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New Findings for the Application of Systems for Explosion-Isolation with Explosion Venting

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Mechanically acting explosion isolation systems like fast-acting valves or explosion isolation flap valves are protective systems which shall avoid transmission of flames and explosion pressure waves via connecting pipes into other parts of apparatus or plant areas.
Latest findings from explosion tests with explosion isolation flap valves connected to explosion vented vessels suggest that these devices might have an impact on the explosion course in the vessel and lead to an increased explosion overpressure in the connected vessel. As the dimensioning of pressure vented vessels according to harmonized European standards does not consider these pressure enhancing effects, a dangerous inappropriate design of the explosion vented vessel cannot be ruled out in particular cases.
Present numerical studies with a special CFD-code (CFD-Computational Fluid Dynamics) showing the course of the explosion inside these systems in a simplified model lead to the conclusion that these effects are possible and can theoretically be expected with other fast acting mechanical explosion isolation systems.
The present study describes the observed effects of the explosion tests in an exemplary way. Apart from that, the first results from numerical simulations are described which can help the systematically study of the phenomenon in the future. The present publication derives additional need for research from the findings so far.

1. Introduction

Explosion protection must be applied if explosion prevention measures like „avoidance of hazardous explosive atmospheres” and „avoidance of effective ignition sources” do not provide sufficient safety for the employees. Large process vessels of limited mechanical strength like e.g. filter housings are often protected by venting according to EN 14491 to reduce the arising explosion overpressure inside the vessel to a tolerable amount. In many cases also explosion isolation measures in the connected ducts according to EN 15089 are required to avoid explosion transmission with pre-compression and pressure piling which would cause severe effects for the connected parts of the plants, see Wiemann (1996). Applicable explosion isolation devices are for example explosion resistant and flame proof explosion slides or valves, chemical barriers, or explosion isolation flap valves. The latter are generally designed for low pressure shock resistance and often used in installations with vented vessels.

2. General requirements for explosion isolation flap valves

As per definition in EN 16447 "an explosion isolation flap valve is a protective system, which prevents a dust explosion from propagating via connecting pipes or ducts into other parts of apparatus or plant areas. It is installed such that the normal process air flow passes in one direction through the valve and keeps it open. It closes when the air flow reverses due to a dust explosion event. After closure the valve shall stay closed long enough to avoid flames from transmitting during an explosion event (…). Explosion isolation shall also be ensured during periods without process flow."
According to this standard the function and the efficacy of explosion isolation flap valves must be proved by means of explosion tests by a notified body in the scope of the European Directive 94/9/EG. The explosion

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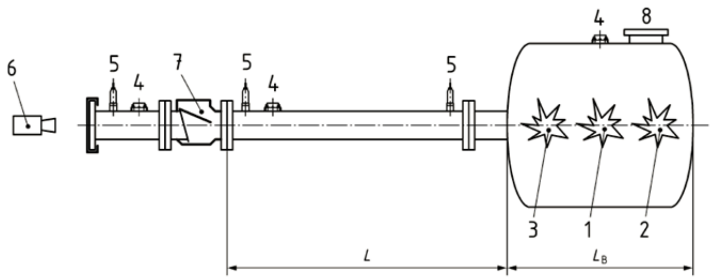
tests need to cover the essential conditions of the intended use in the experimental set-up. EN 16447 describes three modules for the testing of explosion isolation flap valves, of which Module C gives the requirements for functional testing. The test conditions mainly comprise an explosion vessel with the explosion isolation flap valve fitted to a connected pipe. If the explosion isolation flap valve shall be connected to vented vessels according to its intended use, the vessel for the test arrangement also needs to be vented. The test set-up as described in EN 16447 is presented Figure 1.



Key

1	Location of ignition source, *Z1*, 50 %	6	Camera
2	Location of ignition source, *Z2*, 10 %	7	Explosion isolation flap valve
3	Location of ignition source, *Z3*, 90 %	8	Explosion vent
4	Pressure transducer (Pt)	*L*	Installation distance
5	Flame transducer (Ft)		

Figure 1: Test condition for the functionality test - module C of EN 16447

The test set-up given in Figure 1 is also used to measure the passage of flames (5) as well as the explosion pressure (4) at various positions of the test set-up. The explosion pressure is registered before the explosion isolation flap valve and inside the test vessel and the pressure/time course is recorded.
In contrast to most fast acting valves which are usually designed for the maximum explosion pressure, explosion isolation flap valves generally have a lower explosion pressure shock resistance and are used in ducts which connect vented vessels with other parts of the plant.

3. Experimental work

Lately, an increase of applications for EC type examinations of explosion isolation flap valves is registered. Consequently the tests with such devices connected to vented explosion vessels at FSA GmbH went up. With these tests the following phenomenon has been observed: in part there have been massive repercussions of the explosion isolation flap valves to the reduced explosion pressure inside the connected vessel. The confirmation of the observed phenomenon would not only have considerable consequences for the testing of such explosion isolation devices but especially for the practical use: the design of the explosion venting of a vessel usually follows EN 14491 on the basis of the dust-specific parameters K_{St} and P_{max}. This is to guarantee that a defined reduced explosion pressure inside the vessel is not exceeded. However, if an explosion isolation device is implemented in the pipe connected to this vessel a significantly higher reduced explosion overpressure inside the vessel might arise in the worst case – a considerable safety hazard if the explosion pressure shock resistance of the vessel is exceeded.
These observations have lead FSA to further investigation of this effect. In a first step some exemplary experiments from tests of explosion isolation devices with different parameters have been selected. All of them have been carried out with the same test-dust and with isolation devices according to the flap principle. The activation pressure of the venting device was approx. 10 kPa in all cases. The test set-up followed the specifications of EN 16447 and thus corresponded basically to the outline of the principle of Figure 1. The reduced explosion overpressures measured inside the test vessel with an explosion isolation flap valve connected were compared to the measured values resulting from reference tests without explosion isolation flap valves.
Reference tests were
- tests with vented vessels without pipe,
- tests with vented vessels with connected pipe with open pipe end,
- tests with vented vessels and blind-flanged pipe.
Table 1 gives an overview of the most important test parameters.

Table 1: Important parameters of the compared test series

Test series	Test No.	Vessel volume V [m³]	Vessel length/diam. ratio L/D [-]	Venting area A [m²]	Pipe diameter D [mm]	Pipe length L [m]	Pipe position
1	D3	10	1.0	0.503	-	-	without pipe
	D1, F1	10	1.0	0.503	800	6	lateral, centre of the vessel
2	A6, C1	60	1.7	1.54	630	2	lateral, lower third of the vessel
	A9, C2	60	1.7	3.14	630	2	lateral, lower third of the vessel
3	B7	4.4	2.5	0.200	400	8	lateral, nearly centre of the vessel
	B10	4.4	2.5	0.200	400	7	lateral, nearly centre of the vessel
5	A3	10	1.0	0.503	400	-	without pipe
	B1, B2	10	1.0	0.503	400	2	lateral, centre of the vessel
4	D28, D29	4.4	2.5	0.200	200	8	lateral, lower third of the vessel

Table 2: Reduced explosion overpressures inside the vented explosion vessel, comparison of the test results with and without explosion isolation flap valve with different test parameters

Test series	Test No.	Measured red. explosion over-pressure in the test vessel $p_{red,\,max}$ [kPa]	Pressure ratios press. with isolation to press. with open pipe Π_{P1} [-]	Pressure ratios press. with isolation to press. without resp. blind-flanged pipe Π_{P2} [-]	Configuration
1	D3	68		2.4	without pipe
	F1	162			with isolation at 6 m
	D1	37	4.4		pipe (L = 6 m), open
	F1	162			with isolation at 6 m
2	A6	60		1.8	pipe (L = 2 m), blind-flanged
	C1	107			with isolation at 2 m
	A9	18		2.0	pipe (L = 2 m), blind-flanged
	C2	36			with isolation at 2 m
3	B7	49	2.9		pipe (L = 8 m), open
	B10	143			with isolation at 7 m
5	A3	28	2.4		pipe (L = 2 m), open
	B1	67			with isolation type 1 at 2 m
	A3	28	3.4		pipe (L = 2 m), open
	B2	95			with isolation type 2 at 2 m
4	D29	171	1.1		pipe (L = 8 m), open
	D28	183			with isolation at 8 m

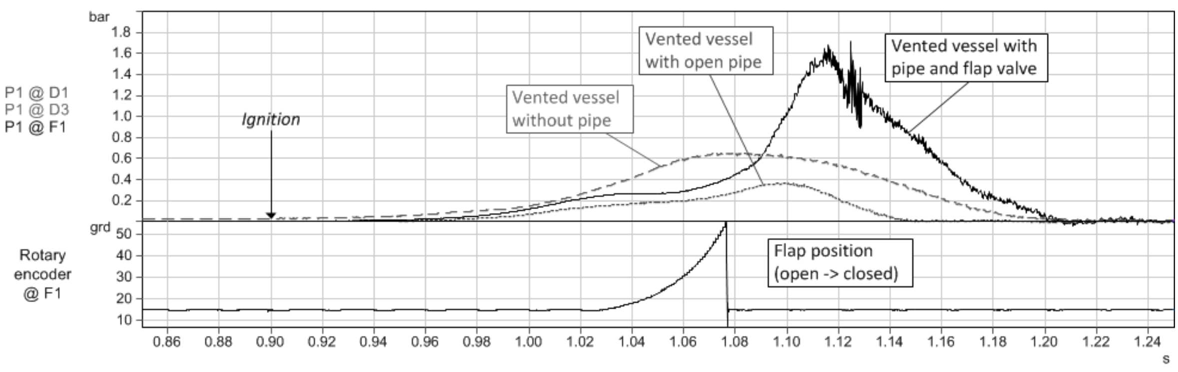


Figure 2: Exemplary pressure/time-curves of the registered reduced explosion overpressures inside the test vessel (test series 1, tests D1, D3, F1)

Table 2 presents the comparison of the measured reduced explosion overpressures inside the vessel for the various configurations tested.
As shown in table 2, the occurring repercussions can be significant. In test series 1 for example the explosion overpressure inside the vessel was increased by a factor of 4.4 due to the isolation device compared to the measured value in the test with the open pipe system of the same length. The other test parameters were identical.
The time/pressure-curves of this series of tests (Figure 2) impressively show the influence of the explosion isolation flap valve. P1 is the signal of the pressure sensor in the test vessel. The rotary encoder signal shows the flap position.
The pressure signals of test D3 (dashed line) show the typical pressure history of a dust explosion inside a vented vessel. In contrast to this, the pressure/time-curve of test D1 (dotted line) is flatter and the maximum value of the reduced explosion overpressure is lower. The additional flange-mounted open pipe has the effect of an additional "venting area". The pressure/time-history of test F1 (solid line) is very similar to the one of test D1 during the initial phase. The slightly higher level can be explained by the obstruction due to the (still open or already closing) explosion isolation flap valve. Few milliseconds before the end of the closing process of the flap the pressure begins to rise increasingly stronger, in fact up to a value of 4.4 times the maximum value of test D1.
In order to understand the principal effects FSA is now working on the development of a research program. A large number of influencing parameters needs to be identified and experimentally tested. Among these are geometric parameters, product and process parameters as well as equipment specific parameters.

4. Numerical work

Complementary to the explosion tests the method of the numerical simulation can also be applied in order to identify the different influencing factors of the observed phenomena. DEKRA EXAM GmbH, Bochum, has therefore performed calculations on the basis of the measured data of the described test series 1 with the use of a CFD simulation model (CFD – Computational Fluid Dynamics). This model represents the explosion process of the test set-up in a simplified way, see figure 1.
The closing of the explosion isolation system is described in the model either comparable to an abrupt and complete blocking or the pipe cross-section is blocked in different sections ("segments") within user-defined periods of time. The opening of an explosion venting in form of a rupture disc is each time modeled comparable to an abrupt opening. Figure 4 shows the principle of the blocking of a pipe cross-section by several segments. This kind of modeling has been used for the simulation of the delayed closing of the explosion isolation flap valve observed in the explosion tests. The timing of the closing has been taken from the measuring data described above.

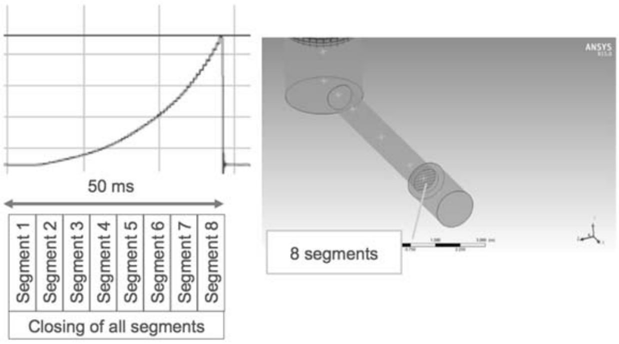


Figure 3: Modelling of the closing phase of an explosion isolation flap valve

This comparably slow closing of the explosion isolation flap valve over a time of 50 ms is called "SLOW 50 ms" in the following display of the results. An abrupt blocking of the flap is called "FAST". For the chronology of the slow closing an exponential course has been chosen, that is the period until the closing of the next segment is getting smaller in the further course. The time of the beginning of the closing after the insertion of the mixture ignition has been varied. Intervals of 0,046 s, 0,068 s and 0,074 s have been chosen.
In a first step the tests have been modeled with the boundary conditions, shown in table 3:

Table 3: Main boundary conditions of the simulation calculation

Size	Value
Volume of the explosion vessel	10 m^3
Length/diameter relation of the explosion vessel	1
Diameter of the pipe	800 mm
Distance between explosion isolation flap valve and vessel	6 m
Maximum explosion pressure of the dust/air mixture P_{max}	App. 9 bar
Maximum speed of the pressure increase of the dust/air-mixture K_{St}	App. 200 bar m s^{-1}
Static activation pressure of the explosion venting p_{stat}	100 mbar
Thermal and flow relevant characteristics of the vessel and pipe wall	Adiabatic and hydraulically smooth

Besides tests with slow or abrupt closing explosion isolation flap valves, tests with one pipe and a blind flange at the end of the pipe ("with pipe & blind flange"), tests without a pipe and with blocked pipe connection at the vessel ("without pipe") and tests with open pipe but without any explosion isolation system ("without explosion isolation") have been modeled.
Figure 4 shows the calculated pressure/time-curves for the tests without any explosion isolation system (left side of the figure) and the results of the tests with an explosion isolation flap valve (right side of the figure). For a better comparability the pressure/time-curve of the calculated case "without explosion isolation" has been added to the presentation:

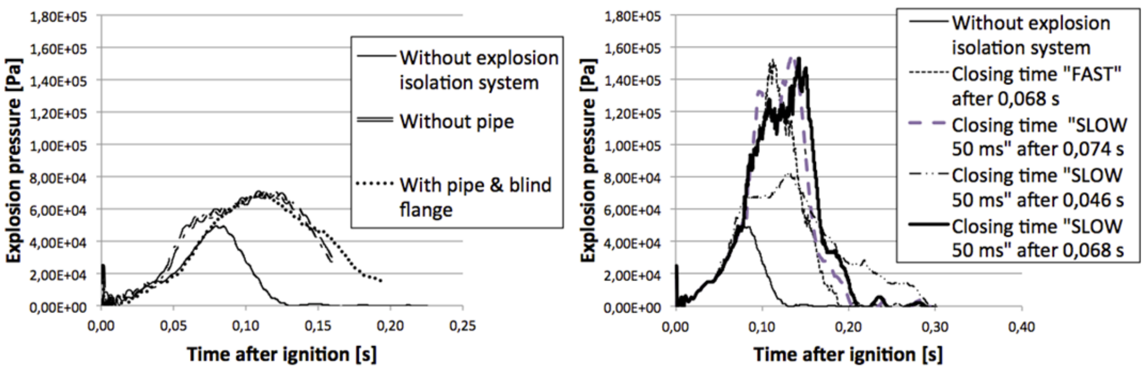


Figure 4: Pressure/time courses of the numerical tests

There is an additional explosion venting in the test „without explosion isolation" above the open ending of the pipe, so that here a relative low reduced explosion pressure is reached. The turbulence when passing through the assumed hydraulically smooth pipe does not lead to a considerable increased explosion acceleration.
In the test "without pipe" the explosion venting takes place only at the rupture disc of the vessel. The reduced explosion pressure can therefore reach higher figures as in the first test "without explosion isolation".
In the test "with pipe & blind flange" a greater volume of explosive atmosphere is available as in the test "without pipe". The result is a slower increase of the pressure with a comparably reduced explosion pressure.
The results suggest that the increased pressure in the vented vessel results among others from the pressure reflections at the surface of the explosion isolation device. This effect is intensified the later the explosion isolation flap valve closes, i.e. the stronger the explosion process has proceeded inside the pipe.
A quick or abrupt closing leads to a similar or slightly lower explosion pressure as a slow closing. During the slow closing there is not only a pressure reflection at the closing segments but also a reduction of the pipe-cross section for a comparably long period. This leads to a higher flow speed and increased turbulence. This increased turbulence increases at the same time the local reaction speed of the dust/air-mixture. Additionally, the changed venting flow behavior inside the explosion vessel influences the course of the reaction and by this the reduced explosion pressure in the vessel.
Figure 5 exemplarily shows the spreading of the calculated pressure and temperature within the set-up by means of a vertical section through the model geometry for the calculated model "FAST after 0,068 s".

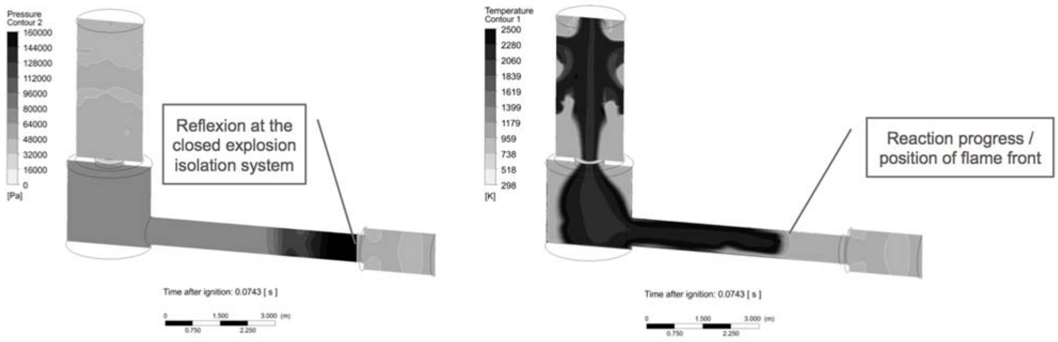


Figure 5: Pressure and temperature courses immediately after the closing of the explosion isolation – calculation model „FAST after 0,068 s“

The increased pressure figures in the area of the explosion isolation due to the abruptly occurring blocking of the flow cross-section are evident. The flame front has not yet reached the area of the explosion isolation flap valve. The maximum explosion pressure inside the explosion vessel is reached after further 40 m s.

5. Summary

Explosion isolation is an important part of explosion protection. It serves for the prevention of uncontrolled explosion propagation from the part of the plant where an explosion originates to other parts of the plant. Quick-closing mechanical systems like fast-acting valves or explosion isolation flap valves are examples for explosion isolation devices in pipe systems which are connected to explosion vented vessels like silos, filters etc. Current explosion tests with explosion isolation flap valves connected to vented vessels showed a significant repercussion of the isolation devices leading to increased explosion overpressures in the vessel compared to installations without isolation device.

Some tests have been depicted by means of a CFD simulation model in order to understand these phenomena better. The calculations could clarify in a simplified form some essential processes of the explosion isolation at vented vessels. According to the current state of knowledge based on the explosion tests and the calculations possible sources for the increased values of the reduced explosion pressure could be identified:

1. Pressure reflections at the closing or closed explosion isolation flap valve whose extend is mainly influenced by the course of the explosion while passing the pipe.
2. Explosion increasing effects by flow turbulence when the explosion passes the pipe and especially during the closing of the explosion isolation flap valve. By this, a repercussion on the explosion course inside the vented vessel takes place due to the changed flow-off behavior in the vessel.

Both of these possible causes lead to the assumption that an increase of the reduced explosion pressure might not at all occur with the use of explosion isolation flap valves only but needs to be considered also with different explosion isolation systems. Furthermore, it has to be expected that in principle every enhancement of the explosion during the passing of a pipe connected to the vessel can have the effect of an increase of the reduced explosion pressure inside the vessel.

The experimental proof of these theses, the working on the specific boundary conditions and further influencing variables and finally the indication for an adequate dimensioning of vented systems need to be the object of further research.

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