Development of a Methodology for Toxic and Flammable Gases Sensors Positioning in Oil Platforms

Giordhanne Bruno Carpaneda Gimenes

Mechanical Engineer, CHEMTECH - A Siemens Company
Rio de Janeiro, RJ, Brazil
giordhanne.gimenes@chemtech.com.br

Aristeu da Silveira Neto, PhD.

Federal University of Uberlândia -FEMEC/LTCM
Uberlândia, MG, Brazil
aristeus@mecanica.ufu.br

Solidônio Rodrigues Carvalho, D.Sc.

Federal University of Uberlândia -FEMEC/LTCM
Uberlândia, MG, Brazil
srcarvalho@mecanica.ufu.br

Valter César de Souza, D.Sc.

Consultant, CHEMTECH - A Siemens Company
Rio de Janeiro, RJ, Brazil
valter.souza@chemtech.com.br

Patrícia Carneiro dos Santos

Process Engineer, CHEMTECH - A Siemens Company
Rio de Janeiro, RJ, Brazil
patricia.santos@chemtech.com.br

ABSTRACT

Computational fluid dynamics (CFD) and mechanical systems optimization concepts are currently quite important tools for engineering problems analysis. A typical application of such tools is gas dispersion studies, a theme of great importance for the oil and gas industry. An important safety item for oil and gas production installations (especially oil rigs) is the use of flammable and/or toxic gas sensors to detect gas leaks capable of starting fires, explosions and causing toxic exposure. The

Importance of these sensor rules may be evaluated if one considers all potential costs of compensations, environmental impacts, life loss and profit loss.

This work presents the development of a computational tool that supplies optimum position and number for gas detectors in an oil platform. Associating CFD simulation results with coherent mathematical treatment, this methodology presents improvements in relation to other studies of gas dispersion and sensor positioning. This mathematical treatment supported by this computational tool is responsible for all calculation methods and for the display of graphical results of the locations to place detectors both for toxic (hydrogen sulfide, for instance) and flammable (like methane) gases.

Gas detection projects are usually based on standards and technical notes that do not supply all necessary information for proper sensor positioning. In the same way, although qualitative methodologies are used intensively and are quite accepted, they are not as accurate because, in most cases, the final decision is based on personal analysis and previous experience. Although experience will always remain an important asset in this kind of service, development of such a computational tool as the one described in this paper will reduce project schedules, besides providing more accurate and less intuitive results.

1. INTRODUTION

One of safety items for oil installations is the use of concentration sensors for flammable and/or toxic gases due to high risk proportionated by leaks (fires, explosions, intoxications and others). Consequences of an accident will result in considerable setbacks including compensation, environmental impact and profit stagnation. Furthermore they damage operator’s image before investors and society. Pioneering companies in safety studies developed methods for the determination of the positioning of these sensors; however such methodologies are not published because of their strategic value.

Nowadays, gases detection project are usually based on norms and technical notes that don't supply all the necessary information for the correct positioning of the sensors. In the same way, qualitative methodologies are used intensely, however, in spite of being accept; they are not so good because, most of the time, final decision is based on the personal analysis and the engineer's experience.

Due to the mentioned reasons, a new methodology of easy application and in agreement with the norms and specifications in vigor is being developed by CHEMTECH Services of Engineering and Software Ltda. in partnership with the Laboratory of Heat and Mass Transfer and Fluid Dynamics (LTCM) (College of Mechanical Engineering (FEMEC) of the Federal University of Uberlândia (UFU)).

This methodology is based on the use of data resultant from gas dispersion simulations through CFD – Computational Fluid Dynamics. These data are treated with statistical methods aiming to identify the necessary places for the installation of gas detectors. This treatment is executed with the support of a computational tool that is responsible for the process calculation and supplies graphical results of most indicated areas for the installation of detectors.

2. METHODOLOGY

The methodology in development can be used both to toxic gas (sulphidric gas, for instance) and to flammable gas. In the present article, however, it will just be broached the detection of flammable gas, through the example of methane (CH_4). This gas is predominant in the natural gas composition (Table 1) and so it deserves special attention in the studies of gases dispersion and allocation of detectors in oil facilities.

ORIGIN	% VOLUME						Density	Superior Calorific Power (MJ / Nm³)
Country / Field	Methane CH_4	Propane C_2H_8	Ethane C_3H_8	C_4 and Higher	CO_2	N_2		
USA/Panh.	81,8	5,6	3,4	2,2	0,1	6,9	-	42,7
USA/Ashlaw	75,0	24,0	-	-	-	1,0	-	46,7
Canada	88,5	4,3	1,8	1,8	0,6	2,6	-	43,4
Russia	97,8	0,5	0,2	0,1	0,1	1,3	-	39,6
Australia	76,0	4,0	1,0	1,0	16,0	2,0	-	35,0
France	69,2	3,3	1,0	1,1	9,6	0,6	-	36,8
Germany	74,0	0,6	-	-	17,8	7,5	-	29,9
Netherlands	81,2	2,9	0,4	0,2	0,9	14,4	0,640	31,4
Persia	66,0	14,0	10,5	7,0	1,5	1,0	0,870	52,3
North Sea	94,7	3,0	0,5	0,4	0,1	1,3	0,590	38,6
Algeria	76,0	8,0	3,3	4,4	1,9	6,4	-	46,2
Venezuela	78,1	9,9	5,5	4,9	0,4	1,2	0,702	47,7
Argentina	95,0	4,0	-	-	-	1,0	0,578	40,7
Bolivia	90,8	6,1	1,2	0,0	0,5	1,5	0,607	38,8
Chile	90,0	6,6	2,1	0,8	-	-	0,640	45,2
BRAZIL								
Rio de Janeiro	89,44	6,7	2,26	0,46	0,34	0,8	0,623	40,22
Bahia	88,56	9,17	0,42	-	0,65	1,2	0,615	39,25
Alagoas	76,9	10,1	5,8	1,67	1,15	2,02	-	47,7
Rio Grande do Norte	83,48	11	0,41	-	1,95	3,16	0,644	38,54
Espírito Santo	84,8	8,9	3,0	0,9	0,3	1,58	0,664	45,4
Ceará	76,05	8,0	7,0	4,3	1,08	1,53	-	52,4

Table 1: Composition of the natural gas.

Source: www.gasnet.com.br

Methane is an odorless and colorless gas. It has low solubility in water and when dispersed into the air (in certain ratios) it becomes a mixture with high explosive power. Some important physical-chemistry properties for this gas are in the Table 2.

METHANE		
NOMENCLATURE	MOLECULAR FORMULA	MOLECULAR WEIGHT
Methane, natural gas, gas of the swamps	CH_4	16,04
PHYSICAL-CHEMISTRIES PROPERTIES		
Physical state and risk classification: flammable, simple suffocating gas	Color and scent: Colorless of soft and sweetened scent.	
Solubility: $2{,}86 \times 10^{-3}$ g/L @ 20ºC	Reactivity: Forms explosive mixies with air and oxidizers agents. Incompatible with halogenous and interhalogenous.	
METHANE FLAMMABILITY		
Lower Flammable Limit: 5 % v/v	Extinguishers agents: CO_2, dry chemical pownder, water vapor for small focuses.	
Upper Flammable Limit: 15 % v/v	Incompatible extinguishing agents: Separately used water can be inefficient. Not to extinguish the flames before eliminating the emptying source, therefore the new ignition can be explosive.	
Toxic products of combustion: He is not toxic, but its partial combustion can generate toxic gases (CO).		
OBSERVATIONS		
It can be flamed by heat, flashes or open flames Cause asphyxia for oxygen reduction. It can provoke giddiness and asphyxia without acknowledgment. In the liquid phase, it can generate burning in the skin and eyes for freezing.		

Table 2: Some properties of methane.

Source: Crowl et al (2002), Cote (2003), Eltschlager et al (2001) e Perry (1997).

According to technical specifications usually employed in the oil and gas industry, alarms in the central control room should go off whenever levels from 20% to 60% of Lower Flammable Limit (LFL) for combustible gases are detected, where LFL is the minimum concentration of gas (% in volume) dispersed in the air that, in contact with an ignition source, is capable to cause combustion of the mixture. In a similar form, the Upper Flammable Limit (UFL) is the maximum gas concentration (% in volume) dispersed in the air that, in contact with an ignition source is capable to cause combustion of the mixture (Figure 1).

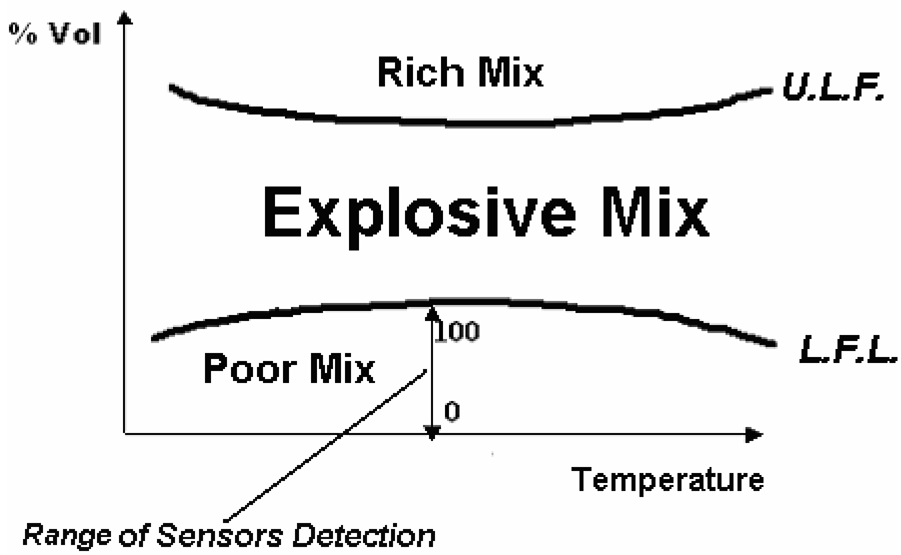

Figure 1: Strips of inflammability of a mixture gas-fuel

Source: Own elaboration

Lower Flammable Limit for methane is 5% in volume in air (Table 2), based on standard conditions of temperature and pressure (20°C and 1 atm). Therefore, the range of detection for this gas will be between 1% in volume (corresponding to 20% of the L.F.L) and 3% in volume (corresponding to 60% of the L.F.L).

In light of this information, three-dimensional gas dispersion simulations are carried out using tools of Computational Fluid Dynamics (CFD) considering geometric aspects, meteorological conditions and gas properties at leak conditions. Scenarios of leaks are simulated with several directions and speeds of wind, including wind calms. Meteorological conditions are important variables in models of gas dispersion (Crown et al, 2002), because gases are dispersed by wind. Atmospheric instability favors dispersion of the gaseous pollutant in the atmosphere. Particularly, in this study developed by the partnership CHEMTECH-UFU, the CFD tool used is the software PHOENICS (Parabolic Hyperbolic Or Elliptic Numerical Integration Code Series) - version 2006, developed by the British company CHAM (Concentration, Heat and Momentum Limited). CHEMTECH is the PHOENIC's licensor in Brazil. More details can be found in the website http://www.cham.co.uk.

In the computational tool in development by CHEMTECH-UFU the user should enter the data referring to leak conditions (probability of leak occurrence in a certain equipment or component) and meteorological aspects (probability of occurrence of each wind direction considered in the simulations). The reference data giving the probabilities of leaks can be extracted from historical reports supplied by the proper operator or from reports published by specialized institutions in health, safety and environment, such as the Health & Safety Executive (HSE), the agency responsible for health and safety regulation in Great Britain. The data for the probabilities of occurrence of winds in the considered directions can be obtained from existing meteorological stations in the area where the plant will be installed. With this information, the probabilities of occurrence of the flow configurations will be calculated. This probability is general and it takes into consideration both the leak occurrence as the wind occurrence and the analyzed direction, synthesizing in a unique value these two variables.

The probabilities calculation, is based on Bayes's Theorem. According to the magazine Ciência Hoje (2006) Thomas Bayes's reasoning is nowadays considered a new form to view the world, as the basis of a true revolution in different fields of the knowledge, from genetics to theology.

Bayes's Theorem is based on one of the basic beginnings of the probability: the probability that an event A occurs simultaneously with an event B, is given by the Equation (1):

$$P(A \cap B) = P(A/B).P(B) \quad (1)$$

Where P(A) and P(B) they are the occurrence probabilities of the events A and B, respectively, and $P(A/B)$ is the probability of occurrence of A considering that B has happened. The development of the Bayes's Theorem is available in specialized literatures in Statistics. The final form of this theorem is given by the Equation (2):

$$P(A/B) = \frac{P(B/A).P(A)}{\left[P(B/A).P(A)\right] + \left[P(B/A^c).P(A^c)\right]} \quad (2)$$

Where A^c is the complementary event of A, also called of $not\,A$. The bayesian reasoning is not intuitive, being conceptually a 'opinion modifier', in other words, the probabilities are adjusted with the knowledge of new evidences.

After the calculation of the probabilities, the next step is to load the output from CFD simulations (in the case of PHOENICS, extension .phi), separating the values of the variable of interest, in this case, concentration (variable C_1). Based on loaded files, reminding that the number of loaded files is the same to the number of simulations, a new file will be generated (C_2). In this file they will just be printed the computational volumes (Figure 2) that contain concentrations among $20\% \leq C_1 \leq 60\%$ of L.F.L. (for the methane, $1\% \leq C_1 \leq 3\%$ in volume). In the computational volumes out of this range, the value "zero" it will be attributed. At the end of this stage a file will be generated one C_3 file for each file .phi loaded.

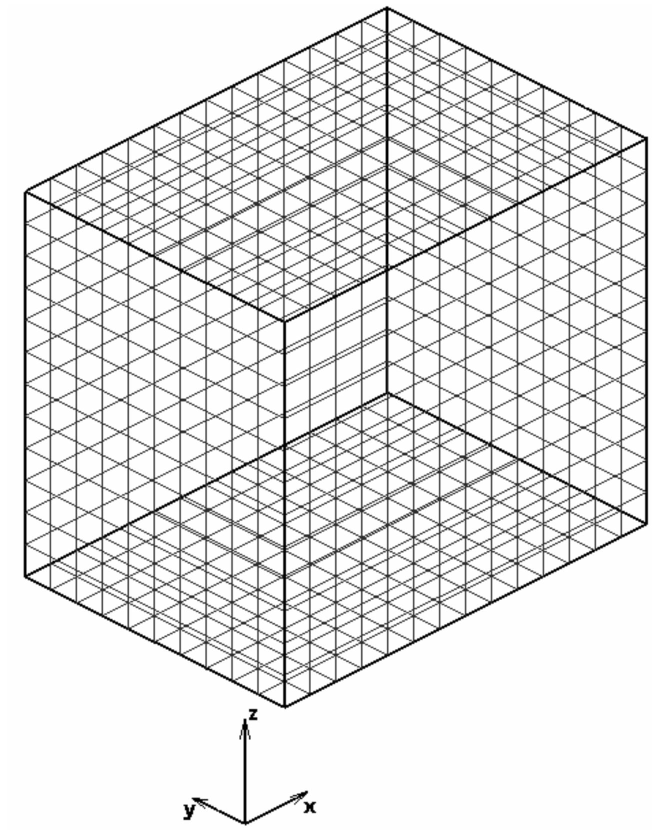

Figure 2: Three-dimensional domain divided in small computational volumes.

Source: Own elaboration.

Soon after, multiply each C_2 file for the respective occurrence probability (resultant of the calculation of the Bayes's Theorem), generating C_3 files. Then, all the files are compared, selecting the highest value for each volume, saving them in an unique file (C_4).

Finally, these values are normalized so that their range varies between 0 (zero) and 1 (one). This final file supplied by the computational tool in development by the partnership CHEMTECH-UFU, may be opened in a graphic software or in the own post-processing module of the CFD tool. This way, it is possible to visualize the field that shows importance index by colors the of the possible areas for allocation of sensors, among 0 (without need) and 1(priority). The Figure 3 summarizes these stages through a schematic flowchart of sequence of files created by this computational tool in development.

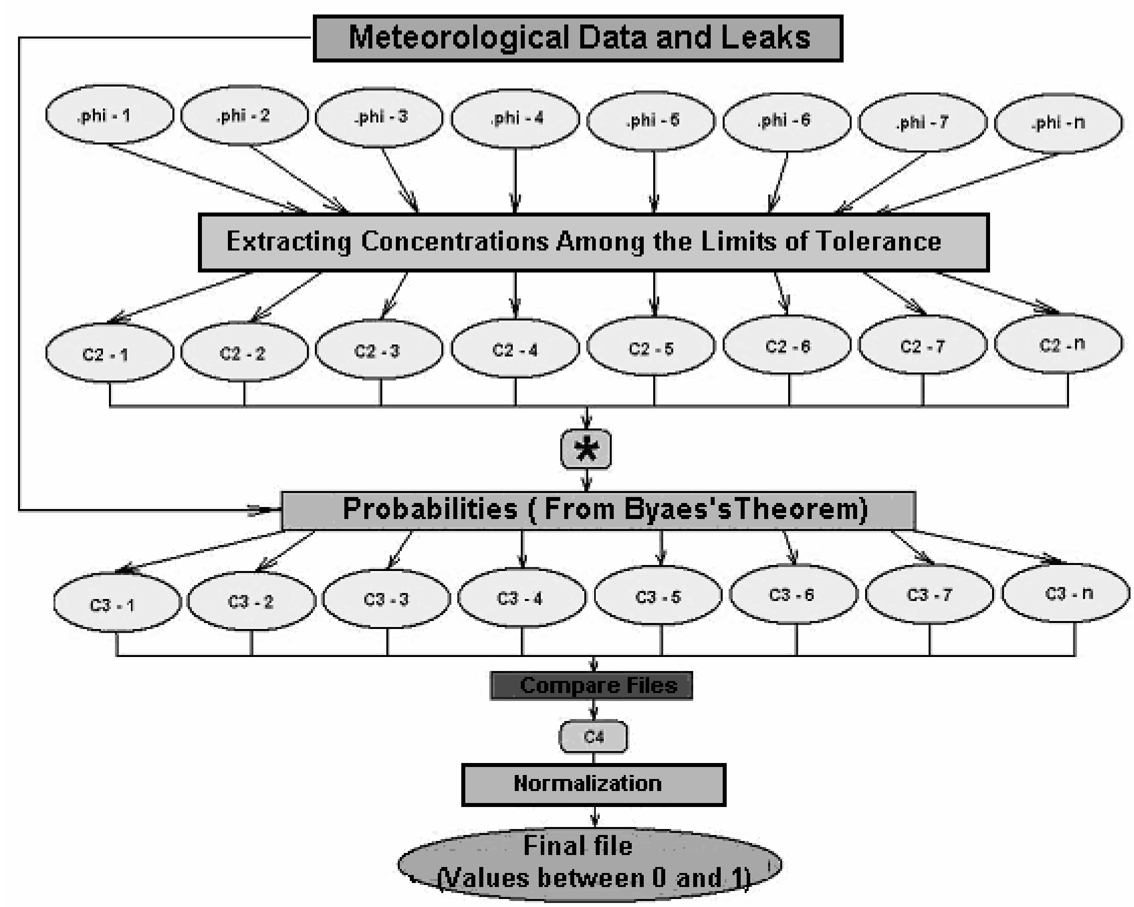

Figure 3: Flowchart of the computational tool.

Source: Own elaboration.

Therefore, at the end of the process, an index will be generated between 0 and 1 indicating probabilities of having gas with concentrations between $20\% \leq C \leq 60\%$ of L.F.L. in the computational volume, considering the probabilities of occurrences of leaks and wind for all the configurations (leak and wind).

It is important to note that is not necessary to know the exact gas percentage in each computational volume. The final file created only considers the existence of gas among $20\% \leq C \leq 60\%$ of L.F.L. this way, to know if the percentage is 21% or 30% adds a little in relation to the needs of the detection system, because any percentage between 20% and 60% of L.F.L. will be detected by the sensors, activating the alarms.

For each computational volume, a number of 0 (zero) to 1 (one) is attributed, that represents in probabilistic terms the classification of importance for each volume in the space potentially receiving a sensor. The methodology offers the advantage of being independent of opinion due to the mathematical treatment explained in this section.

3. RESULTS

Thin computational tool in development was applied to a previous sensor location project executed by CHEMTECH in 2003, in order to validate the proposed methodology. The results obtained in 2003 (through the qualitative methodologies) were compared with the results provided by the new methodology. Figure 4 shows the sensors positioned by CHEMTECH in the earlier study.

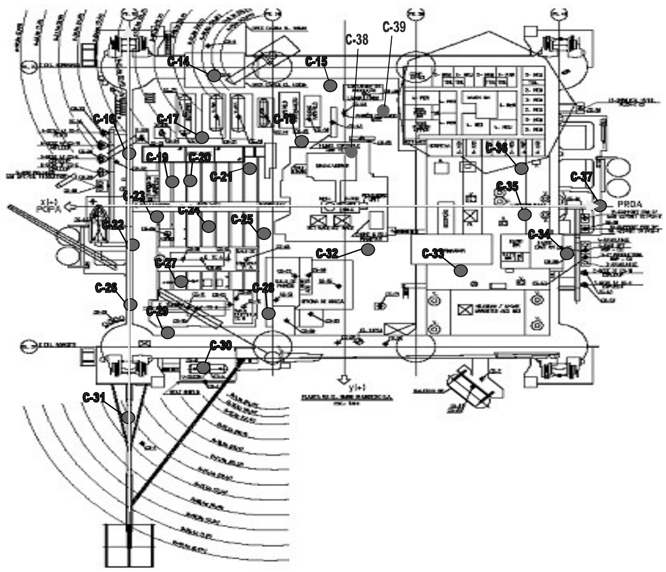

Figure 4: Sensors positioned by CHEMTECH in 2003

Source: Own elaboration

Figure 5 shows the comparison between the original location and the results obtained by the new methodology.

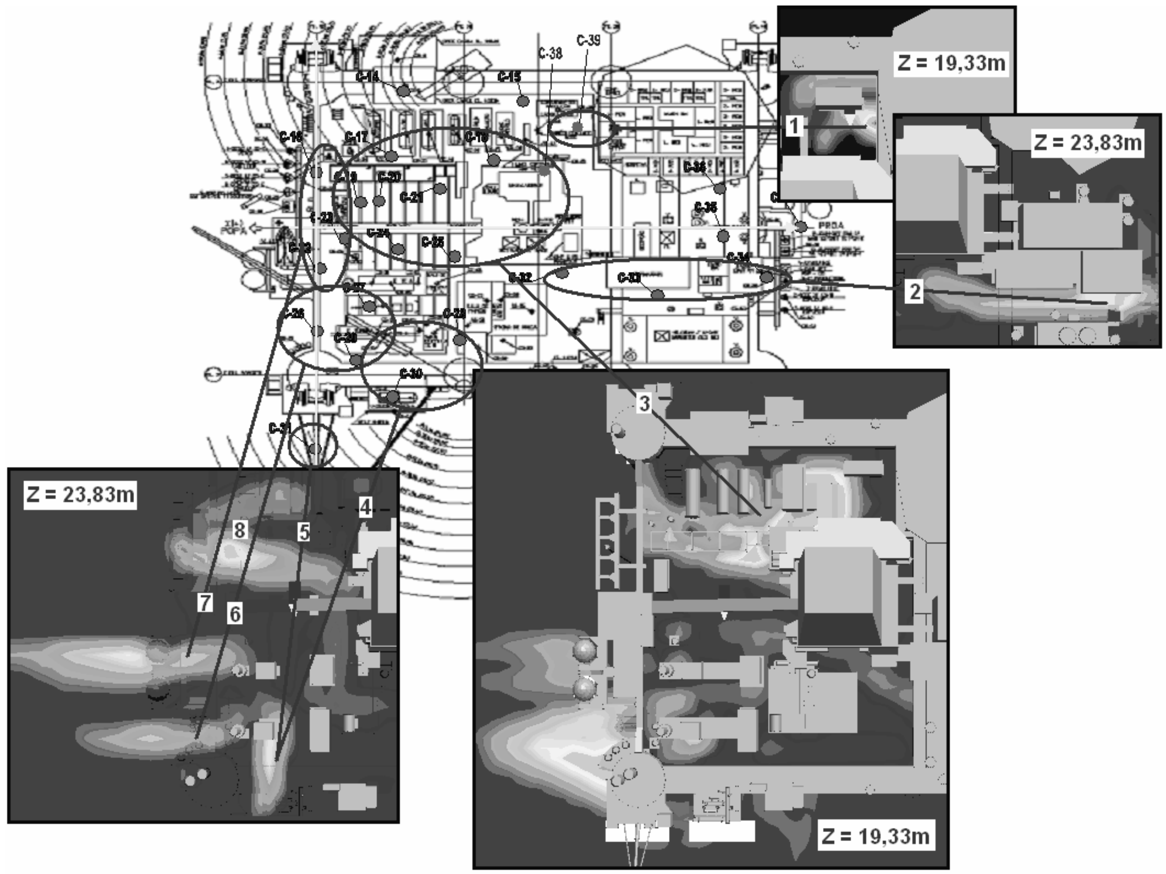

Figure 5: CHEMTECH 2003 versus the new methodology

Source: Own elaboration

The last figure shows that the results provided by the new methodology are similar to the results obtained in 2003. The scale of colors indicate the best regions for the installation of detectors, where “z” is the elevation in meters. With the support of this new tool, it was possible to take into consideration the analysis of many plumes with gas concentration between 20% and 60% of L.F.L. much more quickly. Qualitative methodologies usually analyses only plumes in the threshold gas concentrations for positioning sensors (20% and 60% of L.F.L.) due to many scenarios to be studied.

4. CONCLUSION

This methodology presents improvements in relation to others studies of gas dispersion and positioning of sensors, forming an alliance between CFD simulation results and coherent mathematical treatment. Development of the computational tool described in this document will reduce the time for conception of the projects, besides supplying more necessary and less intuitive results. It is important to remember that, in spite of the great progress that this methodology provides, researches will continue, in order to advance in aspects related to an optimum number of sensors.

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