Numerical Simulation of Dust Layer Dispersion Due to Rarefaction Waves

R. Klemens, P. Kosinski*

Warsaw University of Technology, Warsaw, Poland

*Corresponding author: Warsaw University of Technology, Institute of Heat Engineering, ul. Nowowiejska 25, 00-665 Warsaw, Poland, tel.: (48-22) 825-02-41, fax: (48-22) 825-05-65, e-mail: <u>pkos@itc.pw.edu.pl</u>

Abstract: One of the methods of dust explosions mitigation is the use of venting systems, the task of which is to diminish the pressure rise. Nevertheless, the systems possess some inherent drawbacks. One of them is the presence of rarefaction wave, which propagates back and may interact with dust layers, which are present inside the facility. The objective of the study is to simulate the process of dust lifting caused by rarefaction waves and show how it may lead to the formation of combustible dust-air cloud.

Key words: CFD, dust explosions, venting systems, industrial safety, rarefaction waves

Introduction

Dust-air explosions in industrial facilities lead to severe accidents and casualties. The main tasks of the researchers who deal with those problems are to investigate the phenomenon and to find methods of prevention and mitigation. One of the most popular solutions is the use of venting systems that reduce the pressure rise and in this way protect the facility against destruction. It produces, however, a rarefaction wave propagating back towards the vessel (see e.g. [2]). This phenomenon, in the presence of dust layers located in the vicinity of the diaphragm may turn out especially dangerous when there has been no serious explosion, but only an instantaneous pressure rise due to some local and small-scale effects. The rarefaction wave may lift the dust from those layers and form a combustible dust-air mixture. In the present research, numerical simulation of the phenomenon has been performed. The objective has been to see whether it is theoretically feasible to predict the formation of the combustible mixture caused by the presence of the rarefaction waves.

The mathematical model used in the calculation is a two-fluid one: it assumes that the both phases are treated in Eulerian manner (see e.g. [1]). The flow of the gas phase is described by Navier-Stokes system of equations, and the dust phase by similar equations where the pressure and viscosity are set to zero.

$$\frac{\partial \rho_1}{\partial t} + \frac{\partial \rho_1 u_1}{\partial x} + \frac{\partial \rho_1 v_1}{\partial y} = 0$$

$$\frac{\partial \rho_1 u_1}{\partial t} + \frac{\partial \rho_1 u_1^2 + p}{\partial x} + \frac{\partial \rho_1 u_1 v_1}{\partial y} = \frac{\partial T_{11}}{\partial x} + \frac{\partial T_{12}}{\partial y} - f_X$$

$$\frac{\partial \rho_1 v_1}{\partial t} + \frac{\partial \rho_1 u_1 v_1}{\partial x} + \frac{\partial \rho_1 v_1^2 + p}{\partial y} = \frac{\partial T_{21}}{\partial x} + \frac{\partial T_{22}}{\partial y} - f_Y$$

$$\begin{aligned} \frac{\partial E_1}{\partial t} + \frac{\partial u_1(E_1 + p)}{\partial x} + \frac{\partial v_1(E_1 + p)}{\partial y} &= \frac{\partial}{\partial x} \left(\lambda \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left(\lambda \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial x} \left(u_1 T_{11} + v_1 T_{12} \right) + \frac{\partial}{\partial y} \left(u_1 T_{21} + v_1 T_{22} \right) + \\ &+ f_X \left(u_1 - u_2 \right) + f_X \left(u_1 - u_2 \right) - Q \\ \frac{\partial \rho_2}{\partial t} + \frac{\partial \rho_2 u_2}{\partial x} + \frac{\partial \rho_2 v_2}{\partial y} &= 0 \\ \frac{\partial \rho_2 u_2}{\partial t} + \frac{\partial \rho_2 u_2^2}{\partial x} + \frac{\partial \rho_2 u_2 v_2}{\partial y} &= f_X \\ \frac{\partial \rho_2 v_2}{\partial t} + \frac{\partial \rho_2 u_2 v_2}{\partial x} + \frac{\partial \rho_2 v_2^2}{\partial y} &= f_Y \\ \frac{\partial E_2}{\partial t} + \frac{\partial u_2 E_2}{\partial x} + \frac{\partial v_2 E_2}{\partial y} &= -f_X \left(u_1 - u_2 \right) - f_X \left(u_1 - u_2 \right) + Q \end{aligned}$$

In the above:

subscripts 1 and 2 denote the gas and the solid phase, respectively *f* and *Q*: the drag force and the heat exchange between the phases, respectively *ρ*, *T*, *p* - density, temperature and pressure, respectively *E* - the total energy *u*, *v* - x- and y-components of the velocity, respectively *λ* - the heat conductivity of the gas phase

- T_{ii} - the stress components

Description of the problem and the results

In the paper, two problems are considered. The first one is one-dimensional computation of the interaction between a rarefaction wave and a dust deposit (Fig.1). The length of the dust deposit has been equal to 50 mm and is situated on the left side of the channel in a highpressure section. The pressure in the section is higher than the ambient one and is equal to 2 bar. On the right side of the high-pressure section there is a low-pressure section with the ambient parameters. The difference of pressure causes the rupture of the diaphragm between them. The case corresponds to some real situations when the venting system started working in connection with some pressure rise in a facility. In the Fig.2 some of the results are shown: in the Fig.2a the dust concentration distribution along the channel is presented for different time moments, and in the Fig.2b histories of dust concentration at two points -100 and 150*mm* from the left side of the channel are shown. It is clear that the dust entrainment due to the rarefaction wave is really observed, and the dust may form the dust-air explosive mixture. The second problem (Fig.3) simulates more real problem: in an imaginary industrial facility dust occupies some space lying on various pieces of equipment. Due to instantaneous rise of pressure, the venting system starts working and produces a rarefaction wave, which causes the entrainment of dust from the deposits. Further movement of the dust particles is caused by the

flow of the air and the gravity. The results of the computer simulation are presented in Fig. 4.

Summary and discussion

In the present paper the results of computer simulation of dust layer dispersion by rarefaction waves have been shown. Two cases have been investigated: the first one, as one-dimensional modelling, may be used to examining the main physical phenomena. The second one simulates a real case in an industrial facility. It has been presented how the opening of a venting system may cause the formation of a combustible mixture. The venting system may start working due to some primary explosion, which has not formed the dust-air explosive mixture, but if it were formed, the resulting dust entrainment would be much more intensive, because of the two mechanisms: shock waves (the primary explosion), rarefaction waves (the venting system).

The working of the venting systems may intensify the process even more due to resulting turbulence. It will be, however, considered in further works.

Acknowledgments

The work was supported by the Committee for Scientific Research in Poland grant 9T12A04319. The calculations have been performed using the computer equipment of Warsaw University of Technology.

References

[1] Collins J.P., Fergusson J.P., Chien K.Y., Kuhl A.L., Krispin J., Glaz H.M., *Simulation of schock-induced dusty gas flows using various models*, AIAA, 94-2309, 1994

[2] Geng J.H., Gronig H., Medvedev S.P. *Shock Tube Study of Dust Layer Dispersion by Rarefaction Waves*, Proceedings of the Fifth International Colloquium on Dust Explosions, Pultusk, 1993

[3] Liu B.Y., Roth P., Zell U. *Particles Dispersion by Shock and Expansion Wave*, J. Aerosol Science, v.15, pp.293-256, 1984

Figures

 $P_1 > P_o$ dust P_o deposit

Fig.1. The one-dimensional simulation of dust lifting from a layer by the rarefaction wave







Fig.3. The two-dimensional simulation of dust lifting from a layer by the rarefaction wave: the scheme of the geometry in the channel and dust deposits.



Fig.4. The two-dimensional simulation of dust lifting from a layer by the rarefaction wave: