Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 27, issue 2 / 2021, pp. 42-48

USING THE PIV TECHNIQUES IN THE EXPERTISE OF GAS EXPLOSIONS

Nicolae Ioan VLASIN[1], George Artur GĂMAN[2], Emilian GHICIOI[3], Gheorghe Daniel FLOAREA[4], Adrian Bogdan ȘIMON-MARINICĂ[5]*

[1]INCD INSEMEX Petroșani, Petroșani, Romania, insemex@insemex.ro
[2] INCD INSEMEX Petroșani, Petroșani, Romania, insemex@insemex.ro
[3] INCD INSEMEX Petroșani, Petroșani, Romania, insemex@insemex.ro
[4] INCD INSEMEX Petroșani, Petroșani, Romania, insemex@insemex.ro
[5] INCD INSEMEX Petroșani, Petroșani, Romania, insemex@insemex.ro

DOI: 10.2478/minrv-2021-0015

Abstract: *Given the possibilities offered by PIV systems, it was considered appropriate to test them in the study of the formation of explosive atmospheres. In this sense, within the INCD INSEMEX Petroșani laboratories, a test stand was created subject to the conditions of applying PIV techniques. Thus, this stand was built of transparent materials, having the possibility to introduce, in the inner volume, the suspended particles and the combustible gas, being at the same time able to be sectioned by the light plane generated by a laser source and to provide the recording conditions using a CMOS camera. The physical experiments concerned both the situation of a normal atmosphere inside the test stand and the situations of the appearance of a fuel gas leak and an efficient source of initiation of the formed explosive atmosphere.*
Keywords: *explosive atmospheres, PIV, air-methane mixture, gas leaks, technical expertise*

1. Introduction

The principle underlying PIV (Particle Image Velocimetry) techniques is to compare the position of a particle suspended in a transparent and homogeneous fluid medium between two images taken at a known time interval. The method is applicable in the study of fluid movement for applications reserved for small-scale laboratory investigations [1]. The hardware system that makes it possible to visualize the displacements in the fluid environment under analysis consists of a laser generator that pulsates a light plane with the wavelength and frequency corresponding to the studied fluid (Figure 1). The correlation of the generator frequency with the recording speed of the CCD or CMOS camera is performed by means of a software or manually controlled synchronizer. The system also contains a particle generator needed to produce (in this case) the oil droplets used as witnesses in the image acquisition process.

The movement of the fluid in the area of interest is highlighted by particles in the laser light plane [2]. The video camera, mounted perpendicular to the light plane, records separate images at each pulse of light. Once a sequence of two pulses of light is recorded, the images are then divided into smaller subsections called query areas [3]. The query areas in each image frame are analyzed pixel by pixel, resulting in an accurate measurement of movement, implicitly of travel speed [4]. Based on these determinations, in the dedicated application is made a map of speed vectors over the entire area of interest, by repeating the intercorrelation procedure for each query area, for the sequences of two frames captured by the video camera.

Given the possibilities offered by PIV systems, it was considered appropriate to test them in the study of the formation of explosive atmospheres. The process of mixing combustible gases with air has usually been explained by the application of diffusion formulas and / or by the calculation of hazardous gas concentrations from accidental leaks or releases. In this context, by visualizing in real time the process of mixing a combustible gas with air, a new

[*] Corresponding author: Nicolae Ioan Vlasin, PhD. Eng., INCD INSEMEX Petroșani, Petroșani, Romania, contact details (General Vasile Milea st. no. 32-34, Petroșani, Romania, insemex@insemex.ro)

field of study is born that can bring a surplus of knowledge in combating explosion events and the development of appropriate protection measures. INCD INSEMEX Petroșani being accredited in the elaboration of technical expertise reports of gas explosion type events, the new field finds its immediate applicability, contributing to the explanation of the mechanisms and causes that led to the occurrence of events of this nature.

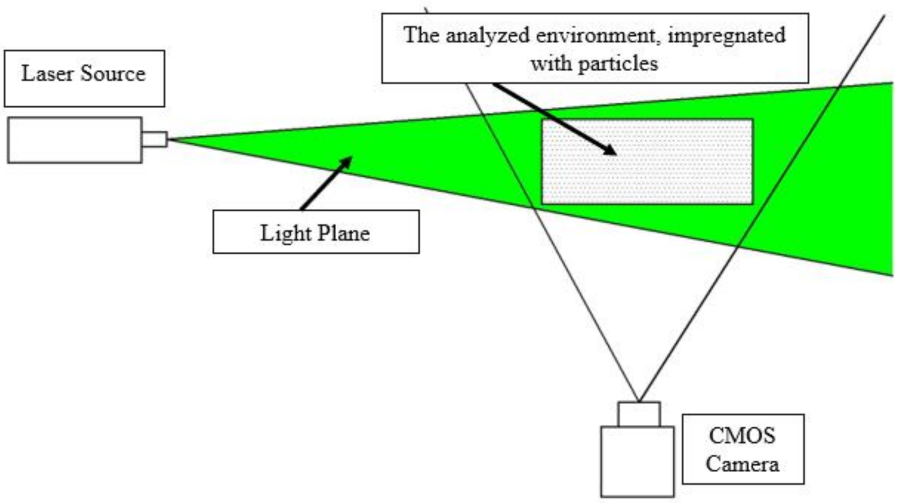


Fig. 1. Schematic diagram of a PIV system

In this sense, within the INCD INSEMEX Petroșani laboratories, a test stand was created subject to the conditions of applying PIV techniques. Thus, this stand was built of transparent materials, with the possibility of introducing in the inner volume of suspended particles and combustible gas, being also able to be sectioned by the light plane generated by the laser system and to provide the conditions of video camera recording.

2. Construction of the test stand

In order to be able to be sectioned by a laser light plane and to be able to record images from inside, the test stand was made of glass. Its geometry includes two rooms of different volumes and an L-shaped hall. Both rooms communicate with the hall through door-like holes, intentionally designed as open holes. The hall is also provided with a hole in the form of an access door to / from the outside. This hole is covered with a very thin plastic foil, with the role of keeping the suspended particles inside the stand and, at the same time, in order to ensure the release of the overpressure generated by the ignition of the explosive mixture (Figure 2).

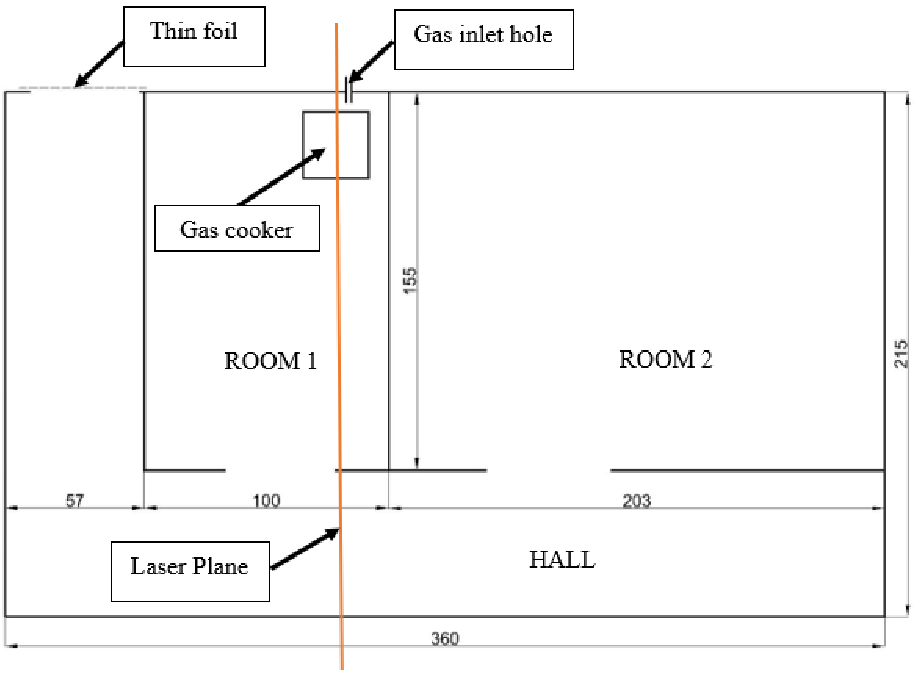


Fig. 2. Geometry of the test stand

vol. 27, issue 2 / 2021
pp. 42-48

A parallelepiped solid body was introduced inside Room 1, acting as a cooking machine, with dimensions proportional to the volume of the room. As shown in Figure 2, the stand was provided with a combustible gas inlet. On the way in, the gas flow hits behind the cooking machine, to simulate the most common cases in reality, in the domestic field.

The suspended particles are introduced inside the stand through the access hole in the hall, after which this hole is closed with the help of plastic foil. Figure 3 shows, as a whole, the test stand made.

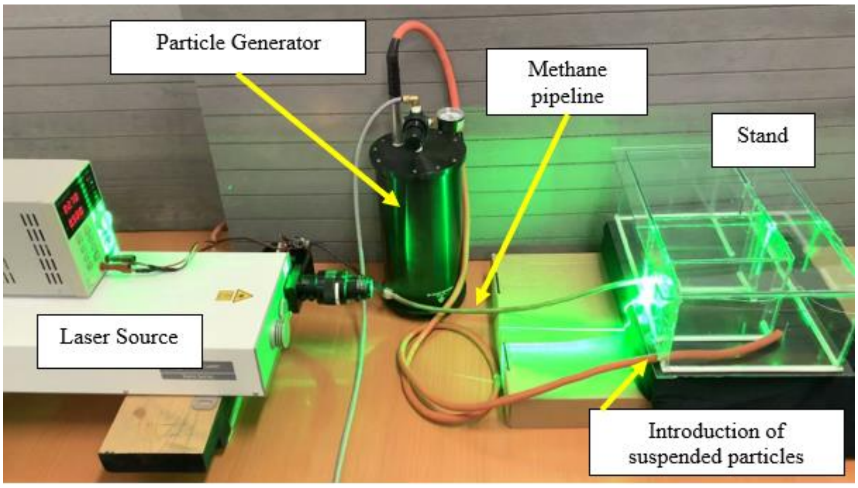


Fig. 3. Test stand

3. Carrying out experiments and interpreting the results

The physical experiments performed on the test stand covered three different situations, simulating the case of an accidental leakage of combustible gas, as follows:

- The situation of the normal atmosphere - the environment is not influenced by external factors;
- The appearance of fuel gas leakage - the volume of the stand receives a supply of methane gas;
- The appearance of the ignition source - initiation of the explosive atmosphere formed inside the stand.

3.1. The situation of the normal atmosphere

After inserting the suspended particles and closing the hall opening with plastic foil, the internal environment of the stand was passed in a rest period of 30 minutes, in order to attenuate the fluid movements generated by this action.

The start of the PIV system resulted in the formation of the light plane (according to Figure 2) and the highlighting of the suspended particles captured in this plane. Simultaneously with the pulses generated by the laser source, the CMOS camera recorded sequences of two frames that it opened in the software dedicated to the PIV system - INSIGHT 4G - for the first processing and display of the vector field of speeds (Figure 4).

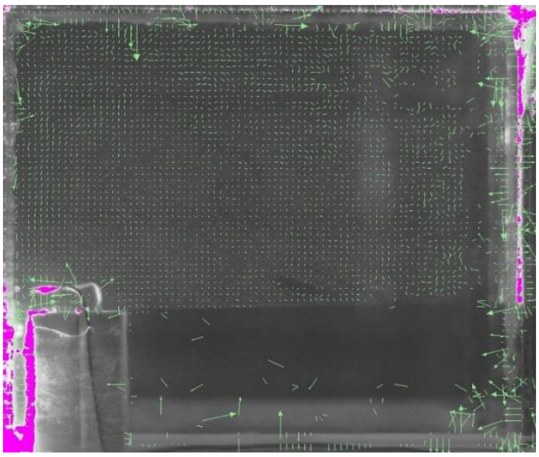
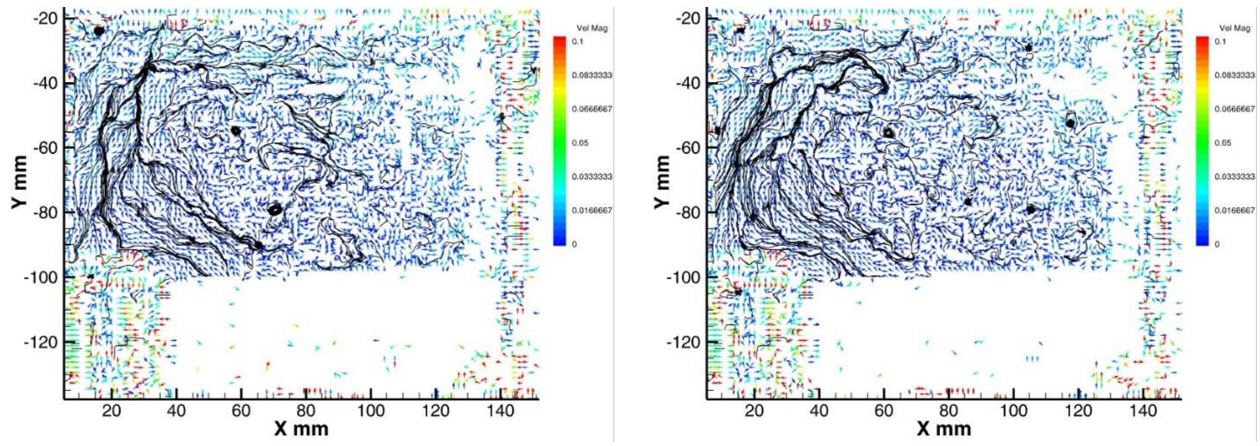


Fig. 4. Vector field of velocities in normal atmosphere, displayed in INSIGHT 4G

vol. 27, issue 2 / 2021
pp. 42-48

For a more detailed analysis of the resulting data, the files generated by INSIGHT 4G were uploaded to the Tecplot 360 application. The features of this software allowed, in addition to a wider range of options for displaying speed vectors, to draw flow lines [5] from inside Room 1, visualizing the fluid movements in the light plane becoming much easier. In Figure 5 are shown the vector fields of the velocities and the currents lines at an arbitrary moment t_0 (a) and at the moment t_3 = 0,2 s (b) during the recordings.



a) b)

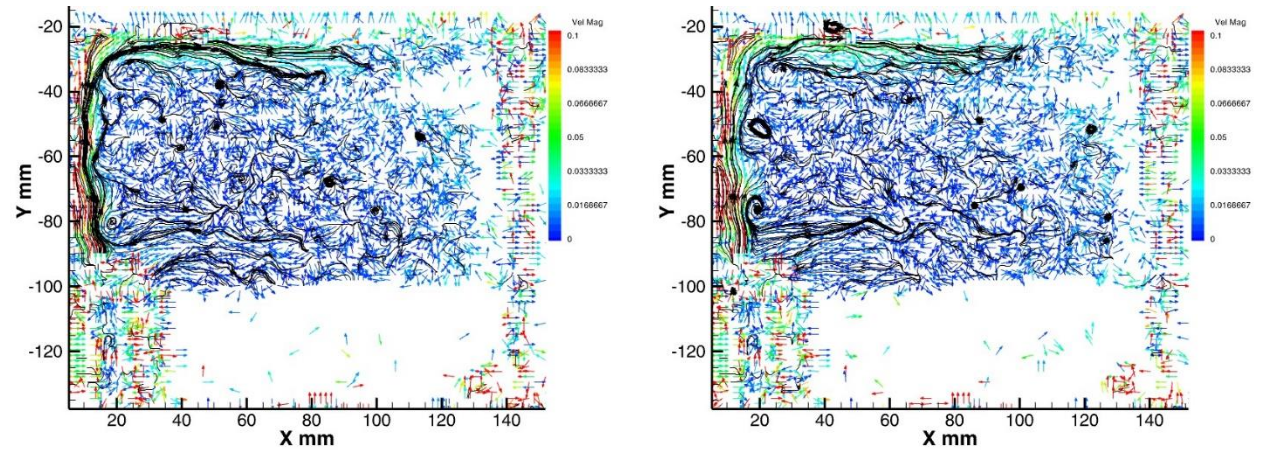
Fig. 5. Vector fields and lines of air currents in normal atmosphere, at t_0 a) and t_3 = 0,2 s b) displayed in the Tecplot 360 application

Figure 5 shows the vector fields on a scale with the range 0 - 0.1 m / s which highlights the existence of convective air currents generated by small temperature differences between solid bodies (cooking machine, walls, floor, ceiling) and the fluid environment. The lack of vectors at the bottom of the field is due to the shadow created by the cooker in the light plane.

3.2. The occurrence of combustible gas leakage

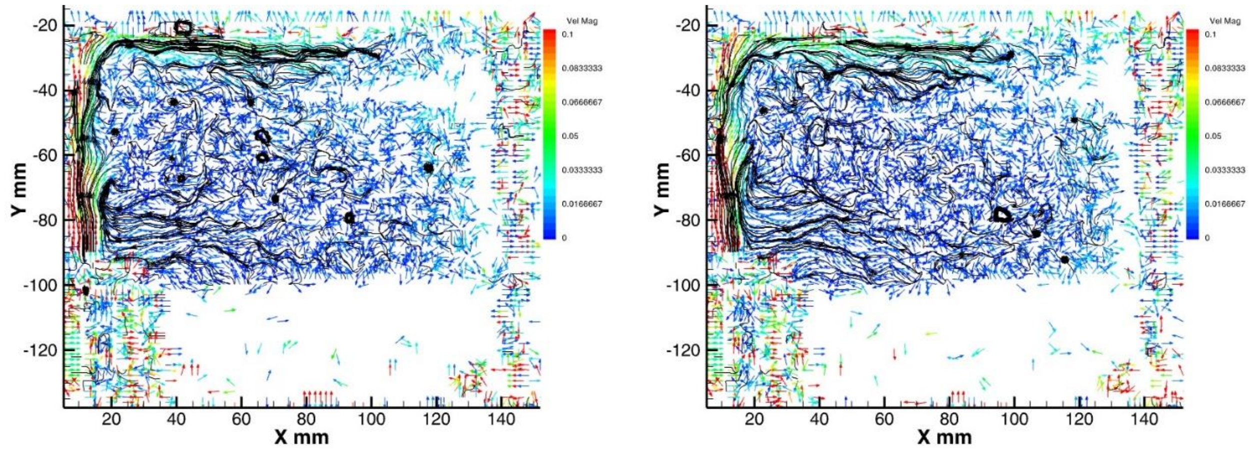
The methane gas flow at a concentration of 96% vol CH4 was introduced through a hole with a diameter of 2 mm, at a pressure of 20 mbar. The recordings made through the PIV system were initiated with a delay of 5 seconds from the zero moment of the introduction of methane gas, to allow a stabilization of the gas flow in the volume of Room 1. As mentioned above, the flow of methane gas was directed to the rear of the cooking machine, in order to obtain a diffusion similar to real cases.

To visualize the vector field in this phase of the experiments, the same steps were taken as in the previous situation, respectively image processing in INSIGHT 4G and Tecplot 360 applications. Figure 6 shows a temporal sequence of images starting with time t_0 = 5 s, highlighting the formation of explosive air-methane gas mixture.



a) t_0 = 5 s b) t_1 = 5,067 s

 vol. 27, issue 2 / 2021
pp. 42-48



c) t_2 = 5,133 s   d) t_4 = 5,267 s

Fig. 6. Vector fields and flow lines at different times in the process of forming the explosive atmosphere, displayed in the Tecplot 360 application, on a scale with the range 0 - 0.1 m / s

Comparing the sequences of images in Figures 5 and 6, we can see the major differences in the arrangement of the fluid flow lines after the appearance of the methane gas source, compared to the situation of the normal atmosphere. Being less dense, the methane gas tends to higher levels of the room volume, at the same time entraining nearby air masses, with which it enters the mixture. With the activation of the methane gas source, the increase of the entropy at the level of the air volume is noticed, as well as the increase of the number of vortices and their intensity, which accelerates the mixing process of the two gases.

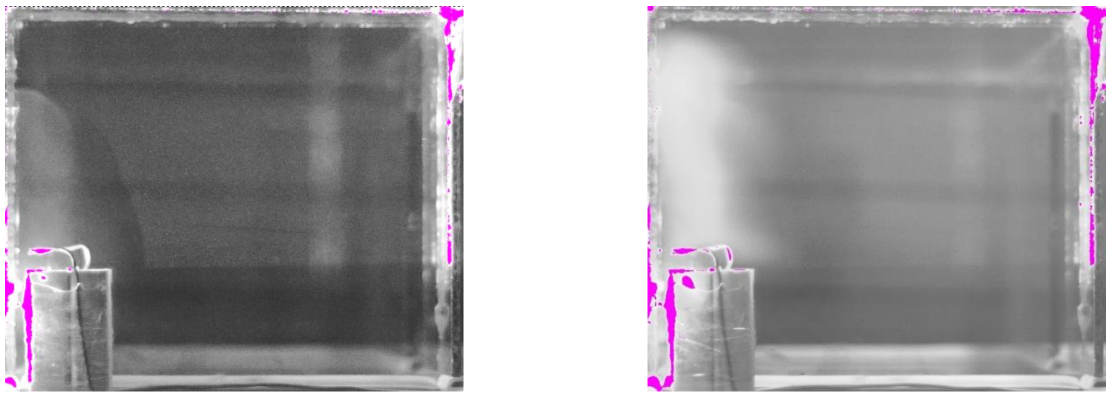
3.3. The appearance of the ignition source

It is well known that an explosion-type event requires the existence, at the same time and space, of three elements: fuel, oxidant and the source of initiation. As the fuel (methane gas) and oxidant (oxygen in the air) are already present in the atmosphere of the test stand, at this stage of the experiments a source of initiation was added. It was placed on top of the cooking machine and consisted of two electrodes between which the electric spark was generated.

An important factor in recording explosion phenomena is the processing speed of the video camera and, in the case of PIV techniques, the pulse frequency of the laser source. Another impediment in the recording of explosions by means of these techniques is the need to use different densities of suspended particles for different speed regimes. Last but not least, the flame front burns the suspended oil particles, making it impossible to visualize the movements of the fluids in the flue gas area.

However, by repeating the experiments it is possible to capture some frames from the beginning phase of the formation and expansion of the flame front, when the speed regime shows relatively low values.

Figure 7 shows a sequence of two images required by the system to generate the vector field, at a time immediately following the initiation of the explosive atmosphere. Because the moment of the spark occurrence escapes from the recordings, the time at which the images were recorded (considering t_0 the moment of initiation) is undefined.



a)   b)

Fig. 7. Sequence of two images representing the phase of formation and extension of the flame front

vol. 27, issue 2 / 2021
pp. 42-48

The image in Figure 7 captures a moment when the flame front is very thin, clearly defining the boundary between flue and unburned gases. In Figure 7 b the flame front evolved both in surface and thickness, making the boundary between reactants and reaction products unclear.

The vector field of the velocities, on a scale with the range 0 - 0.8 m / s, as well as the fluid current lines are shown in Figure 8.

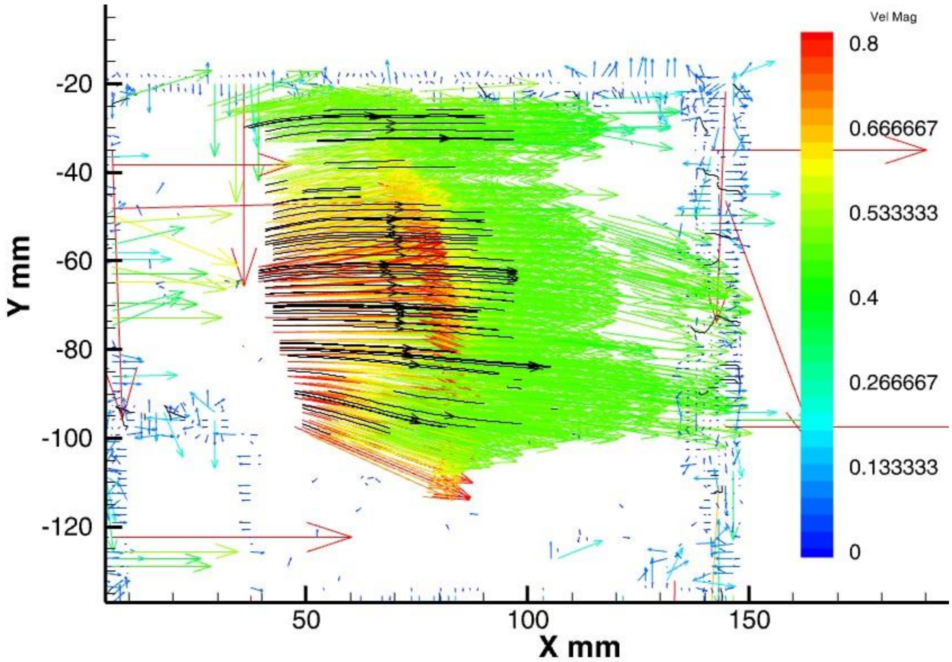


Fig. 8. Vector field of low speed and current lines highlighted in the Tecplot 360 application

The images recorded after the sequence in Figure 7, having no suspended particle content, did not generate velocity vectors.

4. Conclusions

Analyzing the results of the experiments performed and described above, by using the PIV system and the exposed methods, the following were highlighted;

- Reaching the resting state of fluids in a closed environment requires a long period of time, the internal movements being dictated by the heat exchange between the solid bodies and the gas volume;
- The appearance of a fuel gas leak influences the entropy of the environment in which it takes place, the continuation of the release leading to the acceleration of the mixing process and the decrease of the time period necessary for the formation of the explosive atmosphere;
- The initiation of the explosive mixture becomes possible when the local hazardous concentration is reached, in the vicinity of the ignition source, not being conditioned by the global concentration, of the entire fluid volume.

The PIV system used in the experiments, with a laser generator frequency of only 15 Hz, may be inadequate for gas explosion process records. Limiting the speed regime and burning the suspended particles are solid arguments in support of this statement. To record the moment of initiation and the subsequent burning process it is recommended to use other techniques (for example Schlieren) and video cameras with higher recording speeds.

However, the system described above has proven effective in developing a method of analyzing the formation of explosive atmospheres, highlighting subtle qualities of the fuel gas diffusion process. Mounted on appropriate stands, respecting the geometry and real conditions in the field, PIV systems can contribute to the decision-making process of positioning toxic / explosive gas sensors in work environments where these requirements exist.

Also, complex experiments can be performed on the stand by positioning the initiation source in different locations and even relocating the fuel gas source. Moreover, the geometry of the stand can be modified depending on the field conditions of the event under analysis.

vol. 27, issue 2 / 2021
pp. 42-48

The use of the PIV system and of the methods described in the paper have immediate applicability in the elaboration of the technical expertise reports of the gas explosion type events, INCD INSEMEX Petroșani being accredited in this respect.

Acknowledgment

This paper was developed within the Nucleu-Programme, carried out with the support of Romanian Ministry of Research, Innovation and Digitalization, project no. PN-19-21-01-05.

References

[1] **Calluaud, D., David, L.,** 2004
Stereoscopic particle image velocimetry measurements of the flow around a surface-mounted block., Experiments in Fluids

[2] **Raffael, M., Willert, C., Kompen, J.,** 2000
Particle Image Velocimetry, ed. Springer-Verlag.

[3] **TSI,** 2015
Insight 4G Global Image, acquisition, analysis, and display software. User's guide, https://tsi.com/product-components/insight-4g-version-11-2-global-imaging,-acquisition,-analysis-and-display-software/

[4] **Adrian, R.J.,** 1983
Laser Velocimetry, in Fluid Mechanics Measurements, ed. Springer-Verlag.

[5] **Tecplot, Inc,** 2021
Tecplot 360 ex User`s Manual, https://download.tecplot.com/360/current/360_users_manual.pdf