

## EXIS = EXploding wire Ignition System

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## 1. Concept

### 1.1 Background

Fifty years ago, back when the company was still known as “Kühner AG,” an ignition source based on the “exploding fused wire” principle was developed during the design of the 20-liter sphere. Insufficient attention was paid to the propagation of the ignition spark through an inductor. The shock wave from the exploding wire and its plasma blew the powder away rather than igniting it. The results were unsatisfactory. Dr. Wolfgang Bartknecht decided at the time to opt for the proven pyrotechnic igniters from Sobbe, and the “exploding wire” project was shelved.

Our 20-liter sphere is now widely used worldwide, but importing pyrotechnic igniters from Sobbe or Simex is becoming increasingly difficult. We even have customers who, as a result, have to manufacture the pyrotechnic igniters themselves. This is an increasingly unsatisfactory situation.

It is time for a renaissance of the “exploding fusible wire” as an ignition source. Of the new publications on this topic, the following are particularly recommended:

**[1] Validation of the New Ignition Source “Exploding Wire” for Dust Explosion Testing in the 20-L-Sphere**

Arne Krietsch, Yolada Kwangvitayanon, Martin Schmidt, Alexander Klippel, and Volkmar Schröder, Federal Institute for Materials Research and Testing (BAM), Department 2 “Chemical Safety Engineering”, D-12200 Berlin, Germany

**Dr. Marc Scheid**, Syngenta Crop Protection, Münchwilen AG, CH-4333 Münchwilen, Switzerland  
SYMPOSIUM SERIES NO. 159 HAZARDS 24 © IChemE

**[2] Comparative study on standardized ignition sources used for explosion testing**

**Dr. Stefan Spitzer**, Enis Askar, Arne Krietsch & Volkmar Schröder  
Federal Institute for Materials Research and Testing, Berlin, Germany

**[3] Influence of the ignition source on safety characteristics of hybrid dust-gas mixtures**

Dissertation for the degree of Doctor of Engineering (Dr.-Ing.)  
by M.Eng. **Stefan H. Spitzer**, Otto von Guericke University Magdeburg

## 1.2 EXIS - Principle

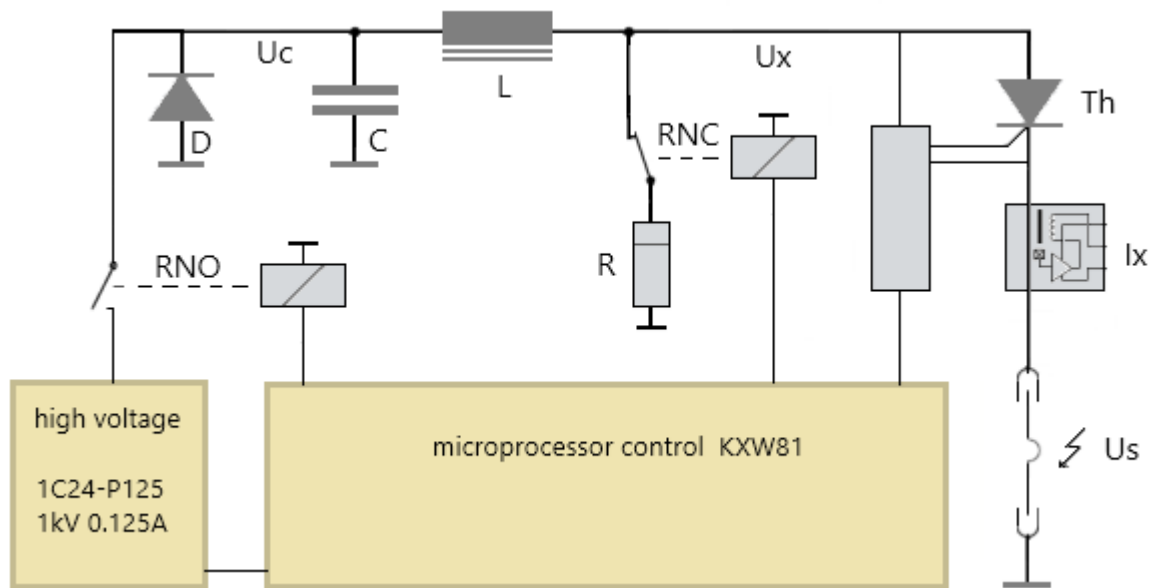


Fig. 1.2.1 Schematic

<b>C</b>	Capacitor	<b>5.05 mF</b>
<b>L</b>	Inductance	<b>1 mH at 1900 A</b>
<b>U<sub>c</sub></b>	Charging voltage	<b>995 V</b>
<b>E</b>	Energy	<b>2.5 kJ = 0.5 * 5.05 mF * 995<sup>2</sup></b>

### Start conditions:

- The safety switch on the sphere is closed.
- The fuse wire is connected (low test current).

### If the start conditions are met, the sequence is as follows:

- Safety relay RNC opens and relay RNO closes.
- Capacitor C is charged to U<sub>c</sub> according to the desired energy.
- Once everything is ready, the automatic test sequence can be started.

### Termination and immediate return to a safe state due to:

- The safety switch on the sphere is open.
- Abort command in the software.
- Power switch or power failure.

### Safe state:

- The thyristor Th between the capacitor and the electrodes is high-impedance.
- Safety relay RNC (normally closed) discharges the capacitor.

Capacitor C and inductor L together form a resonant circuit. In the EXIS concept, power diode D handles the current flow for the negative half-wave. This prevents a negative residual charge in the capacitor after the spark ends. All stored energy is used for the spark.

## 1.3 Ignition Sparks

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### 1.3.1 One or Two Spark Gaps?

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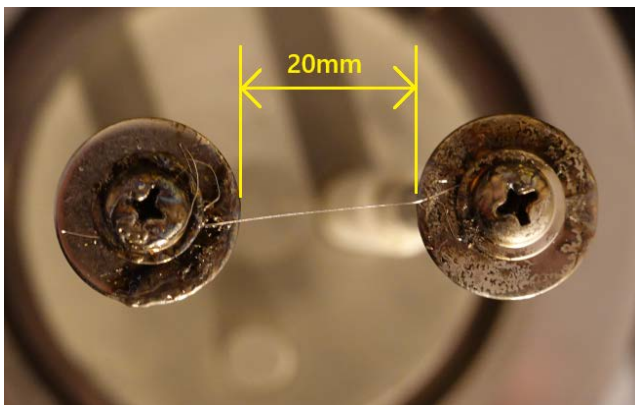
Our device will be the first commercially available device of its kind and will thus set a standard. The first question that arises is: one or two spark gaps?

Scheid and Spitzer used two spark gaps with a voltage of 460 V and a relatively small electrode gap. This is quite complex for the equipment and in operation.

We can assume that a single **spark gap of double the length** would exhibit the same ignition behavior. Double the length means double the voltage across the plasma channel. This is feasible. We will therefore use only **one** spark gap in our project.

### 1.3.2 Spark gap

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Electrode spacing = 40 mm

Body disc Ø 20 mm

→ Spark length = 20 mm

The wire is clamped between the washer and the screw. This is very quick.

Washers and screws are consumables and can be easily replaced as needed.

Figure 1.3.1 Spark gap



Nickel wire 0.12 mm, 99.6% pure Ni200  
on Amazon: 25 m = €5.90



Large washer M5 x 20mm  
on Amazon: 50 pieces = €11.30

The melting point of stainless steel is 1500°C and that of tungsten is 3400°C. That is why Scheid and Spitzer used tungsten electrodes. However, the temperature of the spark plasma is far higher. I learned from Marc Scheid that the wear on the tungsten electrodes was considerable due to sparks of this high energy, and the electrodes often had to be replaced.

That is why we can save on the expensive tungsten parts and use inexpensive stainless steel washers instead.

### 1.3.3 Spark energy

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ASTM uses the following for determining MEC or LOC:

“The recommended ignition source for measuring the MEC/LOC of dusts in 20-L chambers is a 2500J pyrotechnic ignitor.” That is, just one igniter!

EN and ISO use the following for determining the MEC (LEL) or LOC:

2 pyrotechnic igniters, each with 1 kJ = **2 kJ**

It therefore makes sense to offer these two energy levels: **2.5 kJ** and **2 kJ**.

It remains to be seen which of the two values will prevail in the standards.

For the investigation of “ignition energy-dependent dusts,” we are adding the following energies:

**Energy selection:**

E [J]	U[V]
2500	995
2000	890
1000	629
300	345
100	199

Capacitors, inductors, power semiconductors, and safety devices designed for a peak current of 2400 A weigh 22 kg on their own. The total weight of the equipment is approximately 30 kg.

Although spark energies of 5 kJ or 10 kJ are theoretically feasible, an apparatus weighing 60 kg or even 120 kg is unrealistic. The apparatus presented in the publications is lighter, but uses components that are by no means built for the required peak current. For us as a manufacturer of commercial equipment, this is unacceptable.

## 1.4 Simulation / Measurements

- Electrode spacing = **20 mm**
- Capacitor voltage = **995 V**
- Capacitor capacitance = **5.05 mF**
- Energy = **2.5 kJ**

### 1.4.1 Simulation with AutoCAD Spice

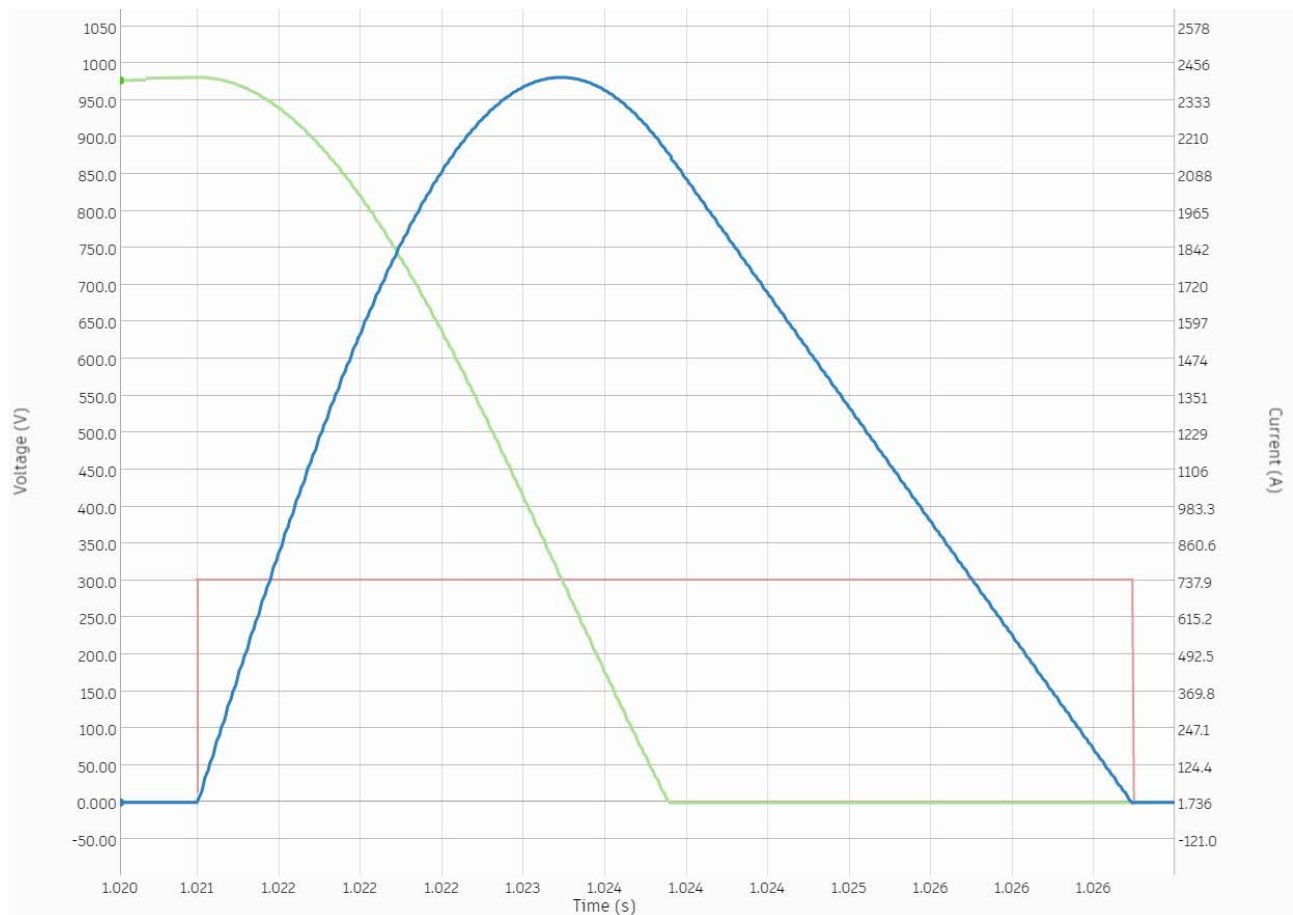


Figure 1.4.1



- Capacitor voltage  $U_c$
- Spark current  $I_x$
- Spark voltage  $U_x$

### 1.4.2 Measurement at 2.5 kJ

- Electrode spacing = **20 mm**
- Capacitor voltage = **995 V**
- Capacitor capacitance = **5.05 mF**
- Energy = **2.5 kJ**



Figure 1.4.2

	Capacitor voltage $U_c$ (100 V/div)
	Spark voltage $U_x$ (100V/div)

- Electrode spacing = **20 mm**
- Capacitor voltage = **995V**
- Capacitor capacitance = **5.05 mF**
- Energy = **2.5 kJ**

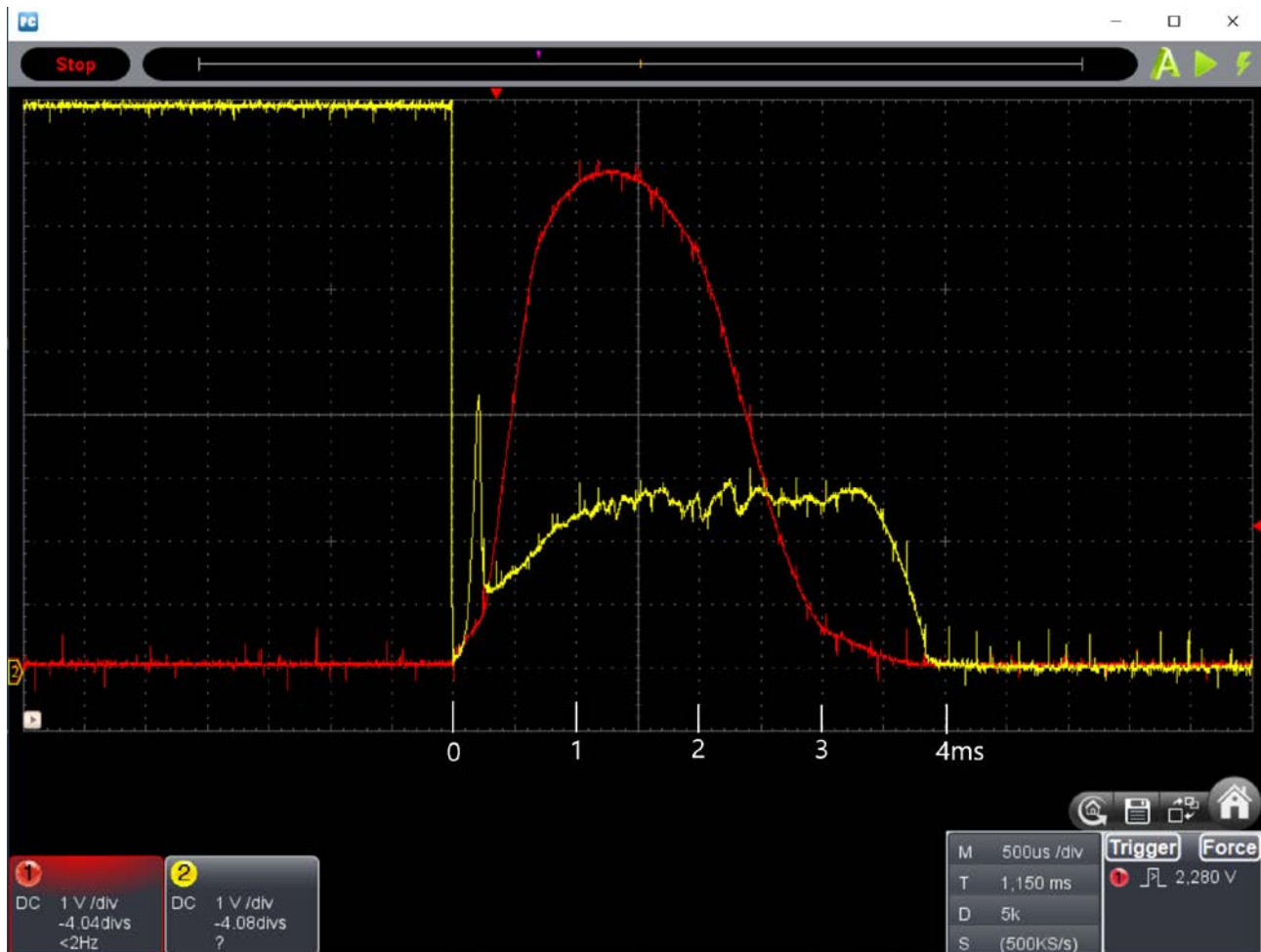


Figure 1.4.3  Spark current  $I_x$  (300A/div) →  **$I_{max} = 2400A$**   
 Spark voltage  $U_x$  (100V/div)

Good agreement between the measurements and the simulation.

The short circuit leading up to the melting of the wire and the subsequent voltage rise are clearly visible.

- Capacitor voltage = **995V**
- Maximum spark current = **2400A**
- Average spark voltage = **250V**
- Spark duration = **4 ms**



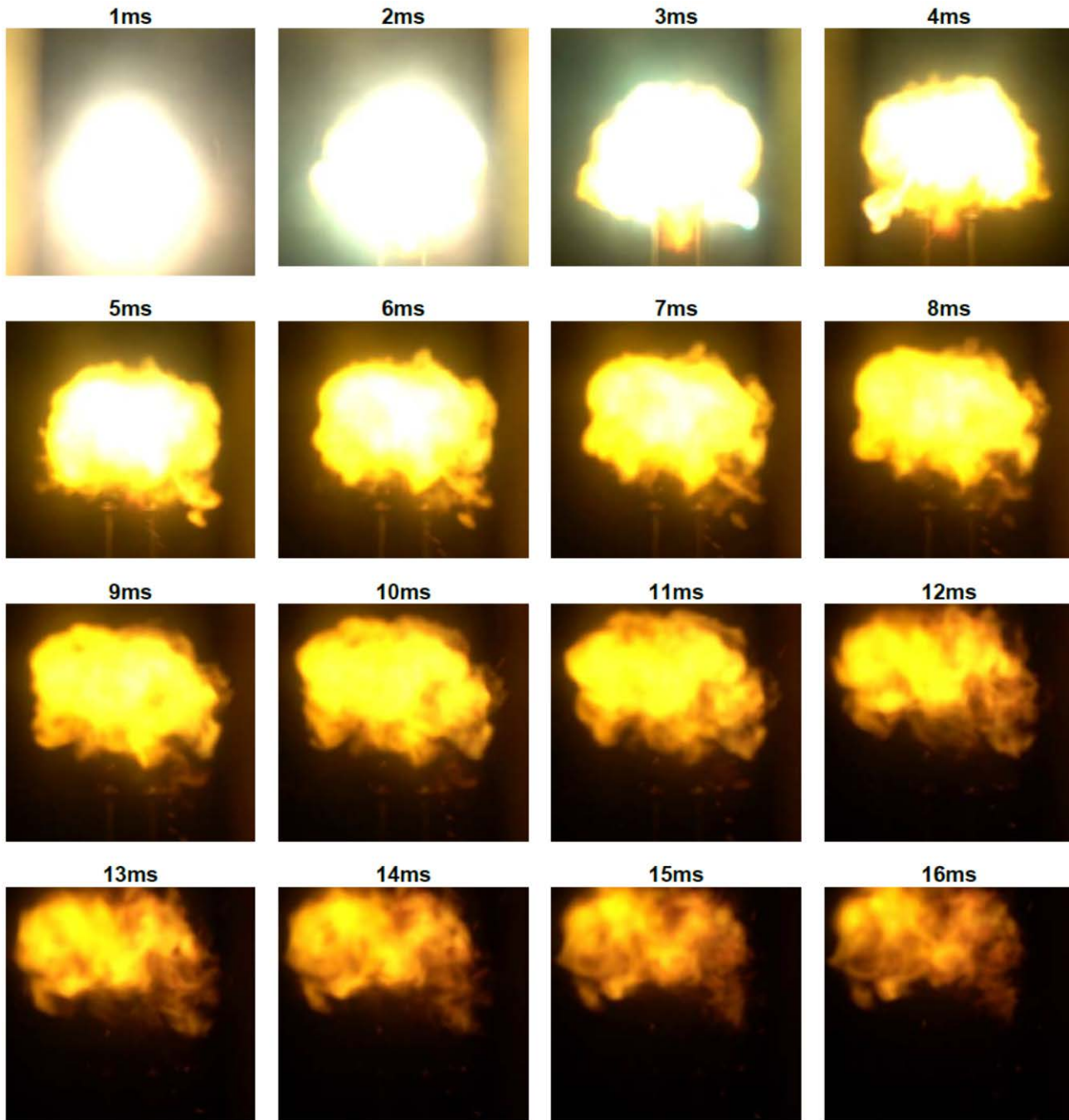
## 1.5 Spark Images

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- SONY RX100 VII camera with a high frame rate of 1 ms/frame
- All images taken outside the sphere
- Spark energy = **2500 J**

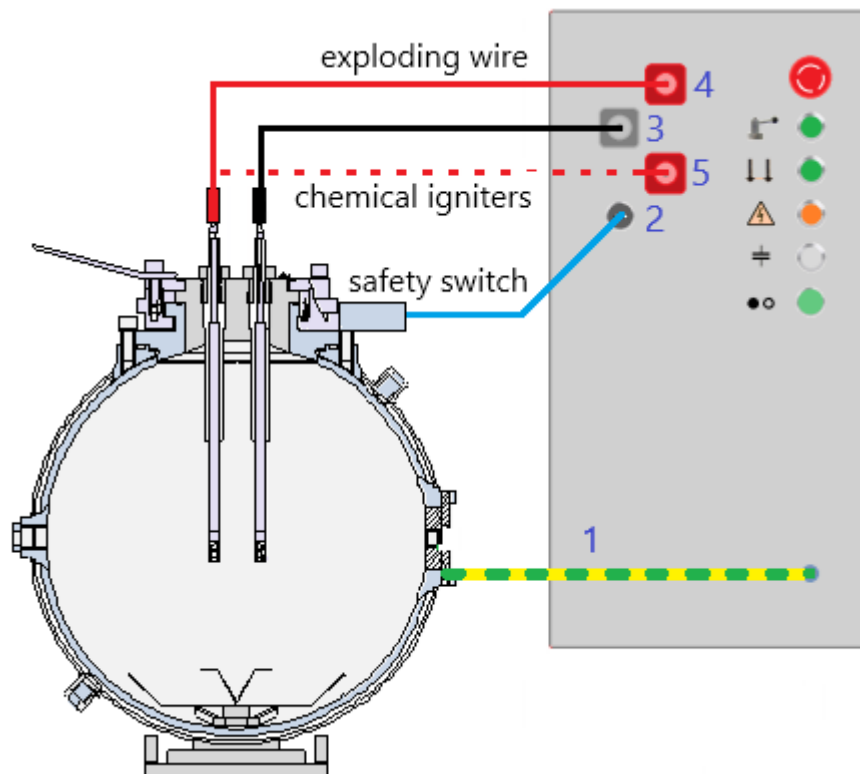
The extreme brightness of the spark was problematic.

It is noteworthy that the energy supply to the spark ceases after 4 ms, yet the spark plasma remains active for quite some time. Compared to pyrotechnic igniters, increasing the inductance and extending the spark duration is not necessary.



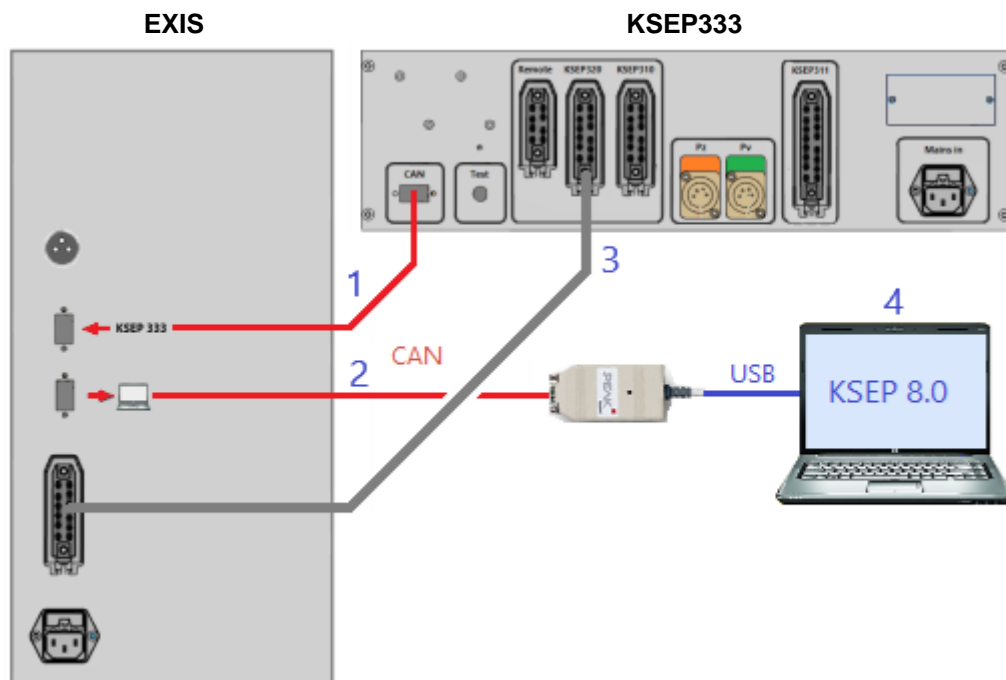
## 2. Installation of EXIS

### 2.1 Connection to the 20L sphere



- 1 Ground connection between the measuring flange and EXIS (reduces interference with the measurement signals)
- 2 The safety switch is connected directly to the EXIS.
- 3 Common ground connection to the electrodes.
- 4 Connection for the exploding wire
- 5 Connection for chemical igniters (EXIS is disabled)

## 2.2 Connection to KSEP333 measurement equipment



With current-generation measurement equipment, the connection is particularly simple:

- 1 CAN bus connection KSEP333 -> EXIS (DSUB 9)
- 2 CAN bus connection EXIS -> CAN adapter (DSUB 9)
- 3 12-pin cable with DIN connector (safety switch and ignition signal)
- 4 PC with Software 8.0 (EXIS operation is integrated)

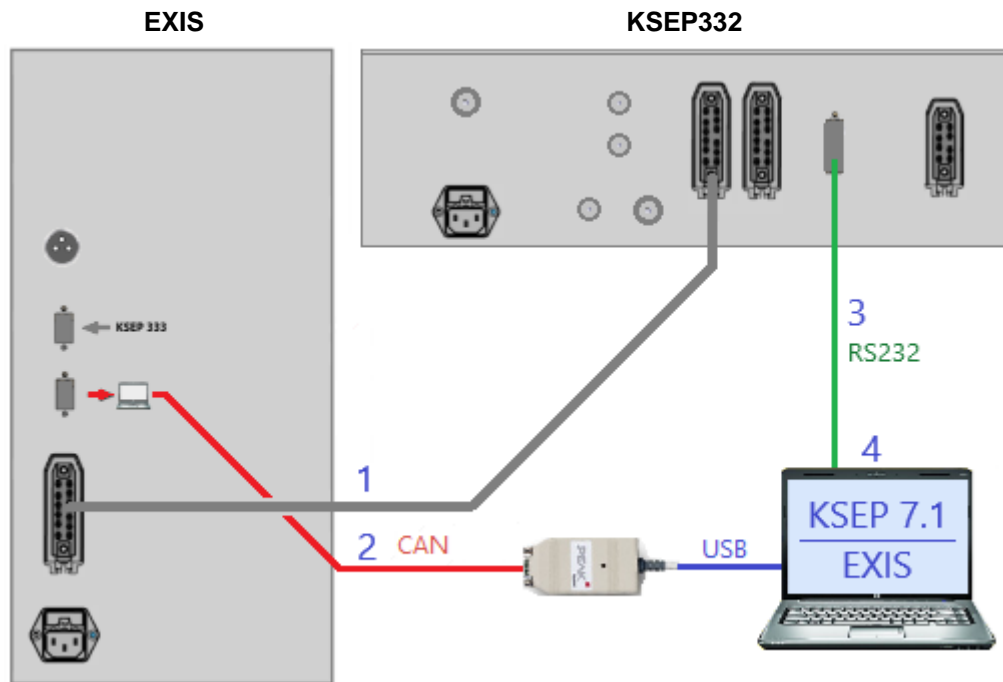


**EXIS** does not support the **KSEP8** program until version 2612. Older versions of KSEP8 must therefore be updated.

See the website [www.cesana-ag.ch](http://www.cesana-ag.ch)

tv [ms]	IE [J]
60	2k
ignition source	EXIS exploding wire

## 2.3 Connection to KSEP332 measurement equipment



Older measurement equipment can also be used with EXIS

- 1 12-pin cable with DIN connector (safety switch and ignition signal)
- 2 CAN bus connection EXIS -> CAN adapter (DSUB 9)
- 3 RS232 connection to PC (DSUB)
- 4 PC with RS232 software KSEP 7.1 and CAN software EXIS (running simultaneously)



In addition to the **KSEP 7.1** program, the **EXIS** program is required for selecting the ignition energy.

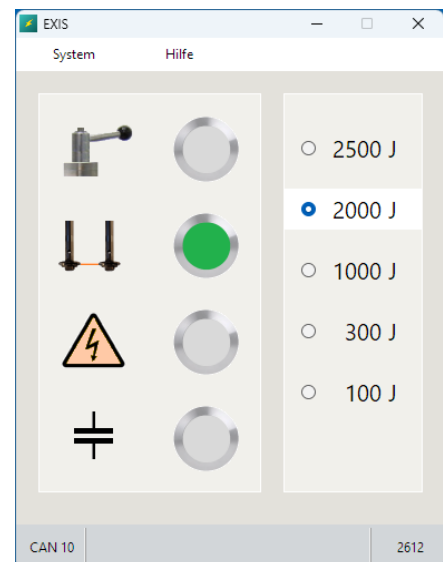
Requirements:

Microsoft Windows 7–11 (32/64-bit)

The **EXIS\_setup.msi** installer is available on the website [www.cesana-ag.ch](http://www.cesana-ag.ch)

The installation is multilingual and largely self-explanatory.

Both programs can be run simultaneously on the same PC.



### 3. Operation



Emergency stop switch, corresponds to the safety switch on the sphere.  
However, it is a latching switch and must be released by turning.  
(Required by law under the Machinery Directive!)

**Green:** The safety switch on the sphere is closed.  
Prerequisite for charging the capacitors.

**Green:** The fuse wire is connected.  
Prerequisite for charging the capacitors.

**Orange:** Capacitor voltage > 12V  
Additional safety information in case of a fault.

**Green, flashing:** Capacitors are charging.

**Green, steady:** Fully charged and ready to spark.

Power switch for the EXIS power supply.  
(Turned off when using chemical igniters.)

#### Start conditions:

- c) Emergency stop switch released.
- d) Safety switch on the sphere is closed.
- e) The fusible wire must be connected (low test current).

#### If the start conditions are met, the sequence is as follows:

- d) Capacitors are charged according to the desired energy.
- e) At the same time, the sphere is evacuated and the prechamber is filled.
- f) Once everything is ready, the automatic test sequence can be started.

#### Termination and immediate return to a safe state by:

- d) Activating the emergency stop switch.
- e) The safety switch on the sphere is open.
- f) Abort command in the software.
- g) Power switch or power failure.

#### Safe state:

- c) The thyristor between the capacitors and electrodes has high resistance.
- d) A normally closed (NC) contactor quickly discharges the capacitors.

### 3.1 Test conditions

#### 3.1.1 KSEP333 measurement equipment

##### KSEP 8.0 software

Dust: Pmax, Kmax

Series	g/m <sup>3</sup>	g/20L	tv [ms]	IE [J]	ignition source
1	250	5.0	60	2k	EXIS exploding wire

EXIS is a component of the KSEP-system and is connected to it via CAN bus.

The set spark energy is automatically transmitted to EXIS.

The charge status of the capacitors is displayed.

The test sequence can only be started after they are fully charged.

#### 3.1.2 KSEP332 measurement equipment

##### KSEP 7.1 software

IE [J]	ignition source
2k	EXIS exploding wire

The spark energy must be set by the user in the KSEP 7.1 and EXIS software.

The test sequence may only be started after the capacitors have fully charged.

##### EXIS software

System Hilfe

Energy Level	Status
2500 J	<input type="radio"/>
2000 J	<input checked="" type="radio"/>
1000 J	<input type="radio"/>
300 J	<input type="radio"/>
100 J	<input type="radio"/>

CAN 8 2612

### 3.2 Pressure curve: Evaluation

#### 3.2.1 Correction of the explosion pressure at $P_{ex} > 5.5$ bar

Due to the less favorable surface-to-volume ratio in the 20-liter apparatus, the explosion pressure is slightly lower than in the 1m<sup>3</sup> standard vessel. This is caused by cooling effects. A comparison of pressure/time records also shows a significantly steeper pressure drop after the maximum value in the 20-L apparatus than in the 1m<sup>3</sup> standard vessel. The correction is performed according to the following equation:

$$P_m = 0.775 \cdot P_{ex}^{1.15}$$

With this correction, the pressure  $P_m$  in the 20-liter apparatus corresponds to that of the 1m<sup>3</sup> standard vessel. The ignition source has no influence on this correction

#### 3.2.2 Correction of the explosion pressure for $P_{ex} < 5.5$ bar

Below 5.5 bar, due to the small vessel volume, the pressure exerted by the ignition source must be taken into account. As  $P_{ex}$  increases, the influence of the ignition source is overshadowed by the pressure exerted by the explosion itself. This correction is calculated as follows:

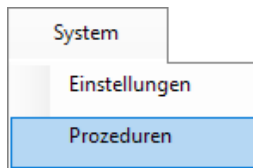
$$P_m = 5.5 \cdot (P_{ex} - P_{ci}) / (5.5 - P_{ci}) \text{ bar}$$

Chemical ignitors	$P_{ci} = 1.6 \text{ bar} \cdot IE / 10,000$	IE [J]	$P_{ci}$ [bar]
		10,000	1.60
		2,500	0.40
		2,000	0.32
EXIS	$P_{ci} = 0.16 \text{ bar} \cdot IE / 2,500$	IE [J]	$P_{ci}$ [bar]
		2,500	0.160
		2,000	0.128
		1,000	0.064
		300	0.019
		100	0.006

#### 3.2.3 Decision "Ignition / No Ignition"

Lower explosion limit (LEL or MEC)		EN 14034-3	ASTM E1515
Limiting oxygen concentration (LOC)		EN 14034-4	ASTM E2931
Ignition energy IE =		2,000 J	2,500 J
Chemical igniters	no Ignition	$P_{ex} < 0.5 \text{ bar}$	$P_m < 0.2 \text{ bar}$
(according to standards)	Ignition	$P_{ex} \geq 0.5 \text{ bar}$	$P_m \geq 0.2 \text{ bar}$
EXIS (suggestion)	no Ignition	$P_{ex} < 0.3 \text{ bar}$	$P_m < 0.1 \text{ bar}$
	Ignition	$P_{ex} \geq 0.3 \text{ bar}$	$P_m \geq 0.1 \text{ bar}$

### 3.3 Procedures



If you primarily use EXIS as the ignition source, it is recommended to set the “Procedures” to this ignition source. This significantly simplifies working with the equipment.

The screenshot shows the EXIS software interface with the following settings highlighted by red boxes:

- File Selection:** ☒ for a new KSEP file
- Procedure:** 2 Dust: Lower explosion limit
- Ignition Source:** EXIS exploding wire, IE [J]: 2k, tv [ms]: 60
- Fuel:** Dust
- Criterion:** no ignition, Pex [bar]: 0.30, Pm [bar]: 0.10
- Calculate:** ☒ LEL
- Graphs:** Pm and dP/dt plots showing concentration vs. pressure/pressure rate.
- Test Options:** mean, maximum, interpolate, linear



Recommendation: Generally set an ignition energy of **2 kJ** for EXIS. This complies with EN and ISO standards for determining the LEL and LOC.

**Current** KSEP file The test parameters of the **current** file are displayed and can be adjusted. Changes are transferred directly to the file.

**New** KSEP file These are the general test parameters. These parameters are automatically applied for each **new** test.



### 3.4 Ignition Type and Ignition Energy

Numerous results measured in the 1m<sup>3</sup>-vessel and in the 20-liter apparatus showed that dusts can be divided into two groups based on the influence of the ignition type and ignition energy on the explosion parameters.

#### 3.4.1 Ignition energy-independent dusts

As shown in Figure 3.4.1, the measured explosion parameters are, within the limits of measurement accuracy, independent of the ignition type and ignition energy used.

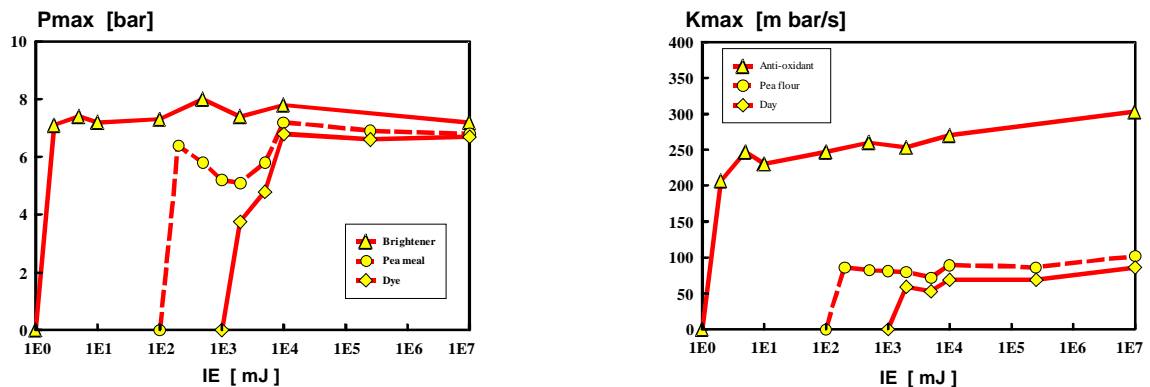


Figure 3.4.1: Definition of energy-independent dusts

It follows that the type of ignition used is irrelevant to the explosion process of these energy-independent dusts. Weak sparks or very powerful chemical igniters produce the same results.

#### 3.4.2 Ignition energy-dependent dusts

For these dusts, a decrease in ignition energy results in a reduction in the characteristic values.

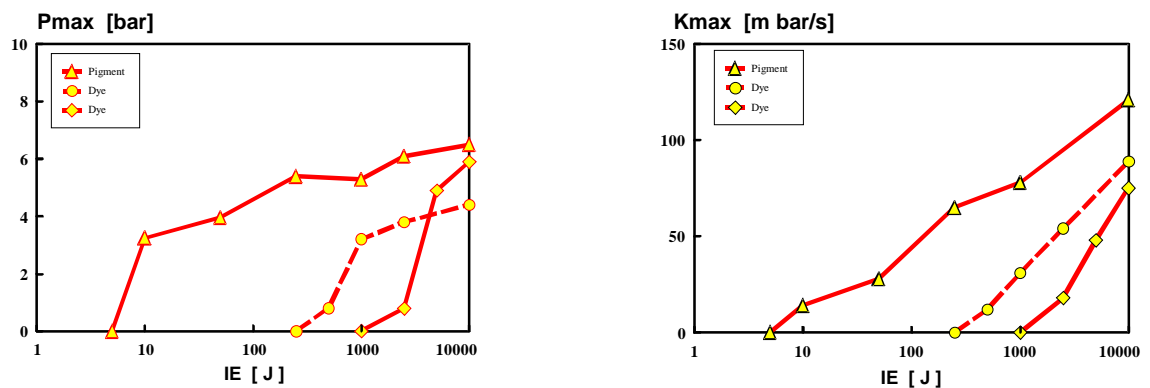
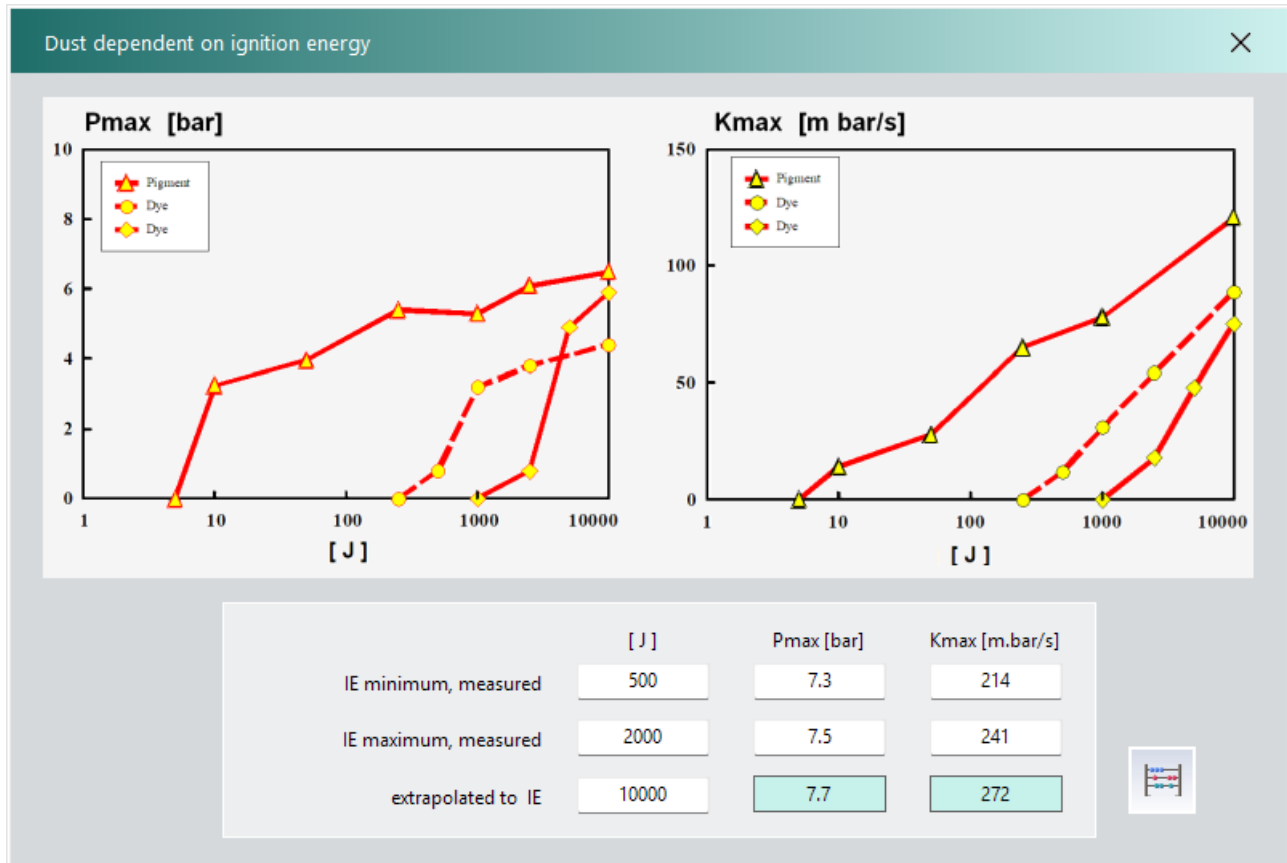


Figure 3.4.2: Definition of **energy-dependent** dusts

### 3.4.3 Extrapolation for ignition energy-dependent dusts

According to the standard, the safety assessment of production facilities is based on the characteristic values determined at 10,000 J ( $2 \times 5$  kJ). In principle, measured values determined at lower ignition energies can be extrapolated to an ignition energy of 10,000 J. This estimation is included in the EXIS program:



Example: The characteristic values for the “ignition energy-dependent dust” SYLOBLOC 250H were measured at 2000 J and 500 J and entered into the table.

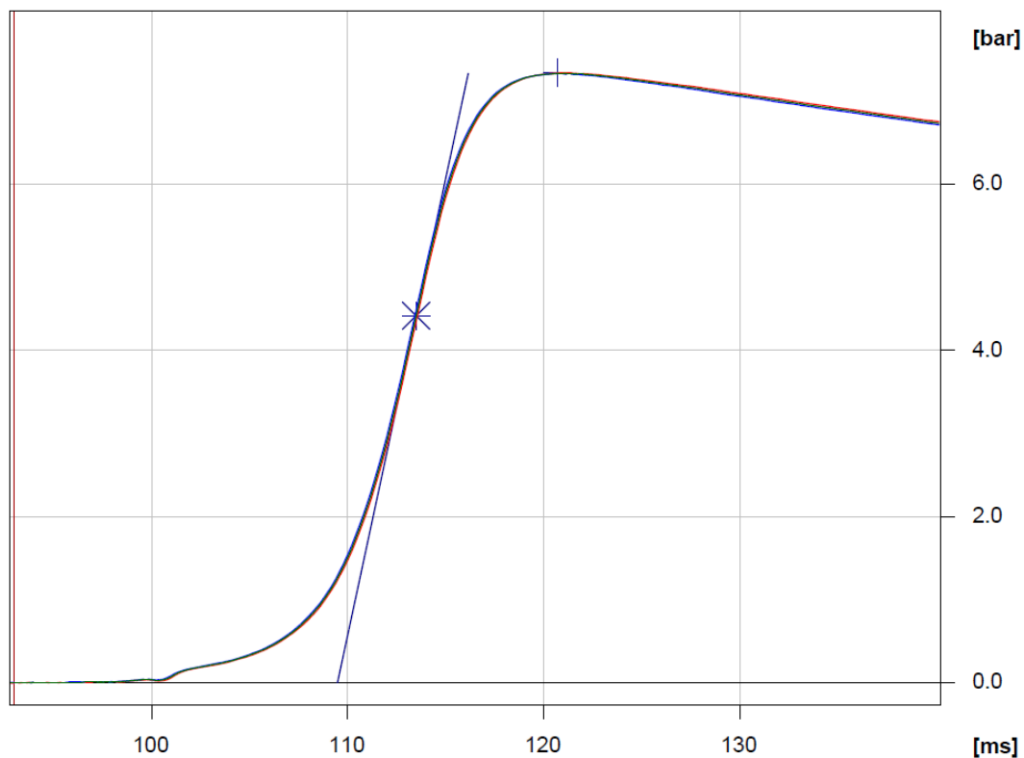
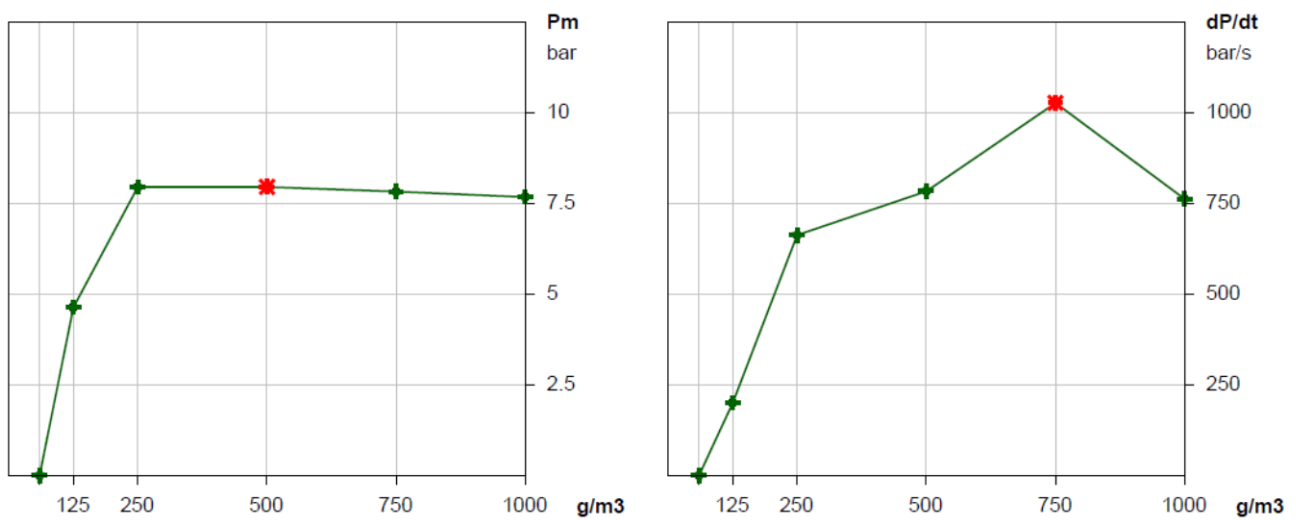
## 4. EXIS - Technology

### 4.1 Comparative Tests

#### 4.1.1 EXIS 2kJ - Niacin CaRo25

##### Dust: Pmax, Kmax

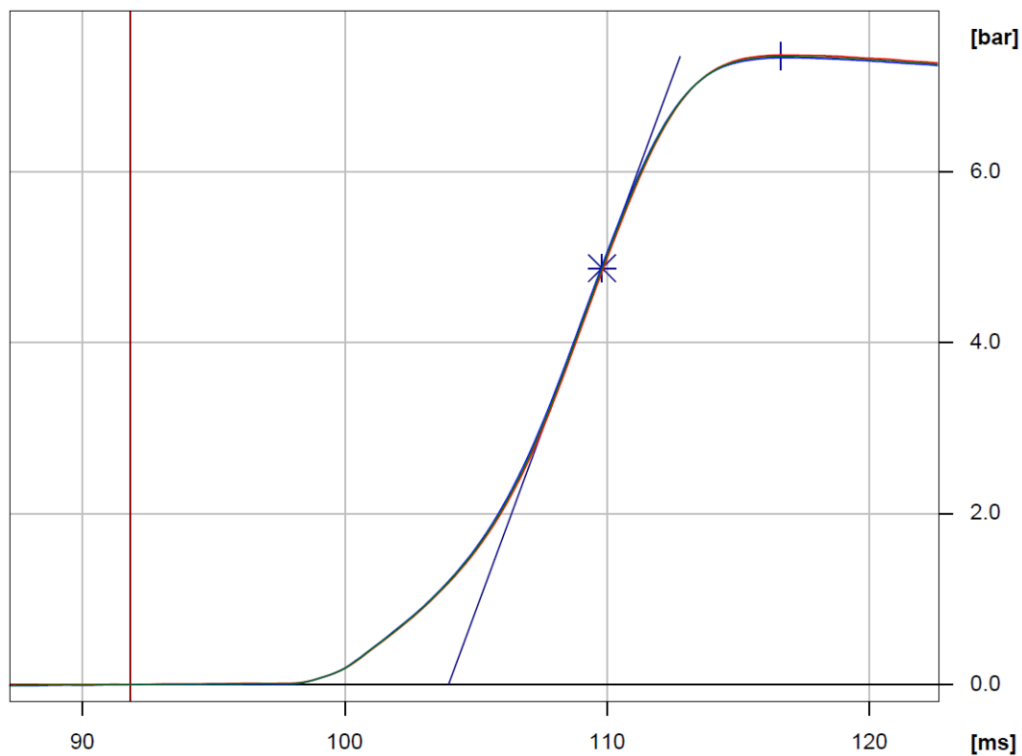
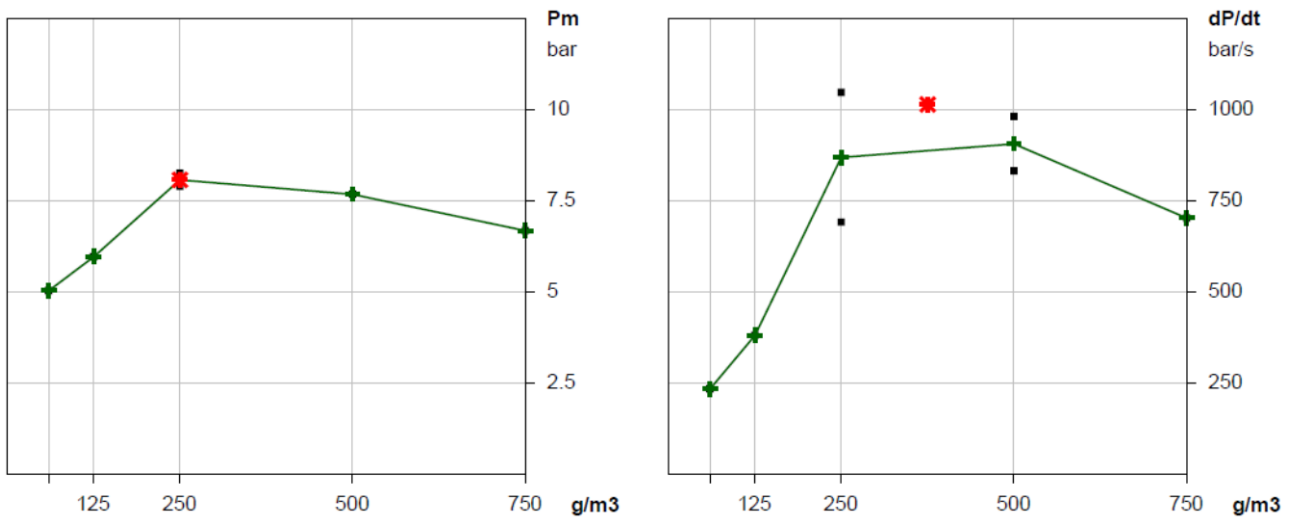
max. explosion pressure	Pmax	=	8.0 bar	± 10%
max. rate of pressure rise	(dP/dt)max	=	1028 bar/s	± 10%
Product specific constant	Kmax	=	279 m·bar/s	± 10%
min. duration of combustion	t1 min	=	26 ms	



#### 4.1.2 SOBBE 2 x 5 kJ - SYLOBLOC 250H

##### Dust: Pmax, Kmax

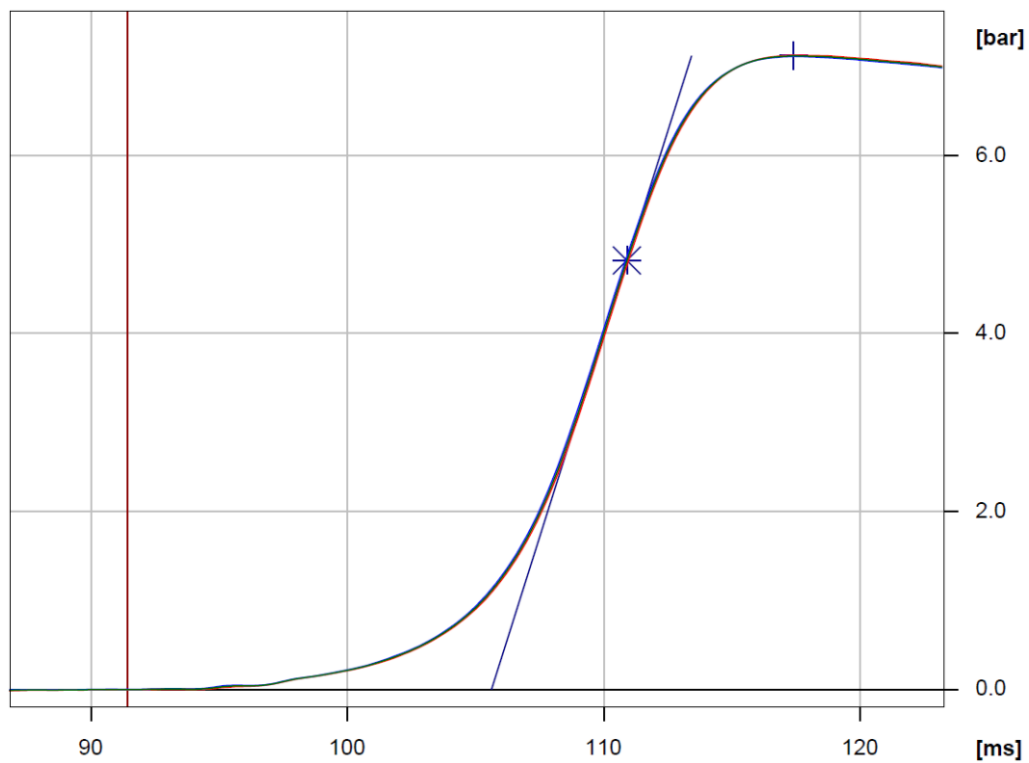
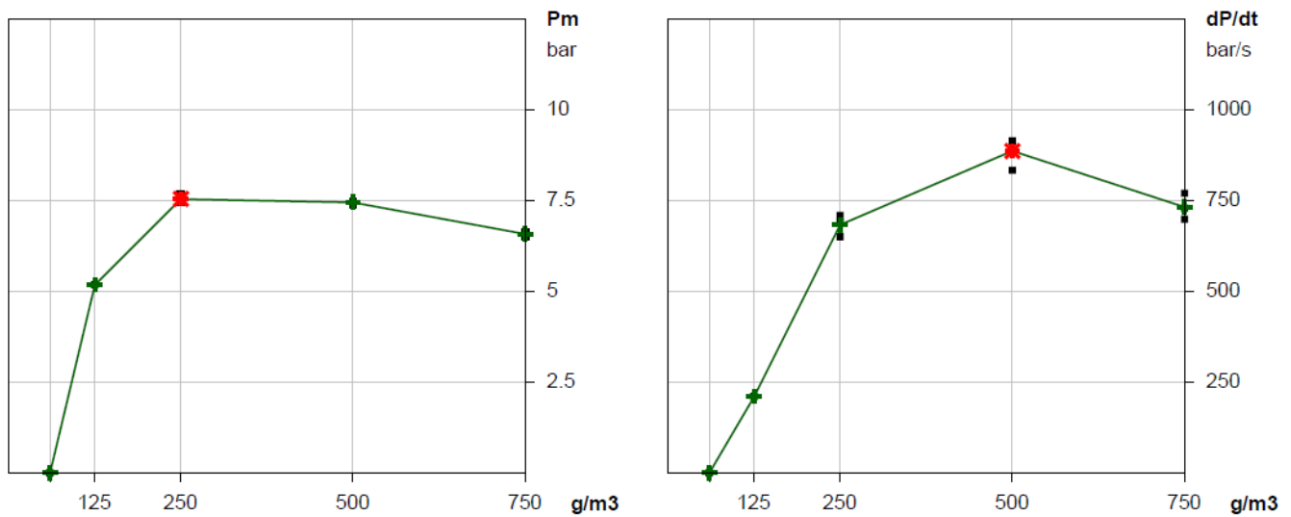
max. explosion pressure	Pmax	=	8.1 bar	± 10%
max. rate of pressure rise	(dP/dt)max	=	1015 bar/s	± 10%
Product specific constant	Kmax	=	275 m·bar/s	± 10%
min. duration of combustion	t1 min	=	23 ms	



#### 4.1.3 EXIS 2kJ - SYLOBLOC 250H, spark gap = 20mm

##### Dust: Pmax, Kmax

max. explosion pressure	Pmax	=	7.5 bar	± 10%
max. rate of pressure rise	(dP/dt)max	=	887 bar/s	± 10%
Product specific constant	Kmax	=	241 m·bar/s	± 10%
min. duration of combustion	t1 min	=	30 ms	



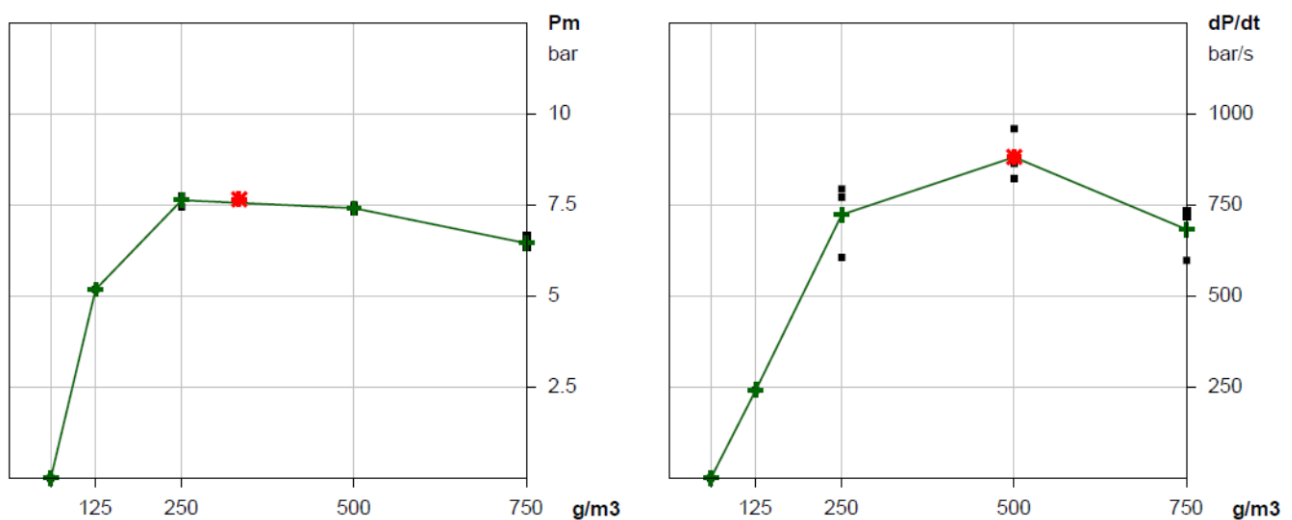
#### 4.1.4 EXIS 2kJ - SYLOBLOC 250H, spark gap = 2 x 20 mm

Repetition of the tests with double the spark gap length:



##### Dust: Pmax, Kmax

max. explosion pressure	Pmax	=	7.7 bar	± 10%
max. rate of pressure rise	(dP/dt)max	=	882 bar/s	± 10%
Product specific constant	Kmax	=	239 m·bar/s	± 10%
min. duration of combustion	t1 min	=	31 ms	

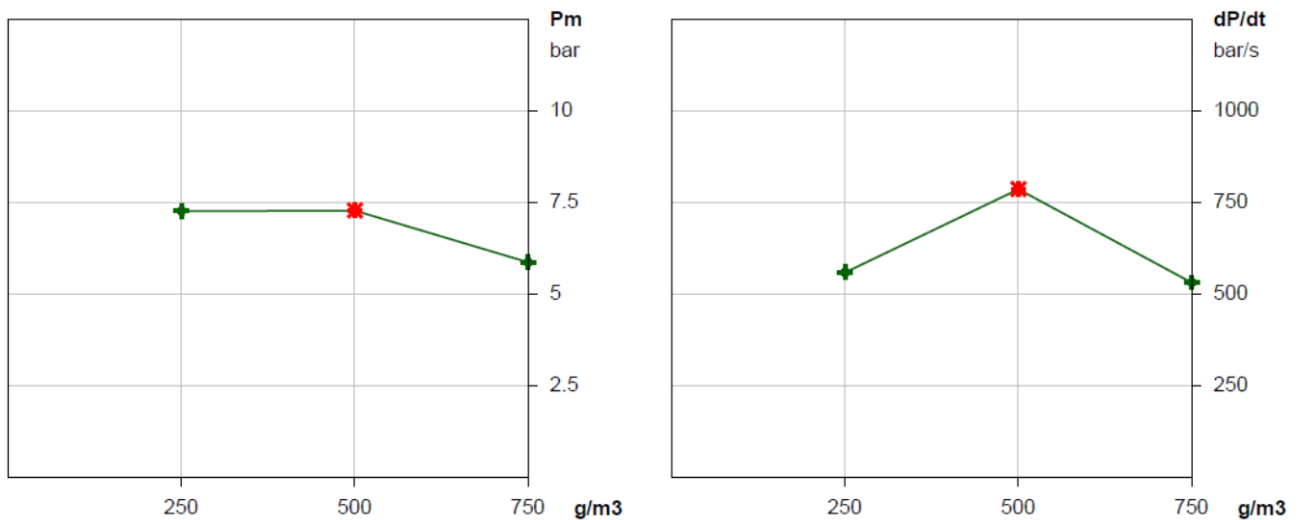


In terms of measurement accuracy, this additional effort did not result in any improvement in the measured values. We will therefore not implement this change in the future.

#### 4.1.5 EXIS 500J - SYLOBLOC 250H, spark gap = 20 mm

##### Dust: Pmax, Kmax

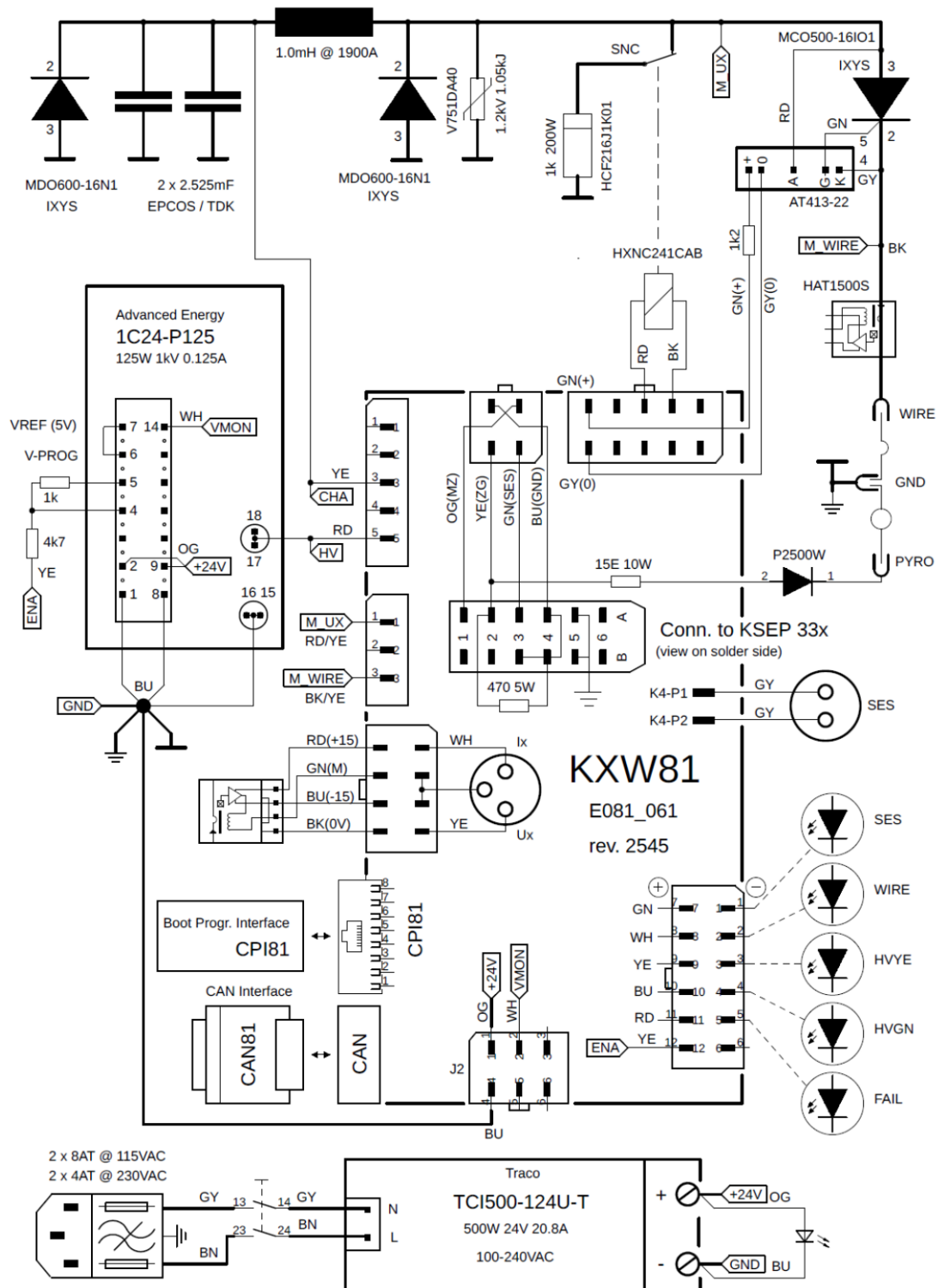
max. explosion pressure	Pmax	=	7.3 bar	± 10%
max. rate of pressure rise	(dP/dt)max	=	787 bar/s	± 10%
Product specific constant	Kmax	=	214 m·bar/s	± 10%
min. duration of combustion	t1 min	=	36 ms	



A significant reduction in the measured values was observed. SYLOBLOC apparently belongs to the rather rare category of “**ignition energy-dependent dusts.**” This is supported by our observations during the determination of the minimum ignition energy. At low energies (e.g., 3 mJ), the ignition behaves like a flame rather than an explosion.

See: 3.4.3 Extrapolation for ignition energy-dependent dusts

## 4.2 Technical Specifications



Power supply: 100–240 VAC, 500 W  
 Dimensions: W x H x D = 220 x 480 x 460 mm  
 Weight: 30 kg