Analysis of dynamical response of air blast loaded safety device

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Abstract. Equipment of many oil and gas processing plants in the Russian Federation is considerably worn-out. This causes the decrease of reliability and durability of equipment and rises the accident rate. An air explosion is the one of the most dangerous cases for plants in oil and gas industry, usually caused by uncontrolled emission and inflammation of oil products. Air explosion can lead to significant danger for life and health of plant staff, so it necessitates safety device usage. A new type of a safety device is designed. Numerical simulation is necessary to analyse design parameters and performance of the safety device, subjected to air blast loading. Coupled fluid-structure interaction analysis is performed to determine strength of the protective device and its performance. The coupled Euler-Lagrange method, allowable in Abaqus by SIMULIA, is selected as the most appropriate analysis tool to study blast wave interaction with the safety device. Absorption factors of blast wave are evaluated for the safety device. This factors allow one to assess efficiency of the safety device, and its main structural component – dampener. Usage of CEL allowed one to model fast and accurately the dampener behaviour, and to develop the parametric model to determine safety device sizes.

1. Introduction

Equipment of many chemical, petrochemical, oil and gas processing plants in the Russian Federation is considerably worn-out. Besides, equipment exploitation regimes are very often disrupted by delays in work materials delivery, low technological and manufacturing discipline etc. This factors cause a decrease of reliability and durability of equipment, and a rise of the accident rate. In current economic situations, companies are forced to use equipment until its partial of full outage.

Any accident on chemical, petrochemical, or oil & gas processing plant can cause a harm of personnel involved in production, harm the nearby plants personnel and civilians. This feature distinguishes chemical and oil & gas plants from other industries plants, which usually do not cause risk to surrounding objects in case of an extreme situation. Thereby, due to high potential danger of petrochemical and oil & gas plants, the problem of safeguarding for such objects is actual.

An air explosion is the one of the most dangerous cases for plants in oil and gas industry, usually caused by uncontrolled emission and inflammation of oil products. Very often constructions used in oil plants cannot sustain such disaster because they designed without consideration of air explosion loading or became depreciated. Air explosion can lead to significant danger for life and health of the plant staff, so it necessitates safety device usage.

Usually that type of the construction is an operating station, which controls most of processes at an oil plant, and where most of the plant staff are present. Reconstruction of such stations requires a great amount of time and could bring financial losses due to the plant idle. In such case, it is most
reasonably to use protective devices instead of reconstruction. Air explosion danger for such buildings as operation stations may be reduced significantly by the corresponding safety device.

2. Safety device features
The team of authors developed a new type of the protective device, which is able to reduce significantly the shock wave front pressure excess and thus to reduce blast loading for the operational station [1].

The safety device includes special dampers, mounted on the frame made from I-beams. The device is designed to disseminate the blast wave energy by partial reflection and scatter in the extinguishers.

The damper is designed as a welded box with specially oriented steel plates inside, which shape is a comb-like channel inside the box. This comb-like channel causes the blast wave reflection between plates and a decrease of the overpressure. The damper also can decrease wave energy by its dissipation to elastic-plastic deformation due to plate collapse. This two energy dissipation mechanism allows one to decrease gradually wave overpressure.

The safety device sketch is shown in Figure 1.

![Figure 1. Safety device and damper sketch.](image)

3. Research method
To analyze the safety device behavior under blast load, it is necessary to solve coupled flow dynamic and dynamic stress problems. Analysis of such problem with analytical methods is complicated due to necessity of solution of a large amount of coupled nonlinear problems, and an empirical method is complicated due to the cost of experiment, involving blast waves.

To find such coupled solution, a numerical simulation model needs to be made. Many commercial solvers can solve the coupled solution of fluid structure interaction. In this study, the authors used the CEL technology in Abaqus/Explicit.

One of the most convenient techniques to analyze fluid-structure interaction problems is to use the Coupled Euler Lagrange analysis method, which is implemented in Abaqus/Explicit. This method allows modelling simultaneously the coupled dynamic flow and stressing problem in a single solution space.

It is necessary to determine efficiency of the protective device due to blast waves loading with different parameters. In addition, it is necessary to determine deformation or collapse behavior of the damper – its deformation behavior affects directly the efficiency of shock wave energy reduction.

Simulation for such analysis is made with an Abaqus/Explicit solver and divided into the following steps:
1. Flow simulation of blast wave propagation through the media.
2. Dynamic stress simulation of the damper.
3. Coupled fluid-structure interaction simulation of blast wave propagation through the deformable extinguisher.

Steps 1 and 2 are necessary to verify fluid and dynamic stress simulation. The coupled model was assembled completely after such verification. The combination for Coupled Euler-Lagrange analysis is shown in Figure 2.
General contact technology was used to transfer pressures and mesh motions between flow and dynamic strength analysis. This technology allows one to tracking automatically interaction surfaces in simulation media.

As a result of simulation, the authors achieved the pressure distribution in gas media and plastic deformations in the extinguisher.

4. Research results

For the analysis of the safety device and its extinguishers, blast wave parameters were defined under the regulation methodic [2] and [3]. Risk class 3 objects containing 5000 kg of gasoline were selected for analysis. Calculated deflagration wave parameters are shown in Table 1.

| R      | E (J) |  | ΔP+ |  | ΔP- | T+ (s) | T- (s) |
|--------|-------|---|-----|---|-----|--------|--------|
| 5000 kg| 50    |  | 2.2E+11 |  | 198 KPa | 30 Kpa | 0.0616 | 0.204  |

Pressure and velocity distribution in gas media are shown in Figure 3 (a, b). The pressure distribution diagram for different points in the extinguisher is shown in Figure 4.

Figure 3. Pressure and velocity distribution in gas

Figure 4. Overpressure distribution in various points in damper.
Table 2 shows the values of minimum and maximum pressure measured in damper points. Achieved values show that overpressure is gradually decreased.

|     | 1 (KPa) | 2 (KPa) | 3 (KPa) | 4 (KPa) | 5 (KPa) | 6 (KPa) | 7 (KPa) |
|-----|---------|---------|---------|---------|---------|---------|---------|
| ΔP+ | 185     | 185     | 132     | 101     | 60      | 8       | 5       |
| ΔP- | -29     | -29     | -22     | -17     | -11     | -6      | -19     |

Stress analysis of the damper is performed. The plastic deformation point is shown in Figure 5. Maximum stress, achieved in the model, is 250 MPa, which leads to yielding of the construction made of steel 3 used in the calculation. The yielding point is located in the channel plate attachment point.

Pressure reduction coefficient $k_{loc}$ is calculated for the damper. The coefficient is determined as $k_{loc} = \frac{P_{in}}{P_{out}}$, where $P_{in}$ – pressure before the extinguisher; $P_{out}$ – pressure after the extinguisher. The pressure reduction coefficient for the analyzed extinguisher design is 18.

The achieved results allow suggesting a hypothesis that the safety device is impenetrable for a blast wave with selected parameters, and considering the protective device as a continuous wall. This assumption allow us to decrease considerably the size of safety device blast wave interaction simulation. For further steps, the safety device, considered as rigid – stress analysis of the full device for acting pressure, will be made after the full analysis.

To determine the overpressure level acting on the operation station structure, the simulation model of blast wave interaction with building was made. Sizes of the building are following: height – 4 meters, length - 15 meters. Explosion occurs 65 meters away from the building front wall. Blast wave interaction with the building is shown in Figure 6.
Pressure distribution over the building divided to specific areas: the flow separation area is near the edges of building walls; the wall central area – the area in the center of the wall where pressure distribution is regular. Overpressure values for considered areas were achieved in simulation, and are provided in Table 3.

**Table 3. Overpressure on specified building areas**

|                         | Pressure  |
|-------------------------|-----------|
| Maximum of building     | 178 kPa   |
| Front wall              | 125 kPa   |
| Roof                    | 62 kPa    |
| Back wall               | 36 kPa    |

Duet regulation [2] over pressure higher than 100 kPa leads to complete destruction of buildings. Hence, it is necessary to decrease overpressure on operational station wall.

The simulation model with the building was covered by the safety device. The safety device with the following parameters are analyzed:

1. Safety device height – 4 m., 5.5 m., 7 m., 8.5 m.
2. Device location distance from the building front wall - 2 m., 4 m., 6 m., 8 m., 10 m., 12 m.

Results of the simulation are organized in diagrams, which show pressure-height-distance dependence. The obtained diagrams allow one to preliminary design the safety device parameters to protect the building with similar sizes from blast load with similar parameters. The global pressure reduction coefficient (GPRC) diagram is shown in Figure 7 a. Pressure diagrams for different areas are shown in Figures 7 b and 7 c.

![Global Pressure Decrease Coefficient](image)

**Figure 7. Global pressure reduction coefficient**

a) GPRC dependence on device height and distance from protected structure.

b) Pressure on device front wall depending on device height and distance from protected structure.

c) Pressure on building front wall depending on device height and distance from protected structure.
5. Model and analysis time
HP EliteBook 8570w with Core i7-3840QM (4x2.80 GHz cores), 32 GB RAM used to run analysis. Three types of model was used do made provided analysis.
   1. 3-dimentional CEL model of the dampener.
   2. Quasi 2-dimensional CEL model of the dampener.
   3. Quasi 2-dimensional CEL model of the protective device and the dampener.

    The run of model 1 takes ~12 hours on the mentioned PC. Model 2 is created to decrease analysis run time. The run of model 2 takes ~1 hour on the mentioned PC. Results of model 1 & 2 were compared, and model 1 turned out to be more conservative than model 2.

6. Analysis verification
To verify the CEL method adequacy for the blast wave-structure interaction analysis, the authors created a special model to verify simulation results and real life test data.

    Comparison of simulation and experimental data of blast wave interaction with the brick wall were made and published in paper [4]. The obtained results show that the difference between the simulation and the experiment is no more than 3-7%.

7. Conclusion
The achieved results confirm that the safety device can decrease overpressure due to the blast wave load on protected structures. This allows putting the device on existing oil & gas plants instead of rebuilding the existing infrastructure.

    The provided method allows designing and analyzing the safety device for different blast wave parameters. The coupled Euler-Lagrange method allows one to model simulation of blast wave interaction with the damper. It is possible to use the method for approximate analysis of blast loads acting on the protective device.

    Future research will consider solution of full 3-dimentional analysis of blast wave interaction with the protective device frame with installed dampeners.

References
[1]  Tlyasheva R R, Smolnikov O L, Tropkin S N, Bayazitov M I 2011 World community: Problems and solutions 30 71-73
[2]  GD 03-409-01 2001 Methodology for assessing the consequences of accidental explosions of fuel and air mixtures. Approved by the resolution of the Gosgortekhnadzor of Russia 26.06.01 № 25. 16
[3]  SR 09-540-03 2003 General Explosion-proof Rules for Explosion-Proof Chemical, Petrochemical and Refineries 2003. 125
[4]  Tropkin S N, Tlyasheva R R, Bayazitov M I, Rafikova Z R, Kuzeev I R 2013 Oil and Gas business. Electronic Scientific Journal 1 476-486