CFD MODELLING OF A PETROCHEMICAL TANK LOSS OF CONTAINMENT AND ITS CONSEQUENCES

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THEME

Computational Fluid Dynamics

Current Industrial Needs and Future Industrial Needs

KEYWORDS

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SUMMARY

The design of a petrochemical terminal imposes new challenges due to increased community sensitivity and awareness of industrial safety. Furthermore, most terminals are located in busy harbours, close to unrelated facilities and inhabited areas, thus requiring focus on layout optimisation and hazard distances.

In the future, industry and the authorities will have, even more than in the past, to quantify and explain to the neighbouring community the effects on the inhabited areas of the worst case scenarios in plants using hazardous materials.

The case of a loss of containment, such as an accidental rupture of a tank, was assumed a few years ago to be a unrealistic scenario. However, in the recent years, such accidents did occur, for example in UK, Belgium, France and caused severe damage to the equipment and to the environment.

The design of a secondary containment, used to reduce the extent and therefore the cost of such an occurrence, can be assessed in terms of safety and effectiveness, using CFD tools.

For the study of these phenomena, FLUIDYN relied on its range of software of fluid mechanics. The software used is the fluid dynamics software fluidyn –

PANWAVE (VOF method). The numerical tool was validated against experimental results. The modelling of the wave, its impact on the retention bunds and subsequent spreading on the petrochemical site and beyond is carried out using two different numerical models and 3D grids: the first one including the tank and the jet area, the second one including the surroundings of the terminal up to several kilometers around. Results are presented and discussed in terms of efficiency of the secondary containment.

1: Introduction

Following an accidental spillage on a petrochemical site, the purpose of the study here is to evaluate the consequences of an accidental tank rupture inside a retention area in terms of ground pollution. Therefore, the simulation needs to assess the amount of liquid spilled outside the retention area and the expected overpressure on the retention walls.
The accidental opening is horizontal and is located at the bottom of the tank.

2: Case description

The domain on which the simulation will be carried out is detailed in the following figure (red square). The tank, subject of the accidental spillage scenario, is shown in red. Tanks are located in each retention but are not shown on the following picture.

The retentions are surrounded by bunds, which are known to hold better than straight walls to overpressures but also to favour large amounts of spillage outside the retention. The site itself is surrounded by a wall (black line on the figure below) which acts as a third containment.

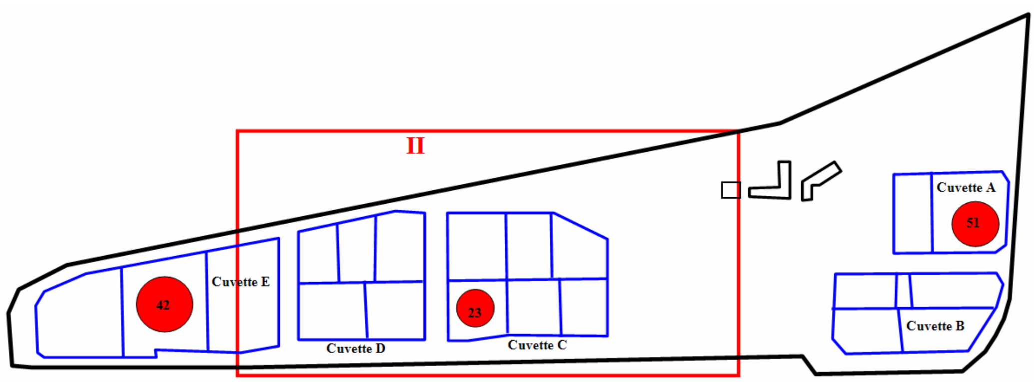


Figure 1: Overall view of the domain of simulation

The following figure presents a close-up view of the ruptured tank. The rupture is defined as a horizontal rupture at the bottom of the tank with an opening of

120° and a height of 50 cm, oriented towards the closest bund as indicated in the figure below. The bunds are highlighted in green in the figure below.

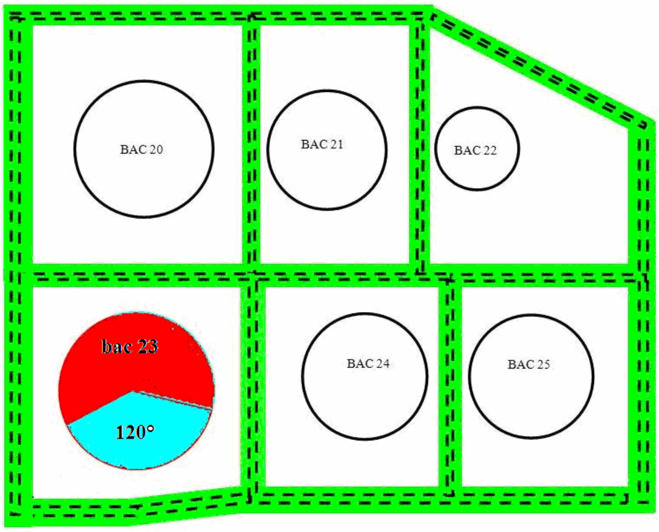


Figure 2: Schematics of the accidental rupture

The liquid stored in the tank is gasoil.

3: Numerical tool

***Fluidyn*-PANWAVE** has been specifically developed for accidental spillage from petrochemical tanks based on the general fluid dynamics platform ***fluidyn*-MP** developed by TRANSOFT.
Its specificities are :

- Generation of the geometry and the grid optimised for this type of problem, with several shapes of bunds and walls
- Adapted boundary conditions
- 2nd order of precision for the numerical solver
- VOF model for simulation of the free-surface flows

Moreover, ***fluidyn*-PANWAVE** was validated against the experiments conducted by HSE.

4: Numerical model set-up

The VOF model is known for a poor performance after a jump (for example in this case, a jump over the retention wall). To get round this shortfalling, two different mesh have been created, one for the retention itself to determine the overpressures exerted on the retention bunds and the second for the surroundings of the retention to estimate the liquid spillage outside the site.

The mesh presented here is the first mesh of the local retention. The geometrical model, carried out in 3D, is based on the site map as well as the geometrical description of the tanks and the walls/bunds (thickness, height, distances to the tanks). The numerical model of terrain will be larger than the retention walls to avoid the influence of the boundary conditions.

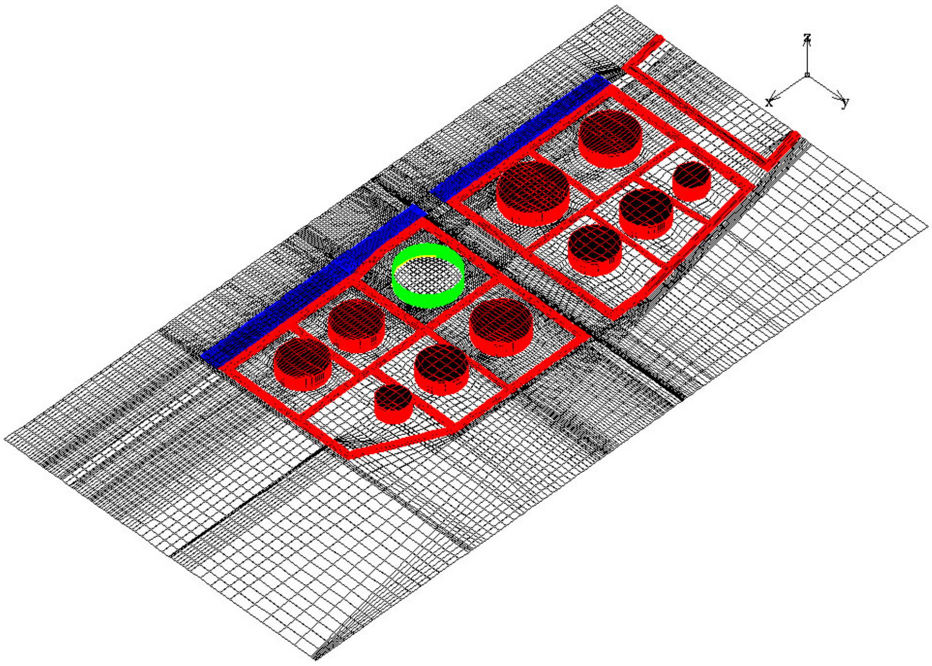


Figure 1: Three-dimensional visualisation of the mesh

The grid is a structured one. It is finer close to the surfaces (ground, walls) in order to ensure a good description of the pressure. The grid is also finer at the opening to improve the precision on the pressure fields.

The ruptured tank is highlighted in green in the above figure. The other tanks in the neighbouring retentions are considered as obstacles to the flow.

The assumptions made for simulations are the following :

- The flow is isotherm, incompressible and laminar.
- Turbulence effects are neglected.
- Surface tension is not taken into account.
- The given pressure values correspond to the dynamic pressure of the fluid.
- The gravity is set up at 9.81 m/s^{-2}.
- The walls (ground, base, tank envelope, retention walls) are considered rigid, adiabatic and smooth. Others boundaries are set up as pressure outflows.

The liquid is considered motionless at the beginning in the tank. At the initial time t = 0 s, an opening is created on the wall of the tank. A wave is formed which impacts the walls surrounding the retention.

The following figure shows the column of liquid at the initial time.

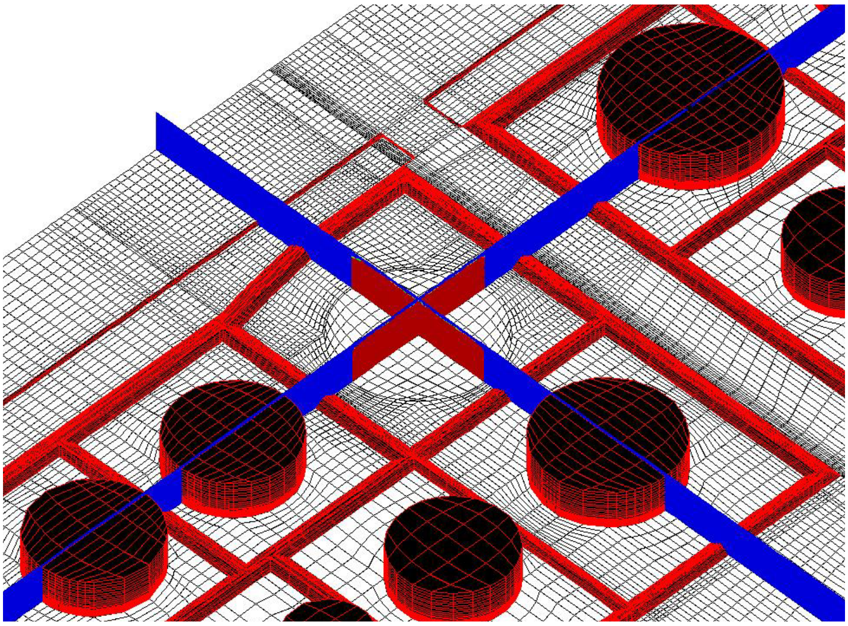


Figure 3: Initial condition for the simulation

5: Results and analysis

The calculations were carried out for a duration of 111 s after the beginning of the collapse of the liquid, in order to find out the maximum overpressures on the walls. The following pictures present the time evolution of the spillage on a vertical section through the center of the tank. After the rupture, the liquid flows over the secondary containment (bund) and rushes towards the wall at the site limits.

t = 1.57 s

t = 2.38 s

t = 3.80 s

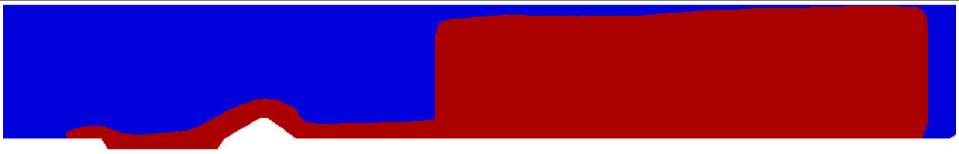
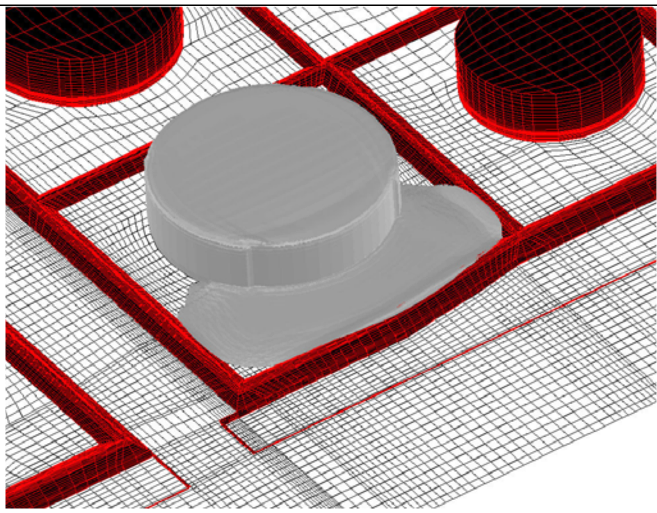


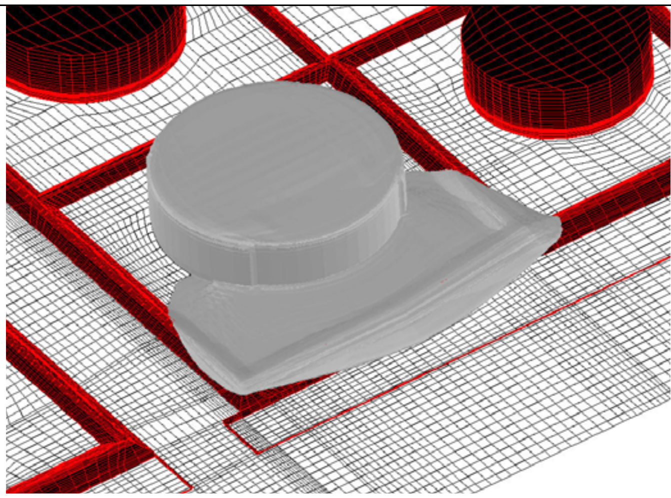
Figure 4: Two-dimensional visualization of the flow evolution

The same temporal evolution of the flow can be found in a 3D view in the next figures. The closeness of the bunds to the tank favour the overspill outside the retention even before the gasoil expands in the retention area itself.

t=1.57 s



t=2.38 s



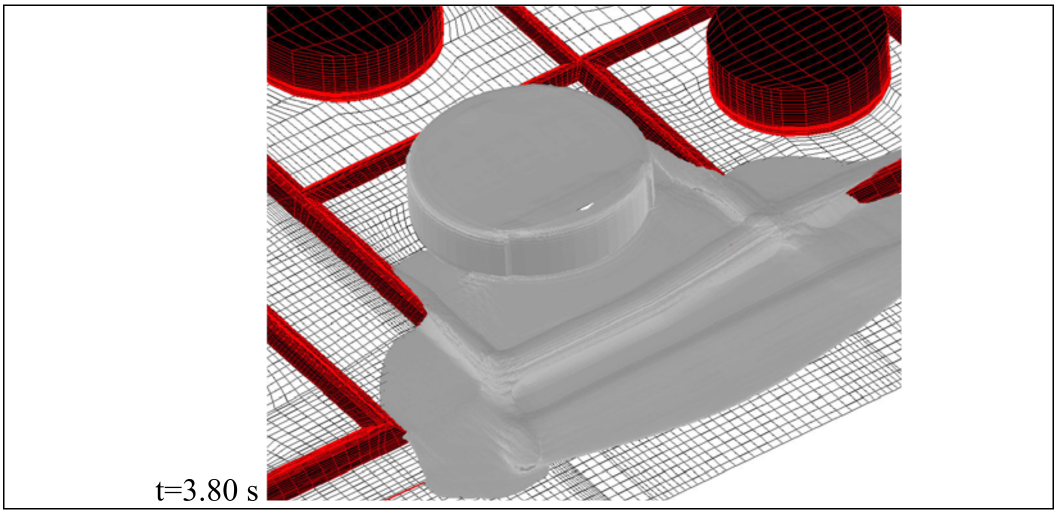


Figure 5: Three-dimensional visualization of the flow

The pressures exerted on walls and on the ground are given in the next figure at the time of its maximum.

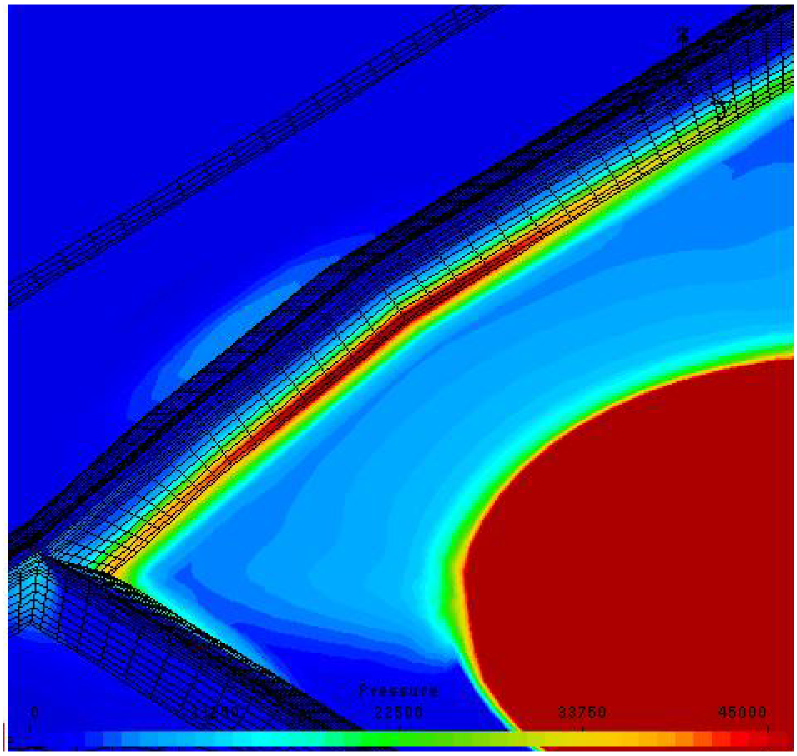


Figure 6: Pressure field at the maximum of pressure on the walls

The temporal evolution of the peak pressure on the wall has been plotted on a vertical section at the nearest wall position to the tank.

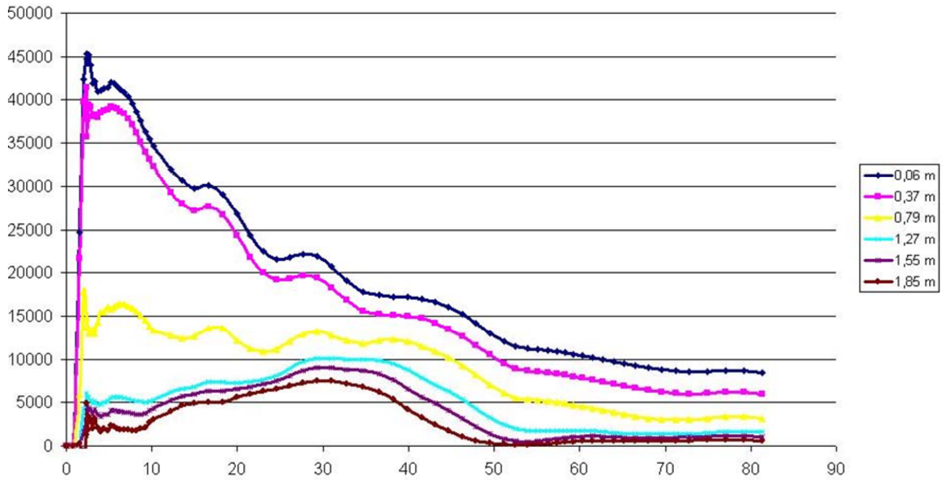


Figure 7: Overpressure (Pa) function of the time (sec) on a vertical section at the closest range to the tank.

The maximum pressure exerted on the wall is of **0.45bars**, and is located at the bottom of the wall. The retention bunds are capable of holding this pressure contour easily.

The second mesh was then used to assess the liquid overflow outside the retention area and the petrochemical site. The figure below shows the extent of the pool of gasoil, 12 seconds after the rupture. The wave towards the South of the domain has a maximum height of 35 cm and a maximum velocity of 8 m/s.

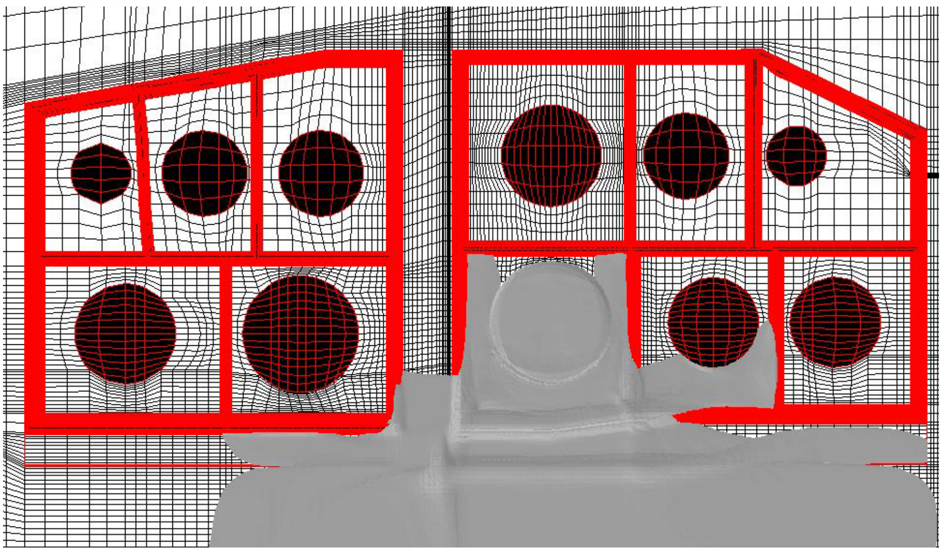


Figure 8: Extent of the release, 12 s into the release

In order to evaluate he amount of liquid spilling over the retention walls, the graph below shows the evolution of the overflow in time in percentage, of the total gasoil volume available initially in the tank.

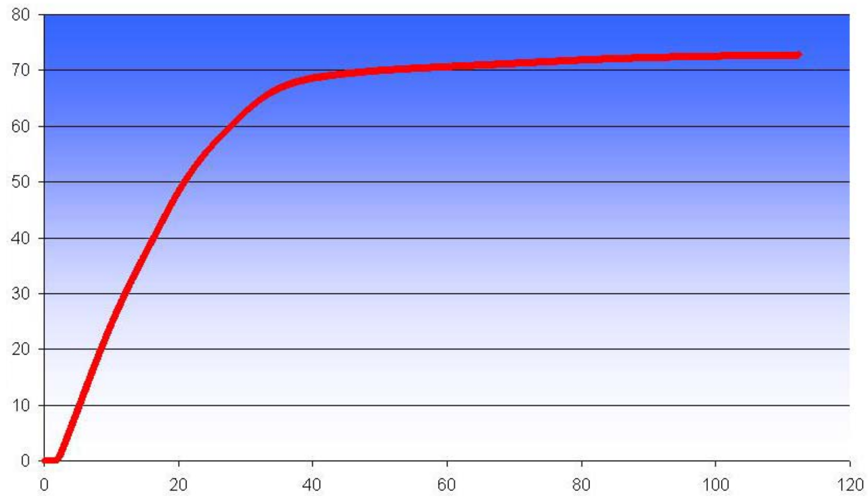


Figure 9: Percentage of volume (%) vs time (sec) over spilling the retention walls

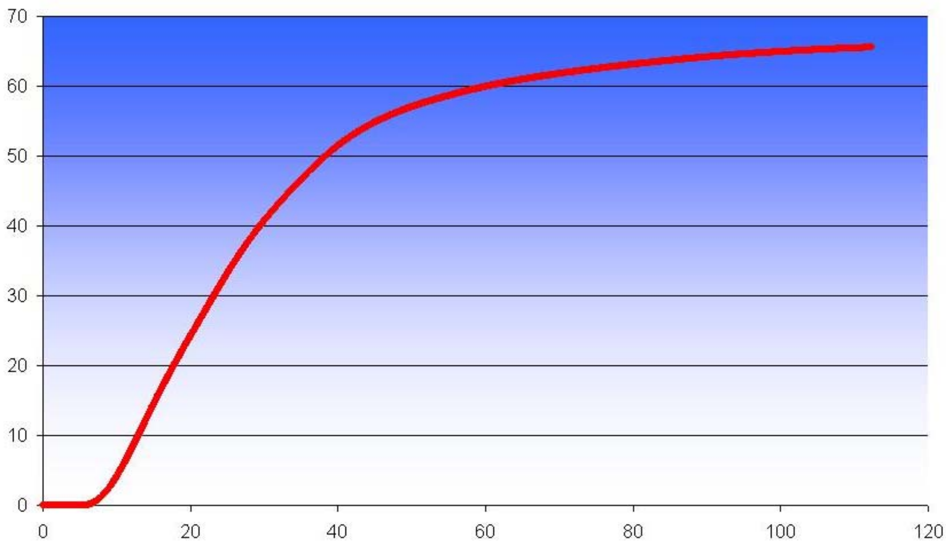


Figure 10: Percentage of volume (%) vs time (sec) expanding outside the petrochemical site

With a storage capacity of 20 000 m^3, 73 % of the volume of the gasoil is spilled over the retention walls, mostly towards the South (90%) as could be expected but also towards the West bund (9%).

Out of the total tank volume, 65% of the liquid flows directly outside of the site (mostly from the South border) and could potentially pollute waters and soil in the vicinity of the petrochemical site.

The spillage results are summarized in the figure below

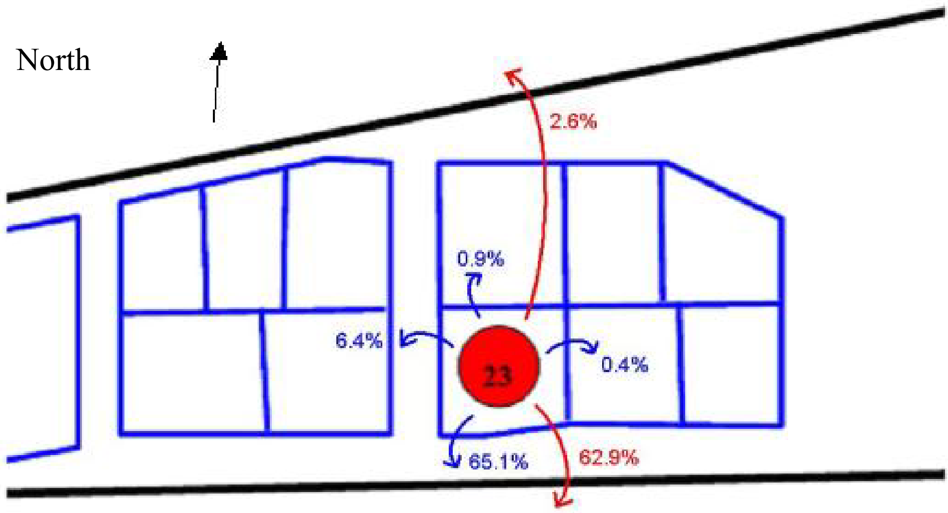


Figure 11: Schematics of estimated spillage

6: Conclusion

***fluidyn*-PANWAVE** software was used to solve the transient simulation of the fluid flow resulting from the release, and to figure out, with an enough refined mesh, the behaviour of the wave and the pressure exerted on the retention walls.

The scenario (horizontal bottom opening) shows an amount of liquid spillage outside the retention bund is about 65 %, which leads to significant environmental consequences.

As far as spillage is concerned, the secondary containment does not play its role efficiently, since it is easily bypassed by the liquid. Moreover the wall acting as third containment along the site borders has almost no effect, considering the wave speed and thickness when it hits the wall.

Containment has therefore to be studied in more details and evaluated again using 3D CFD simulations.