Bundesanstalt für Materialforschung und -prüfung

Sicherheit in Technik und Chemie

01.12.2021

BAM

Hybrid-1

Gas / Dust
Methane / Corn Starch

BAM – Hybrid 1

Main differences between the existing standards

Gas Standards	Dust standards
Ignition source	
Induction spark / Exploding wire	Chemical igniter
One ignition source	Two ignition sources
2 J - 20 J	2 x 1 000 J and 2 x 5 000 J
Mixture preparation	
Quiescent conditions	turbulent conditions
Partial pressure method	Injection of pressurized dust-air-mix

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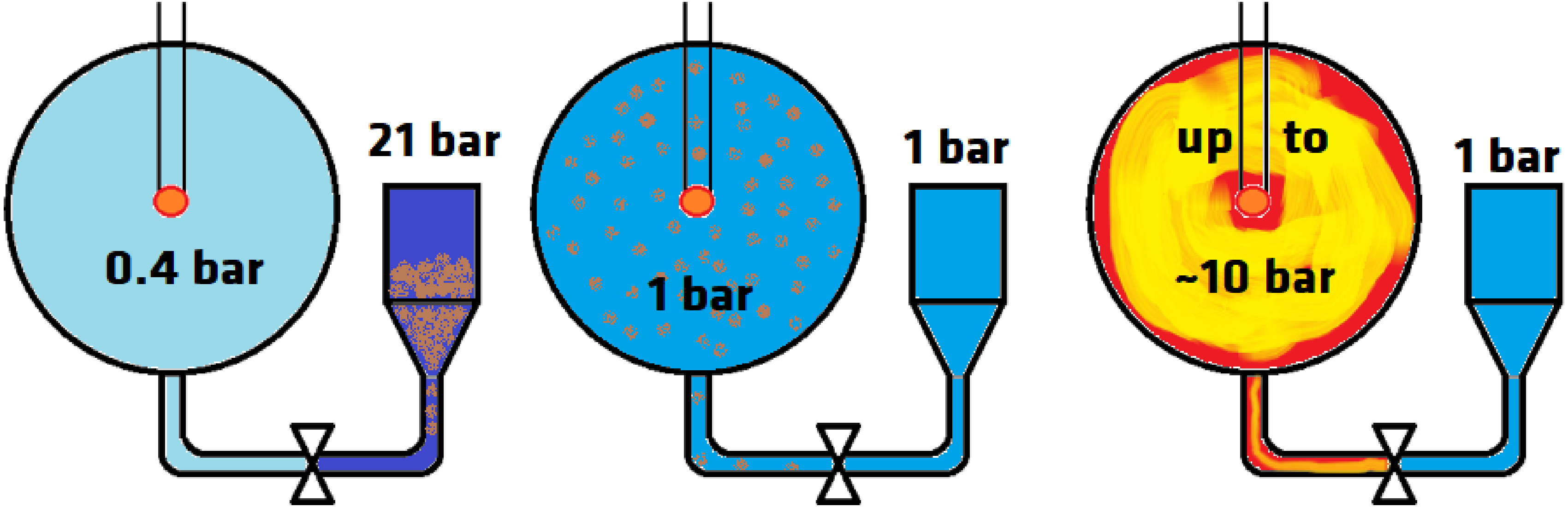
Pre-Ignition Pressure Rise (PIPR or Pd)

Dust standard in brief:



0.94 bar to 1.06 bar is allowed in ASTM 1226
0.9 bar to 1.1 bar is allowed in DIN EN 14034

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Pre-Ignition Pressure Rise (PIPR or Pd)

Dust standard in brief:
0.94 bar to 1.06 bar is allowed in ASTM 1226
0.9 bar to 1.1 bar is allowed in DIN EN 14034

with 0.4 bar at beginning
→ pre-ignition pressure rise of 0.54 bar to 0.66 bar allowed according to ASTM 1226
→ pre-ignition pressure rise of 0.5 bar to 0.7 bar allowed according to DIN EN 14034

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Pre-Ignition Pressure Rise (PIPR or Pd)

Higher PIPR leads to

- higher explosion pressure because of higher initial pressure
- lower burning gas concentration (for hybrid mixtures)
- higher initial temperature due to adiabatic compression
- higher level of turbulence

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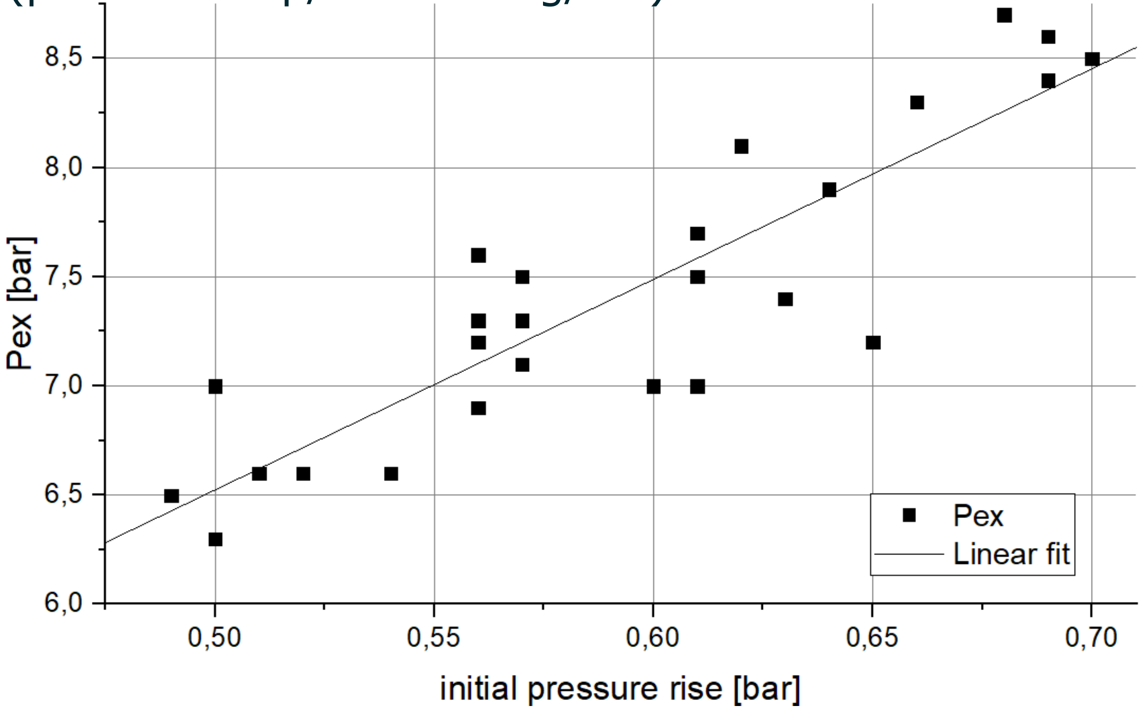
Corn starch 500 g/m³ (pmax and dp/dt at 750 g/m³)



BAM – Hybrid 1

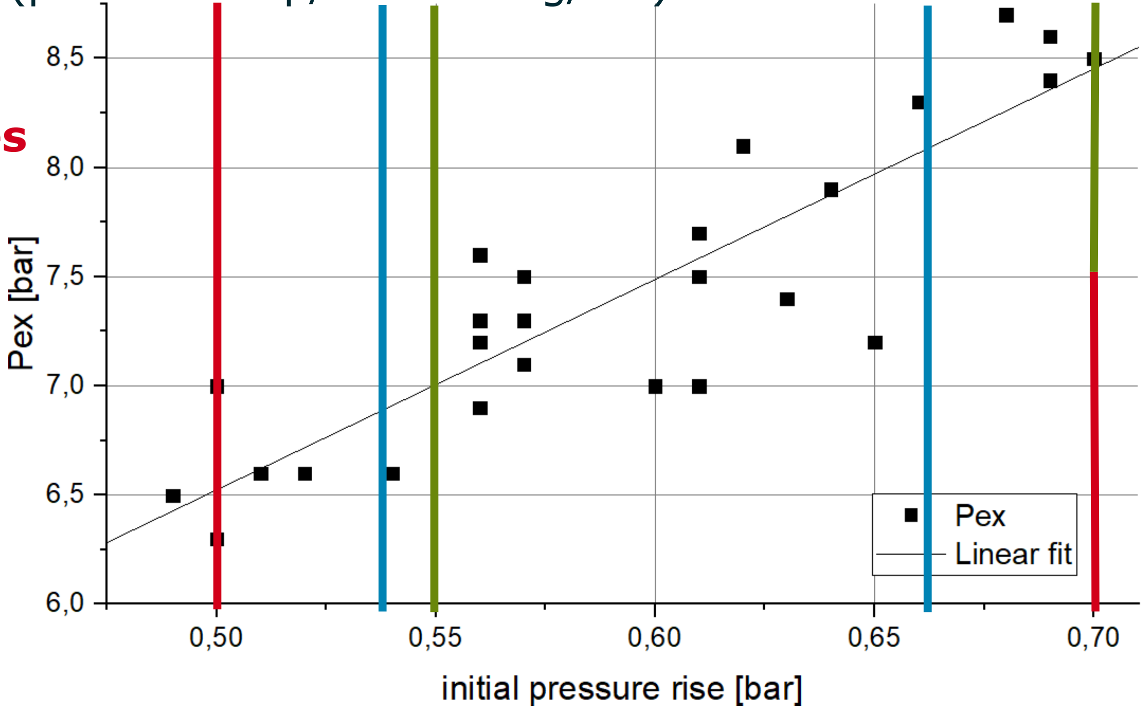
Corn starch 500 g/m³ (pmax and dp/dt at 750 g/m³)

Allowed range of Pressure rise:

DIN EN 14034-series

ASTM 1226

K-SEP-Software (standard 20L)



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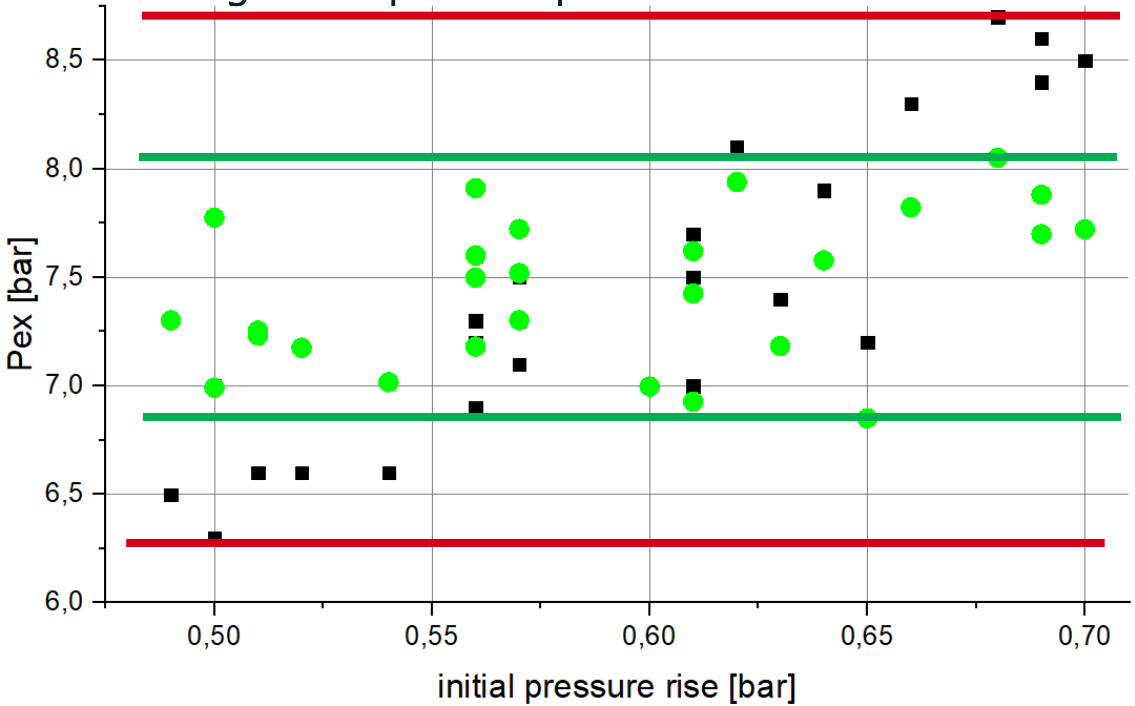
Higher initial pressure leads to higher explosion pressure

Take ratio of P_{ex}/P_0
for hybrid mixtures
or narrow range

± 18 %
± 8 %



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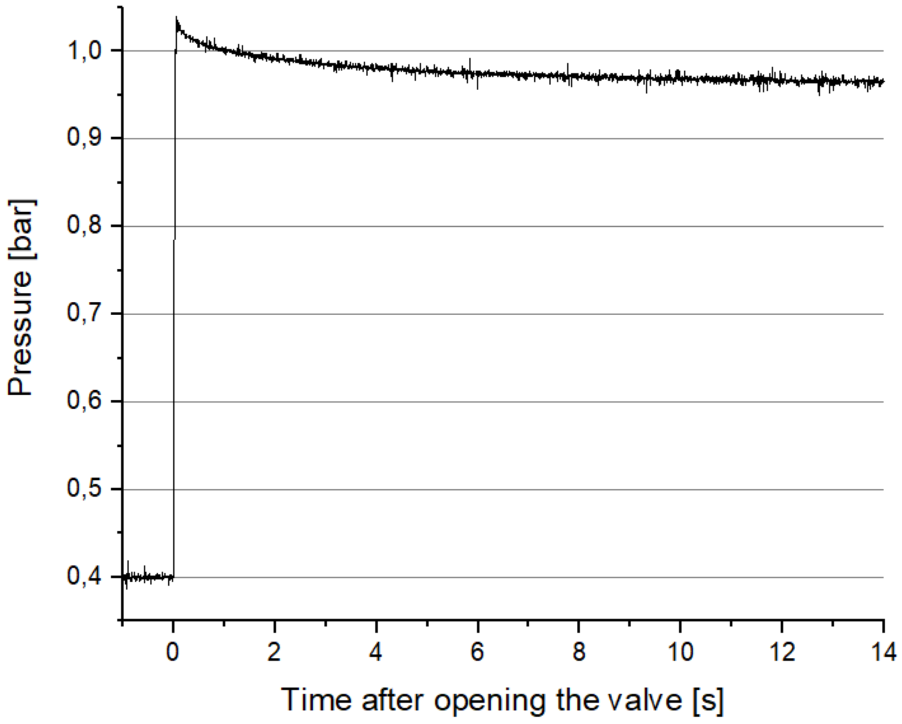
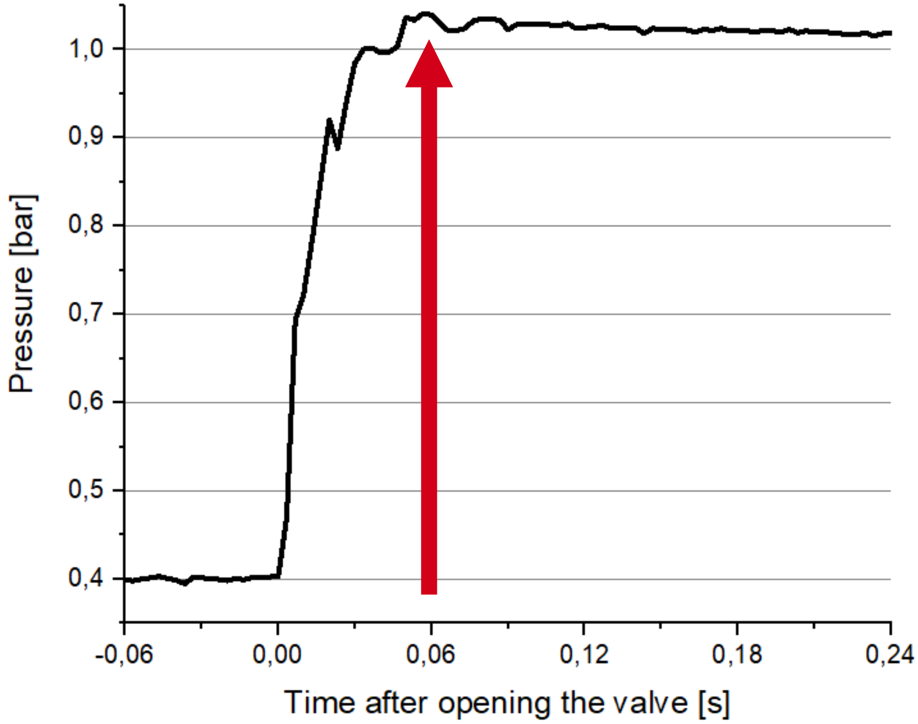
Post Injection Pressure Drop (PIPD)





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- Explosion at 1.040 bar
- Endpressure 0.960 bar

- $\frac{T1}{T2} = \frac{p1}{p2} \rightarrow T_2 = \frac{P_2}{p_1} * T_1 = \frac{1.04\ bar}{0.96\ bar} * 293{,}15\ K = 317.6\ K$
- Initial temperature is 44,4 °C and not 20 °C
  111.2 °F 68°F

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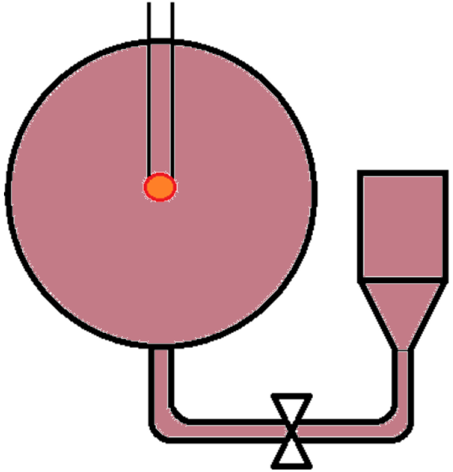
Mixture Before Opening the fast-acting valve

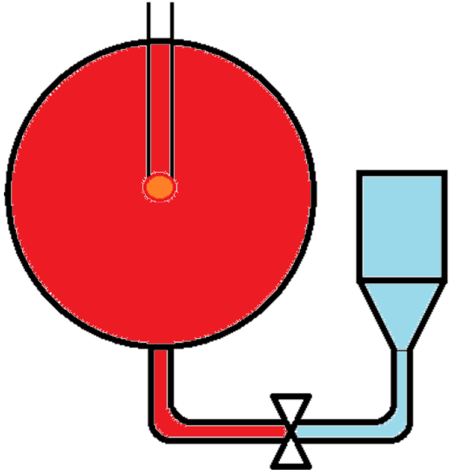
With premixtures on

Boths sides



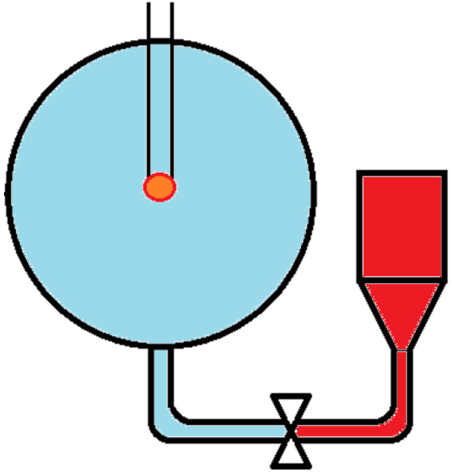
Desired amount of burnable gas

inside the 20L-sphere



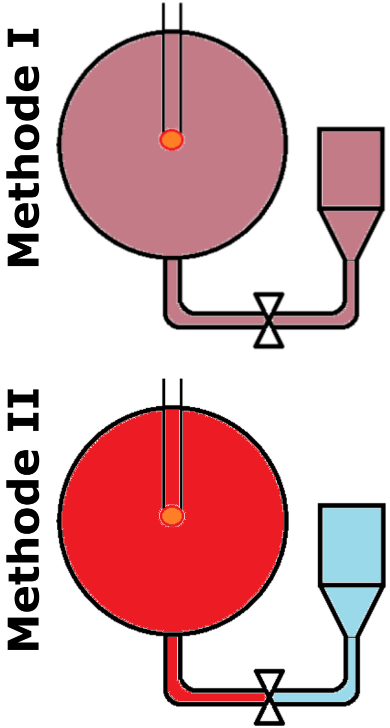
high amount of burnable gas

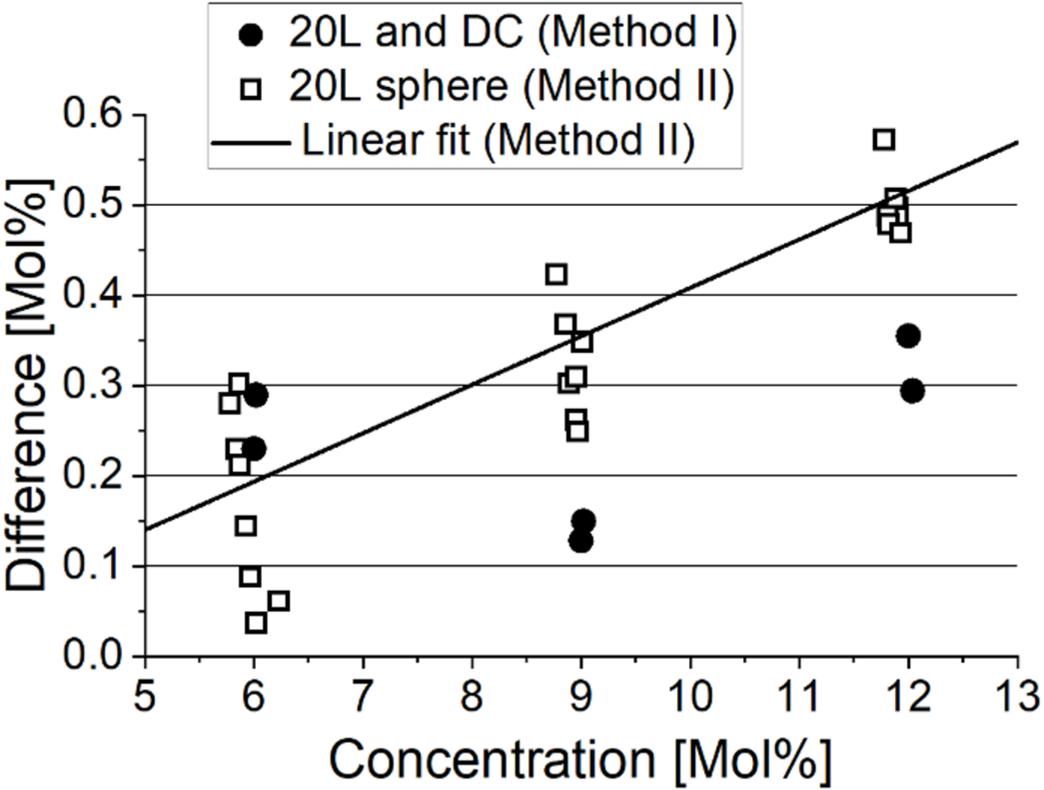
in dust storage container



Air

BAM – Hybrid 1


Methode I
Methode II


20L and DC (Method I)
20L sphere (Method II)
Linear fit (Method II)
Difference [Mol%]
Concentration [Mol%]
0.0
0.1
0.2
0.3
0.4
0.5
0.6
5
6
7
8
9
10
11
12
13

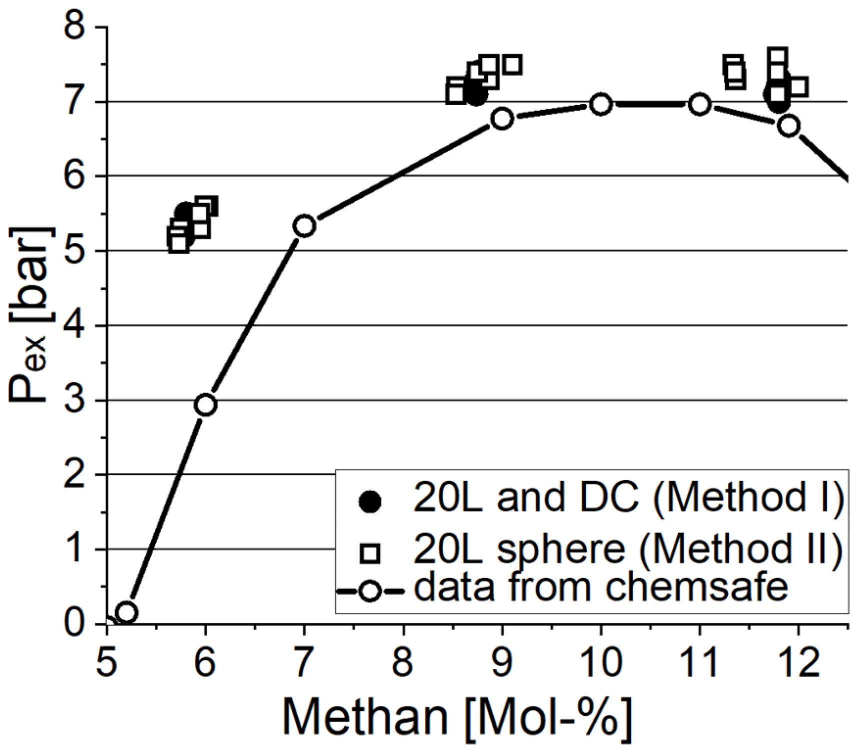
BAM – Hybrid 1

Cgas=Pgas/Pi ± 2 - 3 Mol-%

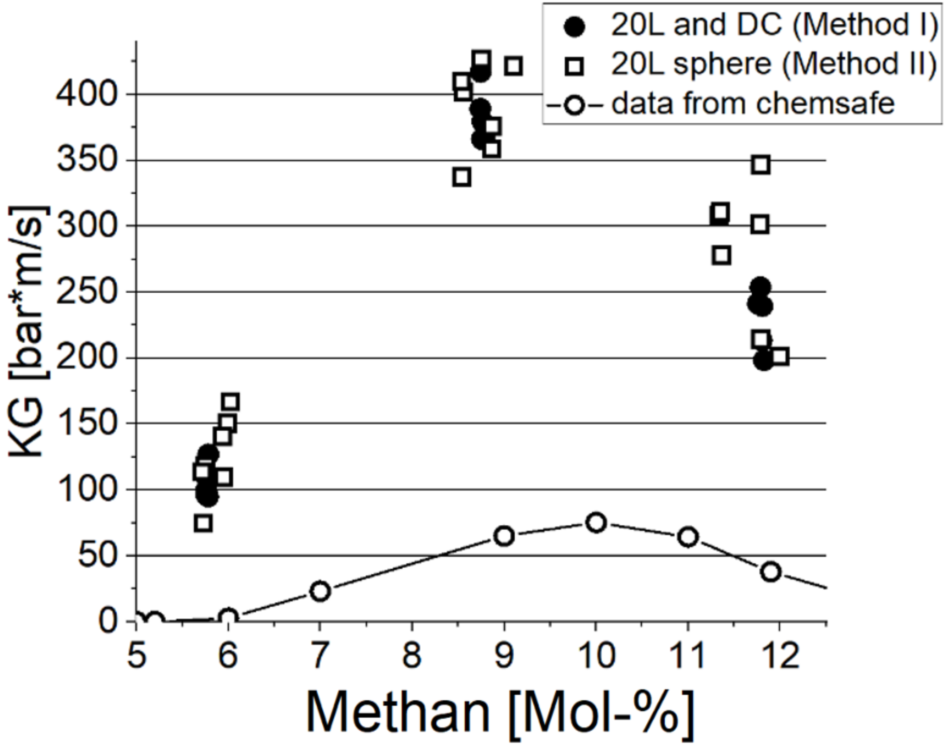
Cgas=Pgas/(PV+PIPR-PIPD)-Deviation ± 0,2 Mol-%

Pgas – Partialpressure fraction of burnable gas
PV – Partial Vacuum before opening the fast-acting valve (0,4 bar)
PIPR/Pd – Pre-ignition pressure rise from dust container (0,6 bar)
PIPD – Post-injection pressure drop due to compression
Deviation

BAM – Hybrid 1



Pex [bar]
Methan [Mol-%]
20L and DC (Method I)
20L sphere (Method II)
data from chemsafe



KG [bar*m/s]
Methan [Mol-%]
20L and DC (Method I)
20L sphere (Method II)
data from chemsafe

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Parameters for Hybrid 1 **(will be in new dust standard)**

1. 400 mbar ± 5 mbar Partial vacuum shall be measured with an absolute pressure sensor – additional sensor needed for Kühner-sphere

2. Explosion pressure ratio instead of overpressure

3. Keep PIPR constant instead of 20 bar in dust container

4. Narrow range of PIPR further because of the Post-injection pressure drop. Suggestion: 0,64 bar ± 0,04 bar

5. X-Wire as potential ignition source

BAM – Hybrid 1
PIPR

Higher pre-ignition pressure rise leads to

- **higher explosion pressure**
  → Take ratio of P_{ex}/P_0 for hybrid mixtures

- **lower burning gas concentration**
  → increase/calculate burnable component in mixture

- **higher initial temperature due to adiabatic compression**
  → No solution yet

- **higher level of turbulence**
  → No solution yet

→ Narrow range and shift it slightly to higher side

BAM – Hybrid 1

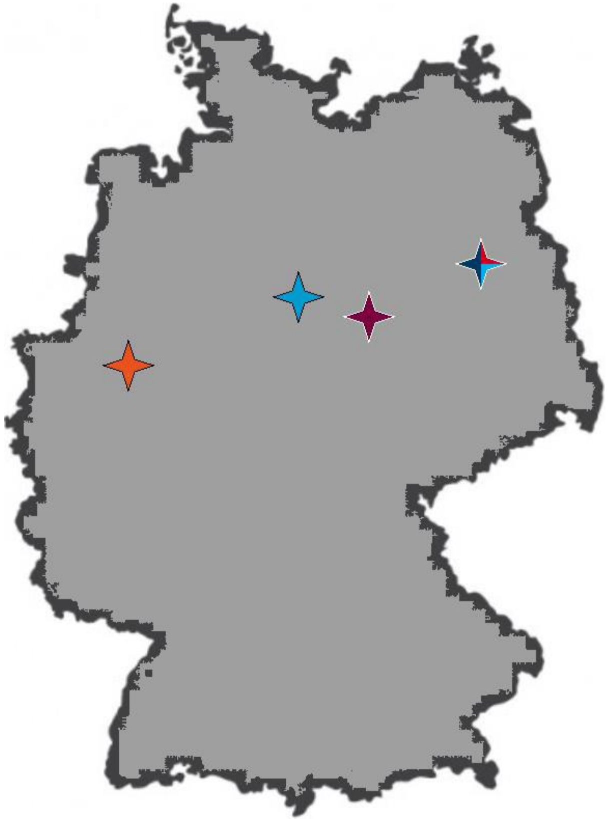
Hybrid Mixtures - differences and additions to dust standard and Kühner manual

1. Add at least one absolute pressure sensor to the sphere
2. Record partial vacuum pressure of 400 mbar and narrow range
3. Check the sphere for leakage-rate
4. Check the amount of gas before testing
5. Method II (gas amount in the 20L-sphere) will be applied usually
6. 2 kJ will be used for all safety characteristics
7. The range for PIPR will be narrowed and shifted a bit to the higher side
8. All of the above must be mentioned in the report

BAM – Hybrid 1

4 institutions in Germany:
BAM - Bundesanstalt für Materialforschung und -prüfung
PTB - Physikalisch-Technische Bundesanstalt
Otto-von-Guericke-Universität Magdeburg
Inburex Consulting

and (so far):
2 in France
2 in Czechia
1 in Italy
3 in the USA
2 in Canada
1 in Australia
1 in Belgium



This is the end…

Thanks for your interest in our research

Any questions so far?

If not now, please don’t hesitate to ask them later via Mail or phone

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BAM – Hybrid 1
Sources

Post-Ignition pressure Drop (Temperature was measured, but not the pressure):

Kenneth L. Cashdollar (1996) – Coal Dust explosibility

Methods of mixing for hybrid mixtures

Method I:

N. Kalkert (1982) – Theoretische und experimentelle Untersuchungen der Explosionskenndaten von Mischungen aus mehreren gas- und staubförmigen Brennstoffkomponenten und Luft

G. Li et. al. (2009) - Inerting of magnesium dust cloud with Ar, N2 and CO2

Paul Amyotte, Kenneth J. Mintz, Michael J. Pegg, Yu-Hong Sun, Kenneth Wilkie (1991) - Effects of methane admixture, particle size and volatile content on the dolomite inerting requirements of coal dust

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Sources

Methods of mixing for hybrid mixtures, Method II:

Manufacturers Handbook – Cesana Ag (2020) – Schweiz - https://cesana-ag.ch/download/B000_070.pdf

D. Gabel, A. Addai, U. Krause (2014) - Lower explosion limit of hybrid mixtures

A. Denkevits (2007) - Explosibility of hydrogen–graphite dust hybrid mixtures, doi:10.1016/j.jlp.2007.04.033

A. Denkevits and B. Hoess (2015) - Hybrid H2/Al dust explosions in Siwek sphere, http://dx.doi.org/10.1016/j.jlp.2015.03.024

Paul Amyotte, Matthew Lindsay, Ruth Domaratzki, Neil Marchand, Almerinda Di Benedetto, Paola Russo (2009) – Prevention and Mitigation of Dust and Hybrid Mixture Explosions

Jian Su, Yang-Fan Cheng, Shi-Xiang Song, Hong-Hao Ma, Wen-Tao Wang, Yu-Xiang Wang & Shi-Xu Zhang (2019): Explosion Characteristics and Influential Factors of Coal dust/sodium Chlorate Mixture on Basis of an Explosion Accident in China, Combustion Science and Technology, DOI: 10.1080/00102202.2019.1689965

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Sources

Methods of mixing for hybrid mixtures, Method II:

Yan Wang, Yingquan Qi, Xiangyang Gan, Bei Pei, Xiaoping Wen, Wentao Ji (2020) - Influences of coal dust components on the explosibility of hybrid mixtures of methane and coal dust

Jiaojun Jiang et. al. (2014) - A correlation of the lower flammability limit for hybrid mixtures

Gysbert Landman (1992) - IGNITION AND INITIATION OF COAL MINE EXPLOSIONS

B. Janovsky, J.Skrinsky, J.Cupak, J.Veres (2019) - Coal dust, Lycopodium and niacin used in hybrid mixtures with methane and hydrogen in 1m^3 and 20l chambers

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Sources

Methods of mixing for hybrid mixtures, Method III:

Peng Zhao, Xin Tan, Martin Schmidt, Weixing Huang, Xingming Qian, Dejian Wu (2020) Minimum explosion concentrations of coal dusts with CHJH2/CO below the gas lower explosion limit

Wentao Ji, Jianliang Yu, Xiaozhe Yu, Xingqing Yan (2018) - Experimental investigation into the vented hybrid mixture explosions of lycopodium dust and methane

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Sources

Influence of turbulence on Safety Characteristics of von gases:

Richard Vernon Wheeler (1919) - The Inflammation of Mixtures of Ethane and Air in a closed Vessel - The Effects of Turbulence

Wolfgang Bartknecht (1981) – Explosions – Course, Prevention, Protection

G.F.P Harris (1967) - The effect of vessel size and degree of turbulence on gas phase explosion pressures in closed vessel

Y.K. Pu et. al. (1990) - TURBULENCE EFFECTS ON DUST EXPLOSIONS IN THE 20-LITER SPHERICAL VESSEL

Trygve Skjold (2003) – Selected Aspects of Turbulence and combustion in 20-Litre Explosion vessels

Spitzer et. al. (2021) - Influence of the mixing procedure on safety characteristics of hybrid mixtures, dx.doi.org/10.13140/RG.2.2.18025.62561

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Sources

Influence of turbulence on Safety Characteristics of von gases:

R. Pilao et. al. (2006) - Overall characterization of cork dust explosion

J.M. Pascaud and P. Gillard (2006) - Study of the propagation of kerosene explosions inside a partitioned vessel

E. Conde Lazaro and J. Garcia Torrent (2000) - Experimental research on explosibility at high initial pressures of combustible dusts

M. Hertzberg, K. Cashdollar, I. Zlochower (1986) – Flammability limit measurements for dusts and gases: Ignition energy requirements and pressure dependencies

Thomas Glarner (1983) - Temperatureinfluss auf das Explosions- und Zündverhalten brennbarer Stäube

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Spitzer et. al. (2021) - Influence of pre-ignition pressure rise on safety characteristics of dusts and hybrid mixtures, https://dx.doi.org/10.13140/RG.2.2.24736.51206