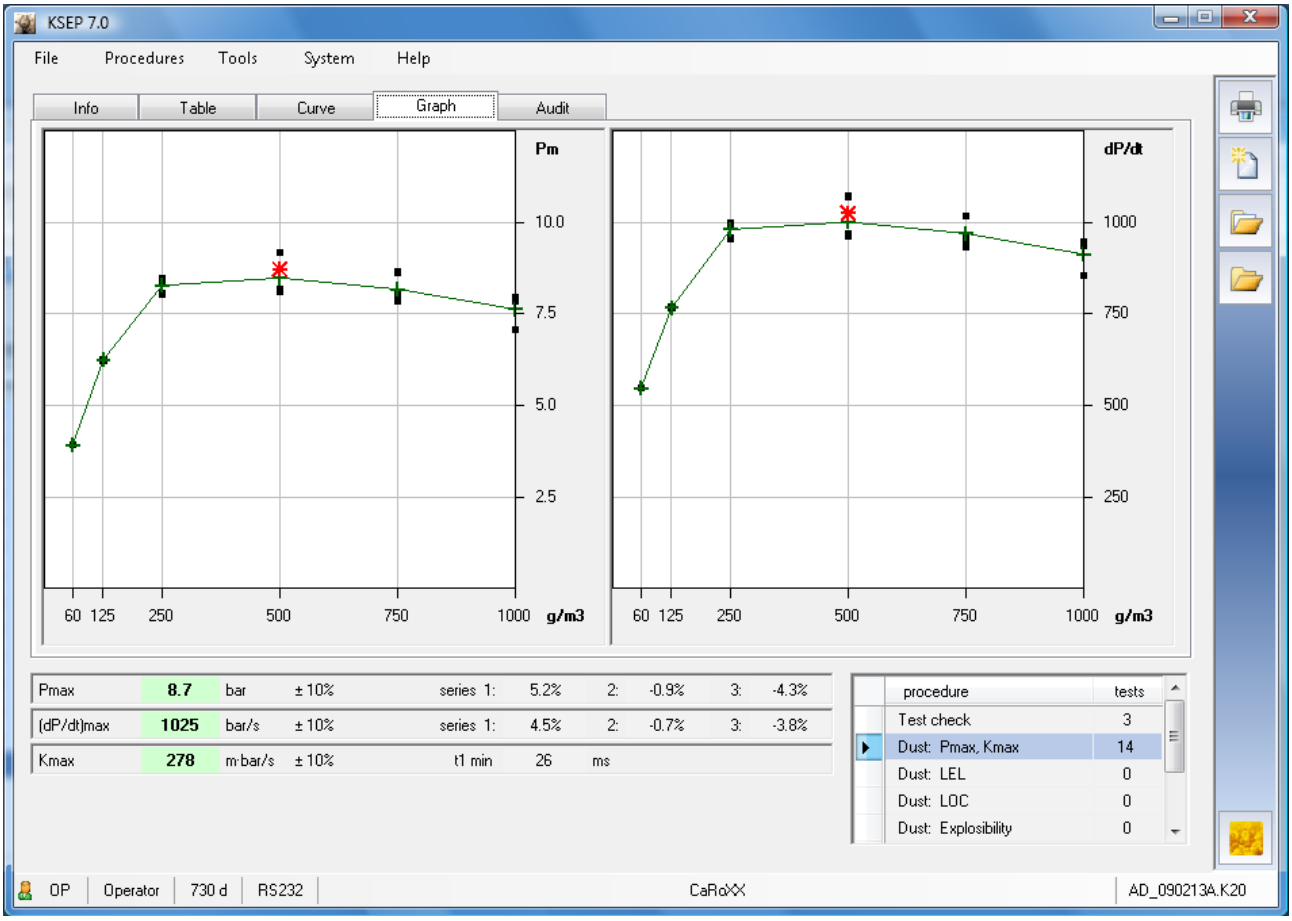
procedure	tests
Test check	3
Dust: Pmax, Kmax	14
Dust: LEL	0
Dust: LOC	0
Dust: Explosibility	0

Symbols on the table:

(green)	maximum value (of each series), green
(orange)	this value is not correct, red
☑	this test is valid and included in the evaluation (to change: click in this field)
▶	the pressure curve is stored (to show the curve: double-click in this field)
▶ (dark blue)	selected curve

4.2.12 Graphics of results

Particular values (squares), mean values (crosses) and for "Pm, dP/dt " the mean of maxima (stars) of each series are displayed. Clean up the results table first, i.e. disable all invalid tests in the result table.



Calculation of the explosion indices:

The explosion indices Pmax and (dP/dt)max are defined as the mean values of the maximum values of each series (total **3 series**).
Subsequently, the explosion index Kmax is calculated from the above (dP/dt)max.

Pm [series n] = maximum value of each series
Pmax = (Pm [series 1] + Pm [series 2] + Pm [series 3]) / 3

(dP/dt)m [series n] = maximum value of each series
(dP/dt)max = (dP/dt [series 1] + dP/dt [series 2] + dP/dt [series 3]) / 3
Kmax = 0.27144 x (dP/dt)max

$$V^{1/3} = 0.02^{1/3} = 0.27144$$

4.2.13 Check of the explosion indices

Pmax is the mean value of the maxima of three series of tests.
Each of the maxima must not deviate by more than **10% of Pmax**
Otherwise this series must be repeated !

(dP/dt)max is the mean value of the maxima of three series of tests.
Each of the maxima must not deviate more than the values given in the table below.
Otherwise this series must be repeated !

(dP/dt)max	Kmax	Deviation
≤ 185	≤ 50	± 30 %
186 - 370	51 - 100	± 20 %
371 - 740	101 - 200	± 12 %
> 740	> 200	± 10 %

This check will be done automatically. Faulty series will highlighted in red color. This series must be repeated !

When testing more than 3 series, select 3 of them with minimum deviation between each other. All other tests (series) must be disabled and excluded from the evaluation.

4.2.14 Conformity with reference values

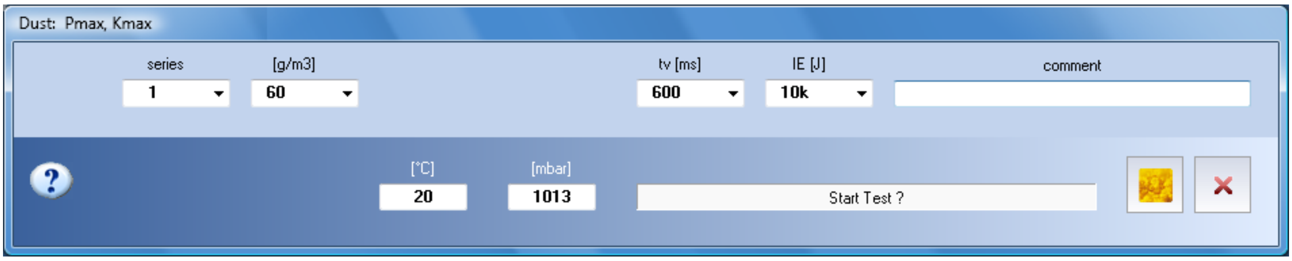
To meet the calibration requirements of the test dust, Your results must be within the given tolerance range. Otherwise check the following cause of errors:

Cause of errors:

1. Synthetic compressed air
2. Faulty or plugged gauge (vacuum, dust container).
3. Leaky apparatus (o-ring, ball valve).
4. Protective Silicon-layer on the sensor’s is too old and too hard.
5. Wrong settings on the charge amplifiers.
6. Missing cooling on the sphere.

4.3 Procedures for $1m^3$ - vessel

For the $1m^3$ - vessel the ambient pressure and the temperature of the vessel has to be considered. These values must be entered before the test. The software corrects then automatically Pex to Pm.



[°C] **Temperature of the vessel**

The temperature of the 20-l-sphere is regulated by water cooling. However in the $1m^3$ - vessel this temperature can rise and has to be considered (see 1.5.4 temperature).

[mbar] **Ambient pressure**

The initial pressure in the 20-l-sphere is regulated to 1 bar absolute. However in the $1m^3$ - vessel the initial pressure is given by the ambient pressure.
This influence has to be considered (see 1.5.5 initial pressure).

5. Test procedures for Dusts

5.1 General rules

5.1.1 Sample preparation

In principle for all determination procedures described here, the dust sample should have a median particle size "M" not exceeding **63µm** and should be in a dry state (e.g. drying at 50°C in vacuum or 75°C at ambient pressure).
In justified exceptional cases the dust can also be tested as supplied.

5.1.2 Check of the equipment

Before testing, check the set-up of your equipment as follows:

Compressed air

- Only normal compressor compressed air may be used (in cylinders).
- Air pressure of bottle > 40 bar.

Leakage

- Pressurize manually the dust storage chamber to 20 bar over pressure. If the gauge drops more than 1 bar in 1 minute, then check the seals of outlet valve.

Operating temperature

- Check the minimum flow of the cooling water: > 0.5 liter / minute.
- Check outlet temperature of the cooling water: < 25°C

5.1.3 Test check (see 4.1)

A test check is an automatic test sequence without dust and without chemical igniters. Thereby, the correct function of the entire system is checked in a simple way. It is strongly recommended that the check be repeated at the onset of each test series !

1. Procedure = **Test check**
2. Dust concentration = 0 g/m^3
3. Ignition energy = 0 J
4. Ignition delay time = 60 ms
5. Adjust compressed air pressure to 20 bar (21 bar absolute).
6. Evacuate the 20-l-sphere to 0.4 bar absolute (indication: - 0.6 bar).
7. Start an automatic test sequence.
8. Open vent valve (left) slowly: just a little air should flow in or out.
   i.e. there should be ambient pressure within the sphere !

A comparison with the ambient pressure is only permissible if it does not deviate significantly from 1013 mbar. Otherwise, an absolute pressure gauge must be connected to the outlet ball valve for this test.

5.2 Dust - Explosion indices: Pmax, (dP/dt)max, Kmax

5.2.1 Test Conditions

Procedure		=	**Dust: Pmax, Kmax**
Ignition source		=	Chemical igniters
Ignition energy	IE	=	**2 x 5 kJ**
Ignition delay time	tv	=	60 ms

5.2.2 Test Method

In a first test series, the maximum explosion overpressure and the maximum rate of pressure rise are determined over a wide range of concentrations. Starting with a low dust concentration of 60g/m³ (1.2g / 20-l), the concentration is increased in steps, until the maximum values for the explosion pressure and the rate of pressure rise have clearly been determined. The following steps must be used:

60; 125; 250; 500; 750; 1000; 1250; 1500 g/m³

After the first test series, the concentration range close to the observed maxima (Pmax, (dP/dt)max) is twice checked, i.e. the tests are repeated at the optimum concentration, the next higher and the next lower concentration. An example:
(Assuming, the maxima of Pm and (dP/dt) are at 250 resp. 500 g/m³)

1. series:	60,	125,	250,	500,	750,	1000 g/m³
2. series:		125,	250,	500,	750	
3. series:		125,	250,	500,	750	

5.2.3 Test Evaluation

The explosion indices Pmax and (dP/dt)max are defined as the mean values of the maximum values of each series (total **3 series**).
Subsequently, the explosion index Kmax is calculated from the above (dP/dt)max.

Pm [series n] = maximum value of each series
Pmax = (Pm [series 1] + Pm [series 2] + Pm [series 3]) / 3

(dP/dt)m [series n] = maximum value of each series
(dP/dt)max = (dP/dt [series 1] + dP/dt [series 2] + dP/dt [series 3]) / 3
Kmax = 0.27144 x (dP/dt)max

5.2.4 Check of the results

Pmax is the mean value of the maxima of three series of tests.
Each of the maxima must not deviate by more than **10% of Pmax**
Otherwise this series must be repeated !

(dP/dt)max is the mean value of the maxima of three series of tests.
Each of the maxima must not deviate more than the values given in the table below.
Otherwise this series must be repeated !

(dP/dt)max	Kmax	Deviation
≤ 185	≤ 50	± 30 %
186 - 370	51 - 100	± 20 %
371 - 740	101 - 200	± 12 %
> 740	> 200	± 10 %

This check will be done automatically. Faulty series will be highlighted in red color.
This series must be repeated !

5.3 Dust - Lower Explosion Limit (LEL)

5.3.1 Test Conditions

Procedure		=	**Dust: LEL**
Ignition source		=	Chemical igniters
Ignition energy	IE	=	**2 x 1 kJ**
Ignition delay time	tv	=	60 ms

5.3.2 Test Method

The 20-l-sphere and the dust storage chamber must be cleaned thoroughly before each test. A test series is initiated with an integral multiple of 10g/m³; e.g. 20 or 30g/m³. The series is continued with a systematic increase of the dust concentration until ignition of the dust/air mixture is observed. Repeat the test with a dust concentration 10g/m³ lower, and continue to reduce the concentration in further tests until a concentration is reached at which no ignition of the dust/air mixture is observed in **three** successive tests.

For dust concentrations higher than 100g/m³ integral steps of 20g/m³ may be used and for concentrations higher than 200g/m³ the 50g/m³ steps may be used.
To obtain accurate values for the LEL, 3 negative tests for each concentration must be observed.

5.3.3 Test Evaluation (IE = 2 x 1 kJ)

Pex [bar]	Pm [bar]	Decision:
< 0.5	**< 0.2**	**no** ignition
≥ **0.5**	≥ **0.2**	ignition

The lower explosion limit LEL is reported as the highest concentration at which a dust explosion is not detected in three successive tests.
If only one test series is carried out (1 negative test), the value for LEL has to be reported as approximately ... g/m³.

This determination is naturally very sensitive to product residues from previous tests. It has thus proved advisable to insert a blank test (igniters only, no dust) between the individual tests with dust to remove the residues following cleaning.

5.4 Dust - Explosibility

5.4.1 Test Conditions

Procedure		=	**Dust: Explosibility**
Ignition source		=	Chemical igniters
Ignition energy	IE	=	**2 x 1 kJ**
Ignition delay time	tv	=	60 ms

5.4.2 Test Method

The 20-l-sphere and the dust storage chamber must be cleaned thoroughly before each test. A test series is initiated, starting with a dust concentration of 30g/m^3.

e.g. 30, 60, 125, 250, 500, 750, 1000, 1250, 1500, 1750, 2000 g/m^3

5.4.3 Test Evaluation (IE = 2 x 1 kJ)

Pex [bar]	Pm [bar]	Decision:
< 0.5	**< 0.2**	**no** ignition
≥ 0.5	**≥ 0.2**	ignition

A dust which cannot be induced to explode over a wide range of concentrations (normally from 30g/m^3 to 2000g/m^3) with an ignition energy of IE = 2 x 1 kJ (chemical igniters) is classified as **not explosible**.
This means that most probably the dust cannot be exploded at all, except by application of even stronger ignition sources (IE > 2 kJ).

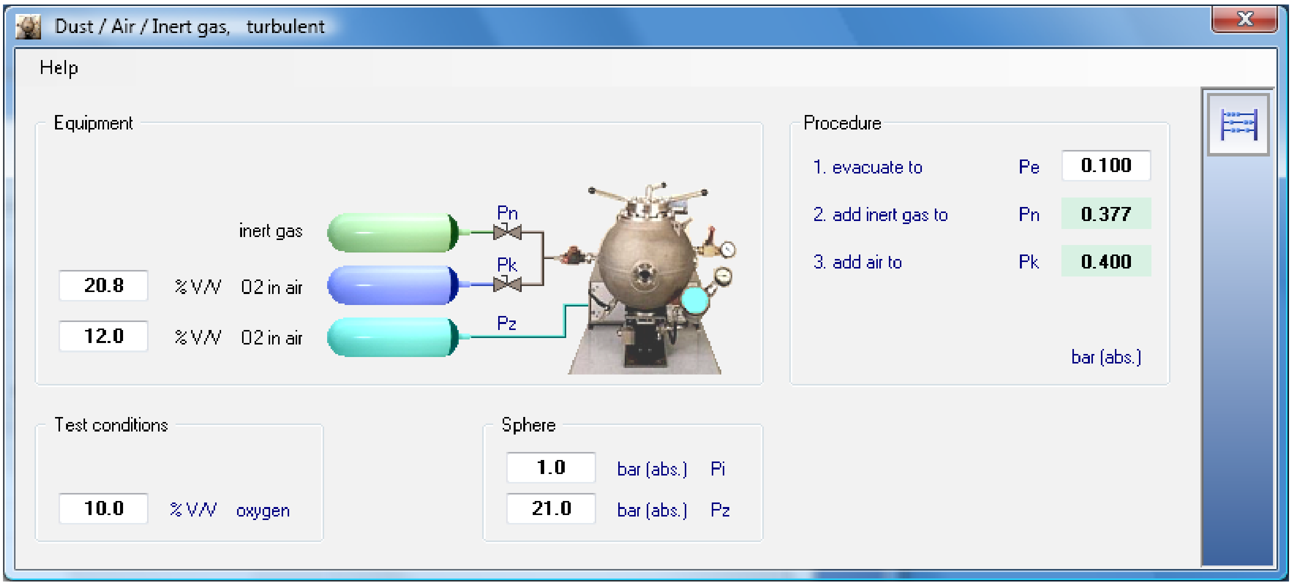
5.5 Dust - Limiting Oxygen Concentration (LOC)

5.5.1 Test Conditions

Procedure		=	**Dust: LOC**
Ignition source		=	Chemical igniters
Ignition energy	IE	=	**2 x 1 kJ**
Ignition delay time	tv	=	60 ms

5.5.2 Test Method

In general, nitrogen is used as an inert gas, therefore the following test conditions are based on nitrogen only. The required nitrogen/air mixtures can be produced easily with the partial - pressure procedure. Prior to the tests it is recommended to check the composition of these nitrogen/air mixtures with suitable instruments.



After the first test series in normal air (O_2 = 20.8% V/V), a second series will be done at e.g. 10% O_2 in N_2 over a wide range of dust concentrations.

If the tests are positive, a possible value of the limiting oxygen concentration can be estimated by extrapolation of the two Kmax-values to 0 m·bar/s. At this extrapolated value the explosion tests will be continued over a wide range of dust concentrations. If positive tests are observed they have to be repeated at a 1% V/V lower value of O_2 in N_2. If negative tests are observed, they have to be repeated at a 1% V/V higher value of O_2 in N_2

In this manner further tests have to be done until dust explosions are no longer possible. To establish no ignition, there must be at least **three** tries with the same dust concentration..

5.5.3 Test Evaluation (IE = 2 x 1 kJ)

Pex [bar]	Pm [bar]	Decision:
< 0.5	**< 0.2**	**no** ignition
≥ **0.5**	≥ **0.2**	ignition

The oxygen concentration which will just not allow an explosion of the dust/air/inert gas mixture in **three** ignition tests is stated as the limiting oxygen concentration LOC.

With decreasing oxygen concentration, the optimum dust concentration is shifted to lower values. The tests must therefore also be performed especially in this concentration range:
(e.g. 30, 60 g/m³).

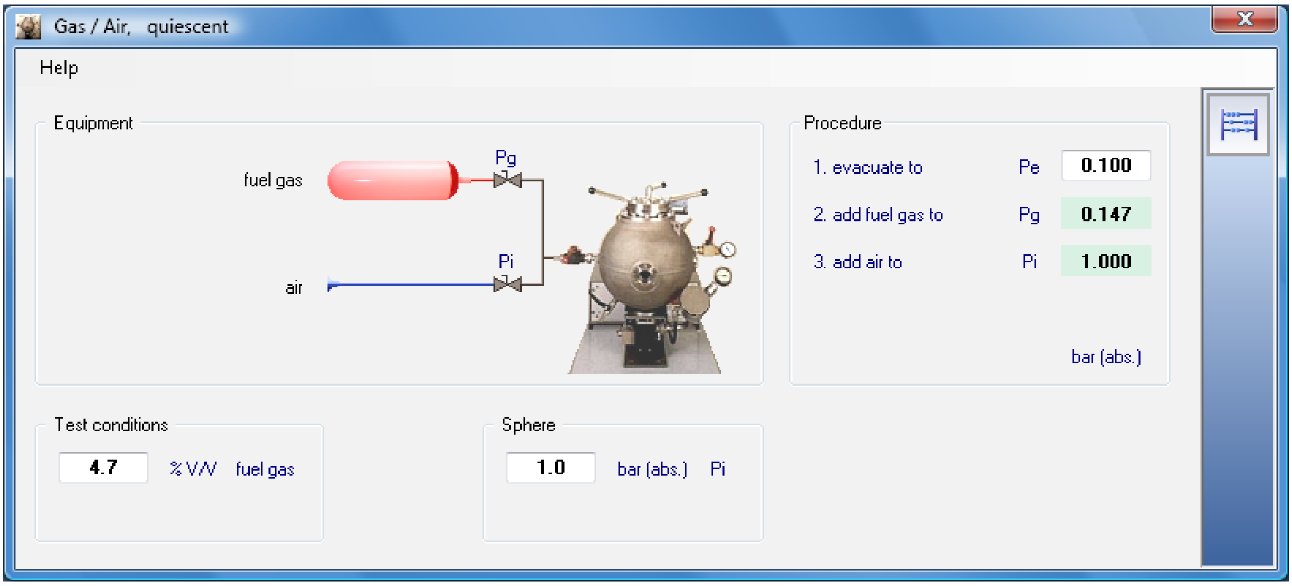
6. Gas and Solvent Vapors (quiescent)

6.1 General rules

It is customary to determine the explosion indices for gas and solvent vapors, if possible, at room temperature and normal pressure, using as an ignition source a permanent spark with an ignition energy of approx. E = 10 J.

The explosion characteristics can be determined either in a quiescent state or under turbulent condition for the gas (vapor)/air mixtures. In the following the condition for the gas/air mixtures will be quiescent and therefore the dust dispersion device has to be removed and the connection sealed.

The required gas-air mixtures can be produced easily with the partial - pressure - procedure. Prior to the tests it is recommended to check the composition of these gas/air mixtures using suitable instruments.



For investigations under quiescent conditions input **tv = 0**. The admixture of the fuels takes place directly in the 20-l-sphere and not through the storage container. Therefore no expansion pressure of the storage container can be measured (Pd = 0 bar). The ignition signal occurs immediately after starting the test. The evaluation of Pd and td will be suppressed.

6.2 Gas - Explosion indices: Pmax, (dP/dt)max, Kmax

6.2.1 Test Conditions

Procedure (procedure)		=	**Gas: Pmax, Kmax, LEL**
Ignition source		=	Permanent Spark
Ignition energy	IE	=	10 J
Ignition delay time	tv	=	0 ms
Dispersion pressure	Pz	=	0 bar (1 bar absolute, no pre-evacuation)

6.2.2 Test Method

In a first test series, the maximum explosion pressure and the maximum rate of pressure rise are determined over a wide range of concentrations. Starting with a gas concentration greater than the LEL, the concentration is either increased or decreased in steps of at most 1% V/V , until the maximum values for the explosion pressure and the rate of pressure rise have clearly been covered.

After the first test series, the concentration range close to the observed maxima (Pmax, Kmax) is twice checked, i.e. the tests are repeated at the optimum concentration, the next higher and the next lower concentration. An example:
(Assuming, the maxima of Pm and (dP/dt) are at 4.5% V/V)

1. series:	2.0,	3.0,	3.5,	4.0,	4.5,	5.0,	5.5 % V/V
2. series:				4.0,	4.5,	5.0	
3. series:				4.0,	4.5,	5.0	

6.2.3 Test Evaluation

The explosion indices Pmax and (dP/dt)max are defined as the mean values of the maximum values of each series (total **3 series**).
Subsequently, the explosion index Kmax is calculated from the above (dP/dt)max.

Pm [series n] = maximum value of each series
Pmax = (Pm [series 1] + Pm [series 2] + Pm [series 3]) / 3

(dP/dt)m [series n] = maximum value of each series
(dP/dt)max = (dP/dt [series 1] + dP/dt [series 2] + dP/dt [series 3]) / 3
Kmax = 0.27144 x (dP/dt)max

6.3 Gas - Lower Explosion Limit (LEL)

6.3.1 Test Conditions

Procedure		=	**Gas: Pmax, Kmax, LEL**
Ignition source		=	Permanent Spark
Ignition energy	IE	=	10 J
Ignition delay time	tv	=	0 ms
Dispersion pressure	Pz	=	0 bar (1 bar absolute, no pre-evacuation)

6.3.2 Test Method

The 20-l-sphere has to be cleaned thoroughly before each test. A test series is initiated, starting with gas concentrations of an integral multiple of 0.25% V/V for example 2 or 3% V/V.
The series is continued with a systematic increase of the gas concentration until ignition of the gas/air mixture is observed. Repeat the test with a gas concentration 0.25% V/V lower, and continue to reduce the concentration in further tests until a concentration is reached at which no ignition of the gas/air mixture is observed in three successive tests.

For the determination of the **UEL (Upper Explosion Limit)** the LEL-procedure can be used accordingly.

To obtain accurate values for the LEL or UEL, **3** negative tests for each concentration must be observed.

6.3.3 Test Evaluation (IE = 10 J)

Pex [bar]	Pm [bar]	Decision:
< 0.1	**< 0.1**	**no** ignition
≥ **0.1**	≥ **0.1**	ignition

The lower explosion limit LEL as well as the upper explosion limit UEL are reported as those concentrations at which a gas explosion is just not possible in **3** successive tests. If only one test series is carried out (1 negative test), the value for LEL or UEL has to be reported as approximately ... % V/V.

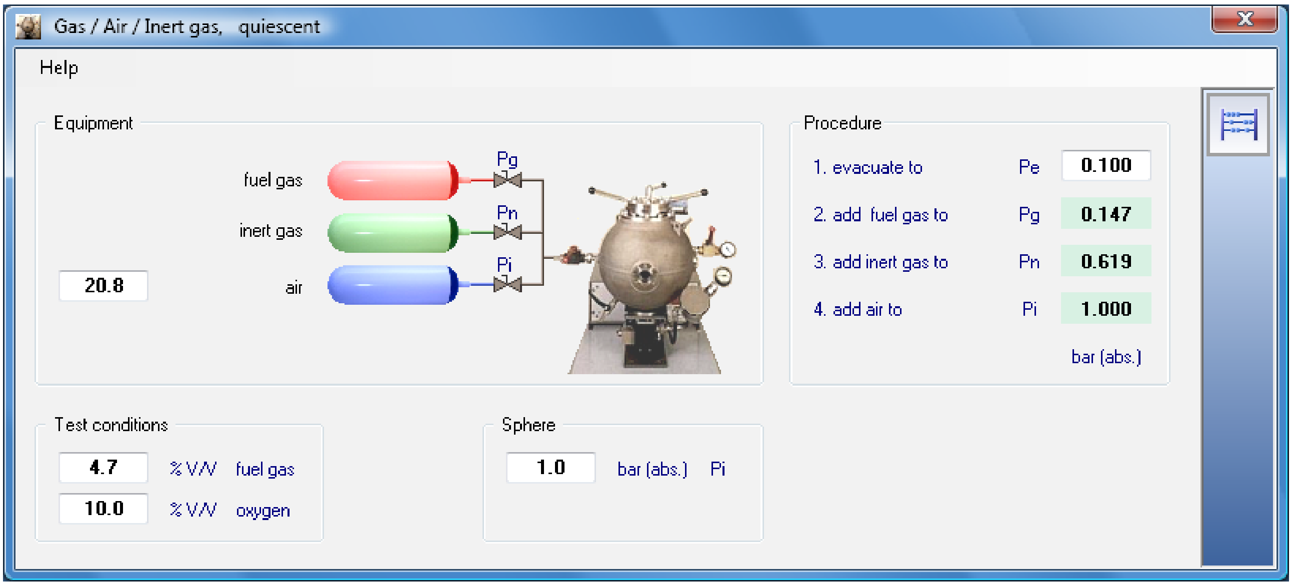
6.4 Gas - Limiting Oxygen Concentration (LOC)

6.4.1 Test Conditions

Procedure		=	**Gas: LOC**
Ignition source		=	Permanent Spark
Ignition energy	IE	=	10 J
Ignition delay time	tv	=	0 ms
Dispersion pressure	Pz	=	0 bar (1 bar absolute, no pre-evacuation)

6.4.2 Test Method

In general, nitrogen is used as an inert gas, therefore the following test conditions are based on nitrogen only. The required nitrogen/air mixtures can be produced easily with the partial - pressure procedure. Prior to the tests it is recommended to check the composition of these nitrogen/air mixtures with suitable instruments.



After the first test series in normal air (O_2 = 20.8% V/V), a second series will be done at about 17% O_2 in N_2 over a wide range of gas concentrations. Then the tests have to be continued by systematic reduction of the oxygen concentration in nitrogen until gas explosions are no longer possible. To establish no ignition, there must be at least **3** tries with the same gas concentration.

6.4.3 Test Evaluation (IE = 10 J)

Pex [bar]	Pm [bar]	Decision:
< 0.1	**< 0.1**	**no** ignition
≥ 0.1	**≥ 0.1**	ignition

The oxygen concentration which will just not allow an explosion of the gas/air/inert gas mixture in **3** consecutive tests is stated as the limiting oxygen concentration LOC and is suitable for practical application.

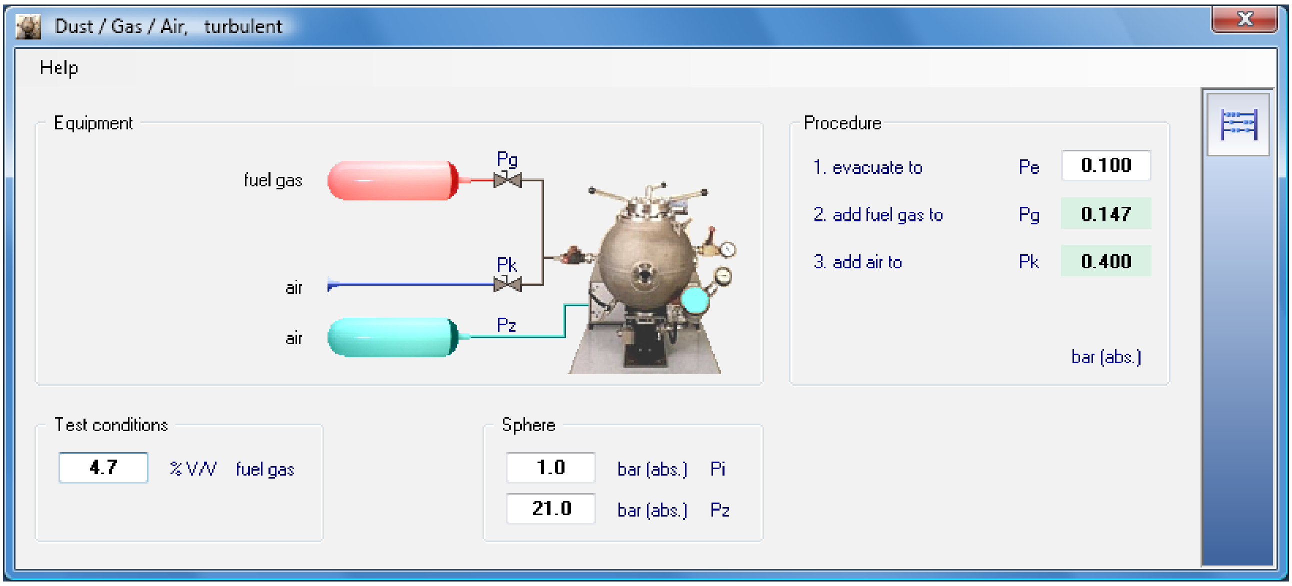
7. Hybrid Mixtures

For the preparation of the hybrid mixtures propane is chosen as the prototype for flammable solvent vapors and is added stepwise to the combustible atmosphere.

7.1 Explosion indices: Pmax, (dP/dt)max, Kmax

7.1.1 Test Conditions

Procedure (procedure)		=	**Hybrid: Pmax, Kmax**
Ignition source		=	Chemical igniters
Ignition energy	IE	=	**2 x 5 kJ**
Ignition delay time	tv	=	60 ms
Dispersion pressure	Pz	=	20 bar (21 bar absolute, pre-evacuation)



7.1.2 Test Method

After the first investigation in normal air (see: 5.2 Dust - Explosion indices), the tests will be repeated after adding of a certain amount of flammable gas into the normal air. The tests are done over a wide range of concentration until the maximum values of the hybrid mixtures are clearly receding. Afterwards, two further test series, as described above, have to be carried out.

For these tests the gas concentration most important for the judgment of the safety situation has to be chosen. Without that it is recommended to carry out the tests over a wide range of gas concentrations. By this test procedure the optimum values of the hybrid mixtures can be obtained.

7.1.3 Test Evaluation

The Kmax values of the hybrid mixtures occur at the stoichiometric gas concentrations of the flammable gas (Kmax-value). For propane this concentration is approximately 4.25 - 4.5% V/V

8. References

VDI-GL 2263	Staubbrände und Staubexplosionen, Gefahrenbeurteilung und Schutzmassnahmen, Beuth-Verlag GmbH, Berlin und Köln, 1986
W. Bartknecht	Dust Explosions; Course, Prevention, Protection Springer Verlag, Berlin, Heidelberg, New York 1989
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