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# Quantitative accident consequences analysis on chemical plant of acetic acid production

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**Abstract**

The growing concern about the possibility of major chemical accidents in India has driven both government and industry to figure out ways to recognise and evaluate potential hazards. A quantitative accident consequences analysis is a formal and structured approach to accident analysis that quantifies the consequence associated with engineering process operations. The application of accident analysis for this study is to achieve two objectives which are to identify hazardous substances and scenarios that can occur in acetic acid plant and the consequences to people outside and inside of the plant involved estimation of the accidental consequences with threat zone distance and area affected calculation. The acetic acid production plant located at MIDC Bhosari, Pimpri Chinchwad in Maharashtra India is the subject of this study. The methodology for this study is applied calculations of chemical inventories and process piping flow, assumptions, and selections are based on plant design supported by simulation using HYSYS software; and using ALOHA and MARPLOT Software for simulation of the accidental consequences. This study has a selected wind direction from East (E), which were blowing into residential area. Methanol reactor, R-101 produced boiling liquid expanding vapor explosion (BLEVE) scenario which has the largest affected area of 572, 461 m$^2$ and the longest distance of 427 meters, compare to other equipment in the plant.

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## 1.0 Introduction

Acetic acid ($CH_3COOH$) is indeed the most essential organic acid as it is being used as raw material in a vast variety of chemical processes with a total global capacity of 16.1 million in 2020 (Martín-Espejo, 2022). The facilities for the production of the acetic acid plant are designed and constructed by standards and procedures. Even so, awareness of the probability of the occurrence of fatalities should not be overlooked. Because of the flammable and hazardous nature of chemicals being handled in the chemical industry, installations within chemical plants have a higher tendency to cause catastrophic damage in terms of fatalities, severe injury, property destruction, and environmental deterioration.

Acetic acid can be synthesised from different feedstocks through different methods or processes, such as oxidation of acetaldehyde, oxidation of hydrocarbons, anaerobic fermentation, and carbonylation of methanol (Deshmukh, 2020). Methanol carbonylation (Cativa process) was the most promising technology for acetic acid synthesis when compared with other routes. Methanol and carbon monoxide are the raw material utilised in this process (Martín-Espejo et al., 2022).

Acetic acid is a colourless liquid with a pungent smell of vinegar (National Center for Biotechnology Information, 2022). This substance is particularly corrosive to the skin and eyes and thus needs to be handled with special caution. Acetic acid can also cause internal organ damage whether it is swallowed or in the case of vapor inhalation. The National Fire Protection Association (NFPA) and the United States Occupational Safety and Health Administration (OSHA) classify acetic acid as a Class 2 flammable liquid. Therefore, it is undoubtedly can cause an explosion or a blast. If heated in the fire or heated normally it can produce harmful and corrosive fumes. The vapor emitted can migrate a significant distance to the ignition source, and it will travel back. So, it triggers a fire or explosion.

There is also interest in performing explosion analysis. In this scenario, a flammable substance which as methanol and carbon monoxide passed through a reactor will have the possibility of a vapor cloud explosion (Dunjó et al., 2010; Victoria & Dragos, 2012).

The threat of a massive fire, explosion, or unintentional exposure to dangerous chemicals hindered the process industries. One of the most common of these three threats is fire, but an explosion is more severe in regard to the damage capacity, frequently resulting in fatalities and loss of property (Khan & Abbasi, 1999). Pool fire has become the most popular form of fire disaster, followed by jet fire, flash fire, and fireball (Casal, 2017a). Pool fires are also the likely source of explosions, and explosions routinely establish new pool fires (Abbasi et al., 2017). When any spilled liquid vaporises rapidly, as occurred with pressure-liquefied gases, a vapor cloud may arise. The cloud could then catch fire or explode, resulting in a flash fire or vapor cloud explosion (VCE). Subsequently, the vapor cloud had travelled several hundred meters downwind before bursting. In this approach, a VCE can endanger process units located distant from the scene of the originating accident (Vipin et al., 2018).

A serious injury is potential if insufficient control and remedies are not established. Although safety mechanisms are built on the devices, the structure is never fully secure (Pula et al., 2006). Chemical emission, as described by (Tseng et al., 2012), presents a major hazard to the safety of employees and those living nearby, as well as polluting the air quality. As a response, one of the greatest severe issues in the sectors of environmental protection and process safety is the prevention and modelling of chemical leaks.

Chemical plants have become a high-risk site for safety incidents because of the flammability, explosivity, toxicity, and harmful effect of the raw material and also because of the distinctive and unsafe manufacturing process (Ramli et al., 2018; Tseng et al., 2012). This is known that approximately 18% of fires are caused by the discharge and overflow of combustible gases and/or liquids. Fires are responsible for around 20% of the overall loss. In contrast, explosions caused around 75% of the entire loss. Failure of effective response controls appears to be the most common cause of accidents. It was responsible for 35% of all accidents. The processing area is the most sensitive to an accident (Khan & Abbasi, 1999).

An example of a chemical plant explosion incident occurred in Xiangshui, Jiangsu Province, on 21 March 2019 (Zhang et al., 2019). The explosion is due to unsafe action of staff or the obstruction of pipes during the manufacturing process, resulting in 78 deaths and 566 injuries. A chemical fertiliser plant in Texas, USA also caught fire and exploded on 17 April 2013. More than 70 houses have been damaged, 260 have been injured and 15 have died. The illegal operation was the cause of the explosion. Many incidents' causes are small; however, they may develop into major safety accidents and turn out to be an enormous serious threat to society. The explosion of a chemical plant will be a starting point for accidents in nearby plants and there will be more serious consequences (Arunraj & Maiti, 2009; Khan & Abbasi, 1999).

Hoechst-Celanese Explosion in Pampa Texas, BP Hull Explosion, and Alcohol Tank Explosion inside a Vinegar plant in France are incident which has caused several deaths as well as damage to the environment and property (Johnson, 2000). Such accidents captured the public's attention and raised questions about engineering project safety. Therefore, a few concerns were constantly raised; project safety, safety design and operation, and mitigation measures (Pandey et al., 2018).

A quantitative approach is not new to the chemical industry in general and to safety in particular. quantitative risk assessment (QRA) is an increasingly utilised tool to help avoid unusual but potentially disastrous accidents as well as to help evaluate risk and improve plant safety in the chemical process industry (CPI) (Abd Rashid, 2021; Villa et al., 2016; Ahmad et al., 2021; Ahmad & Rashid, 2019; Aizad & Rashid, 2019; Rashid et al., 2021). QRA has existed for a lengthy moment. It was widely applied in the nuclear sector earlier to its application in the CPI (U. S. Nuclear Regulatory Commission, 1975). The first procedure of a QRA is to identify hazards. The HAZOP Analysis, failure mode and effects analysis (FMEA), 'what if' analysis, preliminary hazard analysis (PHA), and checklist analysis are examples of approaches being used for hazard identification. HAZOP is the topic of significant investigation aimed at enhancing the safety of chemical plants, which are progressively operating at greater temperatures and pressures and involving more complicated, sophisticated processes (Dunjó et al., 2010).

Quantitative risk assessment, as described by (NORSOK Standard, 2010), consists of the following activities such as context establishment, risk identification, risk analysis, and risk evaluation.

Communication, consultation, monitoring, and review activities must be conducted before, during, and after evaluation to ensure that its objectives are met. Crucial QRA outcomes are achieved as early as the feasibility and idea levels of the design stage, or at least as early as the budget of the plant and likely accidents may be anticipated, as stated by (Weber, 2006). Conversely, to (Shariff & Zaini, 2013) question, QRA is frequently used in detailed design and engineering installation since process designers typically feel uncertain about the risk rating from process industries during the initial planning phase. QRA was revealed as the most efficient analytical and predictive risk evaluation method for complicated chemical process systems. Yet, the current analysis concluded that greater development of Risk Assessment tools is necessary to attain their full applicability. A dynamic risk management framework enables for the essentially helps of actual modifications in the process, leading to a higher analyst knowledge of potentially overlooked hazards. Ignoring the fact that risk assessment applications have greatly enhanced the safety of chemical process facilities, catastrophic disaster scenarios continue to occur, and risk assessment methodologies must be continually refined and evolved to ensure a given degree of safety (Villa et al., 2016).

A striking example of that record is QRA. Developments show that QRA will serve a more essential role in risk management throughout the CPI in the ahead (Van Sciver, 1990). Regarding the above-mentioned cases, a quantitative risk assessment methodology will be applied in the study. Quantitative risk management is a comprehensive utilization of available information in defines hazards and quantifies risks to individuals or populations, properties, and the environment, and risk evaluation (Casal, 2017; Dunjó et al., 2010; Ramli et al., 2018; Shao & Duan, 2012).

Many researchers do a QRA method to evaluate the safety of the plant and its surroundings. The current findings reported by (Ramli et al., 2018) were about both petrochemical operations in this study were classified as Major Hazard Installations (MHI) because they dealt with the storage of hazardous chemicals (sulfuric acid) over the threshold quantity specified in the control of industrial major accident hazard (CIMAH 1996) Reg. 1996. As a consequence, the threat zones for all red, orange, and yellow zones are broader than 6 miles. Following that, the suggested safest evacuation path will assist the company in planning for emergency preparedness.

The occurrence of pipeline leakage accidents and their effect on the power plant were studied by Shao and Duan, using the last branch lines unit as an analogy. The findings demonstrate that the plant's social risk is connected to population distribution near natural gas pipelines and mortality probability elements. In this article, three leakage sizes were evaluated: 100 mm, 200 mm, and 1200 mm. Once the pipeline leaking hole is 1200 mm, emergency rescue measures need to be taken to minimise the risks of spreading over most of the community, which is within the range of natural gas explosion limitations (Shao & Duan, 2012b).

Earlier research (Rashid et al., 2021b) analyses the number of deaths that might be caused by a methanol reactor accident at a suggested plant in Perak, Malaysia. This study investigates the effect of carbon dioxide-hydrogen-methanol-carbon monoxide-water combination outflow from a methanol reactor on the projected mortality percentage, taking into account numerous incidents at varied reactor pressure settings. The leakage diameters are 10 mm, 25 mm, and 160 mm, varying from small to large. Furthermore, $CO_2$ from 160 mm leaking size causes the highest number of mortality (15.7%) throughout the night.

Recent study focused on sulfuric acid manufacturing plants utilizing threat zone monitoring (Ahmad et al., 2021). The study explored the impact of each major piece of equipment in sulphuric acid plants, such as the drying tower, sulphur burner, multi-bed reactor, absorber tower, and electrostatic precipitator, if the major chemical, specifically sulphuric acid, sulphur, sulphur trioxide, and hydrogen sulphide, existed inside it. The afflicted region's observed distance increases from 10 mm diameter leakage to 150 mm diameter leakage. The greater the dimension of the apparatus leaks, the larger the area affected by the event.

The incident case is a frequent complication triggered by a failure event. The accident event could involve one or several. According to the previous literature, most research analysed just one worst-case accident scenario. The worst-case scenario is a circumstance in which the worst potential disaster occurs, putting people and the environment in danger (Arunraj & Maiti, 2009). The formation of accident scenarios is simulated using a collection of mathematical models. ALOHA is an emergency response system developed for both fast deployments by responders and application in emergency preparedness. The model can simulate the dispersion model for over 900 chemicals and is mostly utilised in the modelling of hazardous material release (Yet-Pole et al., 2009) and chemical vapour dispersion.

Numerous outcome measures have been discussed in the literature. They differ from strictly qualitative to extremely quantitative assessments. (Hokstad & Steiro, 2006) proposed 11 different failure categories. These are death in fatal accidents, death in other accidents, severe injuries, chronic illness, limited functionality, acute pollution of the surrounding factors, prolonged pollution of the external environment, material damage, loss of production, loss of information, and loss of reputation. The first nine loss classes relate to four goals, namely human, environment, material, and production (Khan & Amyotte, 2005).

Previous study shown the importance of quantifying consequences of accident scenario such as toxicity, thermal radiation and overpressure. Therefore, this paper focus on quantitative analysis of accident consequences, specific for a new proposed acetic acid plant in Maharashtra, India, which has many major equipment such as reactor, distillation and mixer. In this study, dominant chemical in every equipment needs to be identified first, then the hazardous characteristic of those chemicals would be determined. Possible accident scenario for every hazardous chemical such as toxicity, pool fire, jet fire, flash fire and vapor cloud explosion (VCE) will be simulated in ALOHA and area of threat zone will be plotted in MARPLOT software.

## 2.0 Methodology

### *2.1 Case study*

The location of the plant in this study is the proposed acetic acid plant to be located at the MIDC Bhosari, Pimpri Chinchwad, Pune in Maharashtra India. The plant was designed to produce 100,000 metric tons per year of acetic acid from 6711 kg methanol per year and 5910 kg carbon monoxide per year.

### *2.2 Methods*

This study was based on a methanol reactor, acetic acid reactor, distillation column, and also a mixer which are the major equipment in this plant as can be seen in Fig. 1.

Table 1 depicts the process conditions for each access equipment used to define the release scenarios. From the table, two dominant chemicals will be discussed in this study which is methanol and acetic acid. As for the first equipment, methanol is the major chemical. Methanol is extremely flammable. Vapours create a mixture that is explosive when combined with air. There's a possibility of a fire or an explosion. Many vapours may be heavier than air, can migrate a significant distance to the ignition source, and will travels back. Methanol might also be ingested with carbon dioxide and carbon monoxide, all of which are used in the plant to produce acetic acid. If methanol burns with either carbon monoxide or carbon dioxide, it may lead to a fire or an explosion. A potential incident happens when humans come into contact with

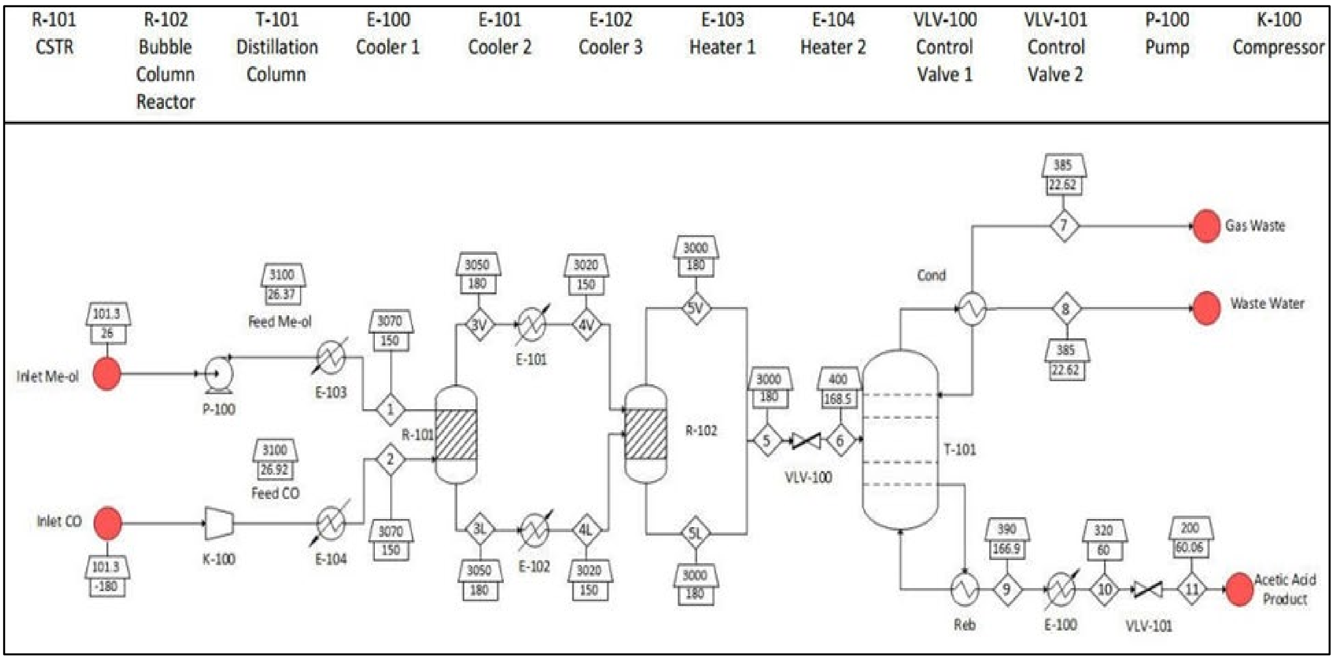


**Fig. 1**: Process Flow Diagram (PFD) for this acetic acid plant

**Table 2:** Process conditions for each access equipment

| Equipment | Piping: Length (m) | Piping: Diameter (m) | Process Conditions: Composition (Mole) | Vapor / Liquid | Temperature (ºC) | Pressure (kPa) | Flow Rate (kg / hr) |
|---|---|---|---|---|---|---|---|
| Methanol Reactor, R-101 | 4.61 | 2.30 | $H_2O$ : 0.0034<br>$CH_3OH$ : 0.9966 | Liquid | 150 | 3070 | 6711 |
| Acetic Acid Reactor, R-102 | 7 | 1.606 | $CH_3COOH$ : 0.9846<br>CO : 0.0043<br>$CO_2$ : 0.0026<br>$H_2O$ : 0.0005<br>$H_2$ : 0.0001<br>$CH_3OH$ : 0.0079 | Liquid | 150 | 3050 | 12490 |
| Distillation Column, T-101 | 1.789 | 1.193 | $CH_3COOH$ : 0.9930<br>CO : 0.0026<br>$CO_2$ : 0.0040<br>$H_2O$ : 0.0002<br>$H_2$ : 0.0002<br>$CH_3OH$ : 0.0001 | Liquid | 168.5 | 3000 | 12620 |
| Mixer, MIX-100 | 3.25 | 2 | $CH_3COOH$ : 0.99304<br>CO : 0.0022<br>$CO_2$ : 0.00439<br>$H_2O$ : 0.0002<br>$H_2$ : 0.0002<br>$CH_3OH$ : 0.0001 | Liquid | 180 | 3000 | 12610 |

methanol, which creates several different health hazards. It is said to be toxic when touched with skin. When contacted with the eyes, it is said to be unpleasant, with symptoms like itching, burning, redness, and tearing. Extended contact can cause damage to the eye or blindness. It is said to be toxic when inhaled. Blindness, drowsiness, dizziness, and CNS-depression may result from inhalation. Extended exposure may cause damage to the liver or a coma. It is known to be toxic if ingested. Ingestion may lead to blindness, headaches, sleepiness, slurred speech, blurred vision, and can result in fatality. The central nervous system is undergoing some delayed effects of liver injury and damage.

As for the next three types of equipment, acetic acid has the highest mole fraction which indicates that it is the main chemical in that equipment. Acetic acid is a type of flammable liquid. There's always the possibility of an explosion or a fire. When heated normally or heated in a fire, toxic and corrosive fumes may normally be formed. The vapor generated can travel a great distance to the source ignition and can flashback. This is what triggers an explosion or fire.

Acetic acid can have an impact on human health. Ingested or inhaled may end up causing damage to internal organs. Symptoms will include eye irritation, respiratory discomfort, cough, and inflammation of the nasal mucous membrane. Acetic acid is corrosive and can cause skin burns or irritation when contact occurs.

**Table 1**: Pasquill stability classes

| Stability Class | Definition | Stability Class | Definition |
|---|---|---|---|
| A | Very Unstable | D | Stable |
| B | Unstable | E | Slightly Stable |
| C | Slightly Unstable | F | Stable |

The results of the released flammable material depend primarily on the weather conditions that prevail. The most important meteorological parameters for the estimation of large scenarios concerning the release of flammable materials are those that affect the escape material's atmospheric dispersion. Wind direction, wind speed, atmospheric stability, and temperature are the key variables.

One of the atmosphere's most significant qualities is its stability. The stability parameter of Pasquill, based on the categorization of Pasquill-Gifford, is a meteorological parameter that defines atmospheric stability. Six stability groups range from `A' (extremely unstable) to `F' (moderately stable) as defined by Pasquill as shown in Table 2.

### *2.2.1 Plant Meteorology*

Hot semi-arid climates bordering the tropical wet and dry with average temperatures ranging between 20 and 28 °C (68 and 82 °F) are typical characteristics of the Pune region. There are four variations of wind directions assessed in this study in which is E, ENE, W, and WNW which is the dominant wind direction as shown in Fig. 2. Meanwhile, Table 3 indicates the atmospheric conditions for the Pune region of the four wind directions. The E wind direction is chosen because the direction is move towards the residential areas. Wind speed is 2 m/s with slightly solar radiation. Wind speeds, solar radiation intensity, and night time sky cover was defined as key factors that describe these types of stability. The stability class in this study falls under stability class C which is slightly unstable because wind speed of 2 m/s and have slight solar radiation. Simulation conducted on 20 December 2020 at 3 p.m using ALOHA and MARPLOT software for all toxic, poo fire and BLEVE scenario.

### 2.2.2 Possible accidental release scenario

The potential for ignition or no ignition is included in each accidental release scenario in the QRA. If ignited, there may be a variety of fire and/or explosion results. Several possible outcomes, each with its probability of occurrence, are evaluated for each release modelled in the QRA.

*A. Pool Fire:* The flammable material released, which is a liquid held below its normal boiling point, is collected in a pool. The pool's geometry would be determined by the environment. When the liquid is stored above the normal boiling point under pressure, a portion of the liquid will flash into vapor and the remaining component will form a pool at the release point.

*B. Flash fire: The* combustion of a gas/air mixture that creates relatively short-term thermal hazards with marginal overpressure is a Flash Fire (blast wave). A vapor cloud that is ignited beyond an obstructed area can usually result in a Flash Fire.

*C. Jet fire:* When the material emitted is gas or high-pressure liquid that instantly ignites, a jet fire may occur. The size of the jet flame is largely dependent on the gas or high-pressure liquid release rate.

*D. Vapor cloud explosion:*The rapid combustion of a fuel/air mixture with the flame velocity reaching sonic velocity and the creation of a blast wave results in a vapor cloud explosion. A flammable hydrocarbon's propensity for explosion depends on its combustion energy and the energy of the source of ignition. Moreover, the percentage of the combustion energy that is converted to explosive energy depends on the chemical's nature.

*E. Boiling liquid expanding vapor explosion (BLEVE:* A sudden release of a large mass of pressurised liquid into the atmosphere may cause a fireball or boiling liquid expanding vapor explosion (BLEVE) to happen. An exterior fire that impinges on the shell of a pressurised vessel above the liquid stage is a primary source, undermining the shell and causing a sudden rupture.

*F. Toxic:* The discharge of a toxic chemical may do little, if there are any, harm to the equipment, but may have an effect on the off-site community and the on-site workers. Any contaminants face extreme hazards of inhalation which can damage the respiratory system or other vital functions.

Harm projections related to thermal radiation and overpressure have been obtained by considering the existing literature on the subject into account. The caused by thermal radiation on humans is primarily a result of radiation intensity and exposure period. The result is expressed in terms of the likelihood of death and the varying stages of burning. (Casal, 2017b; Dunjó et al., 2010; Ramli et al., 2018; Shao & Duan, 2012a).The following Table 4 and Table 5 give the

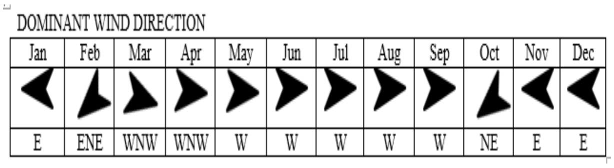


**Fig. 2**: Dominant wind directions for Pune region

**Table 3**: Atmospheric parameters of wind directions for Pune region

| **Atmospheric Parameters** | |
|---|---|
| Atmospheric Temperature | 28 °C |
| Relative Humidity | 0.593 |
| Average wind speed | 2 m/s |
| Elevation | 562 m |

**Table 4**: Fatal radiation exposure level

| **Radiation Level (kW/m2)** | **Fatality** | | |
|---|---|---|---|
| | **1%** | **50%** | **99%** |
| | **Exposure in seconds** | | |
| 4.0 | 150 | 370 | 930 |
| 12.5 | 30 | 80 | 200 |
| 37.5 | 8 | 20 | 50 |

**Table 5**: Fatal radiation exposure level (Details)

| Radiation ($kW/m^2$) | Damage to Equipment | Damage to People |
|---|---|---|
| 1.2 | | Solar heat at noon |
| 1.6 | PVC insulated cables damaged | Minimum level of pain threshold |
| 2.0 | | |
| 4.0 | *** | Causes pain if duration is longer than 20 secs. But blistering is unlikely |
| 6.4 | *** | Pain threshold reached after 8 secs. Second degree burns after 20 secs. |
| 12.5 | Minimum energy to ignite wood with flame: Melts plastic tubing. | 1% lethality in 1 minute. First degree burns in 10 secs. |
| 16.0 | *** | Severe burns after 5 secs. |
| 25.0 | Minimum energy to ignite wood at identifying long exposure without a flame. | 100% lethality in 1 minute. Significant injury in 10 secs. |
| 37.5 | Severe damage to plant | 100% lethality in 1 minute.<br>50% lethality in 20 secs.<br>1% lethality in 10 secs. |

**Table 6**: Over Pressure damage criteria with damage to people

| Overpressure (mbar) | Mechanical Damage to Equipment | Damage to People |
|---|---|---|
| 300 | Heavy damage to plant and structure | 15 deaths from lung damage<br>>50% eardrum damage<br>>50% serious wounds from flying objects |
| 100 | Repairable damage | >1% eardrum damage<br>>1% serious wounds from flying objects |
| 30 | Major glass damage | Slight injury from flying glass |
| 10 | 10% glass damage | *** |

**Table 7**: Over pressure damage criteria with mechanical damage to equipment

| Overpressure | | Mechanical damage to equipment |
|---|---|---|
| Bar | kPa | |
| 0.0014 | 0.14 | Annoying noise (137 dB if of low frequency 10-15 Hz) |
| 0.0021 | 0.21 | Occasional breaking of large glass windows already under strain |
| 0.0028 | 0.28 | Loud noise (143 dB), sonic boom, glass failure |
| 0.0069 | 0.69 | Breakage of small windows under strain |
| 0.0103 | 1.03 | Typical pressure for glass breakage |
| 0.0207 | 2.07 | Safe distance (probability 0.95 of no serious damage below this value); projectile limit; some damage to house ceiling; 10% window glass broken |
| 0.0276 | 2.76 | Limited minor structural damage |
| 0.03-0.069 | 3.4-6.9 | Large and small windows usually shattered; occasional damage to window frames |
| 0.048 | 4.8 | Minor damage to house structures |
| 0.069 | 6.9 | Partial demolition of houses, made uninhabitable |
| 0.138 | 13.8 | Corrugated asbestos shattered; corrugated steel or aluminium panels, fastenings fail, followed by buckling; wood panels (standard housing) fastenings fail, panels blown in |
| 0.09 | 9.0 | Steel frame of clad building slightly distorted |
| 0.138 | 13.8 | Partial collapse of walls and roofs houses |
| 0.207 | 20.7 | Concrete or cinder block walls, no reinforced, shattered |
| 0.158 | 15.8 | Lower limit of serious structural damage |
| 0.172 | 17.2 | 15% destruction of brickwork of houses |
| 0.207 | 20.7 | Heavy machines (3000lb) in industrial building suffered little damage; steel frame building distorted and pulled away from foundations |
| 0.207-0.276 | 20.7-27.6 | Frameless, self-framing steel panel building demolished; rupture of oil tanks |
| 0.276 | 27.6 | Cladding of light industrial building ruptured |
| 0.345 | 34.5 | Wooden utility poles snapped; tall hydraulic press (40,000 lb) in building slightly damaged |
| 0.345-0.482 | 34.5-48.2 | Nearly complete destruction of houses |
| 0.482 | 48.2 | Loaded, lighter weight (British) train wagons overturned |
| 0.482-0.551 | 48.2-55.1 | Brick panels,8-12 in thick, not reinforced, fail by shearing |
| 0.62 | 62.0 | Loaded train boxcars completely demolished |
| 0.689 | 68.9 | Probable total destruction of building; heavy machine tools (7000 lb) moved and badly damaged, very heavy machine tools (12,000 lb) survive |

effect of different heat flux levels. Table 6 and 7 presents over pressure damage criteria with damage to people and equipment respectively.

Using different software packages, such as Aloha, Marplot, and Google Earth, the process is carried out. First, the chemical is taken into account in the study. With the help of software packages called ALOHA, a release scenario is modelled. To construct the model, the cause of the event and other meteorological information and related topographical data must be fed into the system. The parameters such as measurements of the leak, position, and so on are discovered and fed into the software system after a successful study of the incident. In this study, the measurement of the leak being assessed is 10 mm, 25 mm, and 150 mm. For suitable scenarios, these are evaluated and modelled.

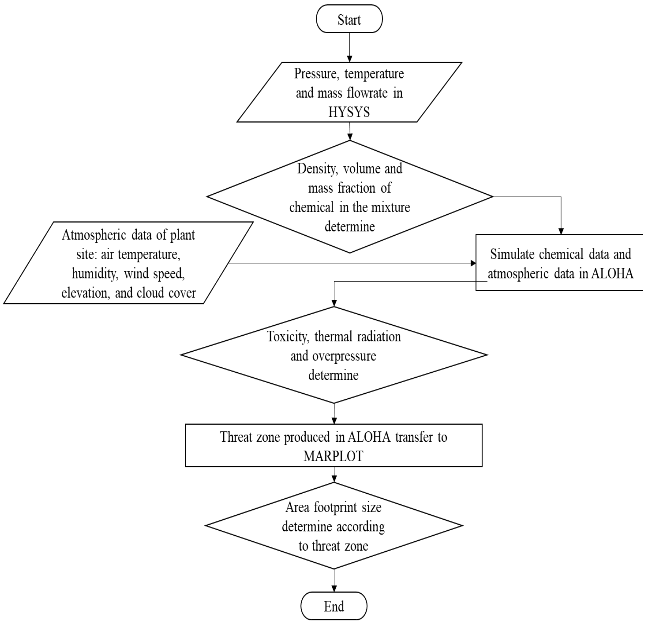


**Fig 3**: Simplified methodology of quantitative accident consequences analysis

It is then simulated with the aid of Marplot software after successful modelling of the case and depicted using Marplot itself or Google Earth in the location map. Thus, any conditions arising somewhere using this approach can be modelled and simulated by an accidental release of a chemical. Simplified methodology of quantitative accident consequences analysis is depicted in Fig. 3.

## 3.0 Results and discussion

In this section, the overall consequences results of the accidental release and explosion possibility of methanol and acetic acid in the acetic acid plant were discussed. The case study was carried out at a chemical plant in MIDC Bhosari, Pimpri Chinchwad, Maharashtra, India. The data collected was then simulated by the software (ALOHA) and appeared on Google Earth in the form of a graphical threat zone (MARPLOT).

**Table 8**: Threat zone area on R-101 for each leaking diameter

| Parameters | Scenario | Diameter Leakage (mm) | Distance of Area Affected (m) | | | Area Affected Footprint ($m^2$) | | |
|---|---|---|---|---|---|---|---|---|
| | | | Red Threat Zone | Orange Threat Zone | Yellow Threat Zone | Red Threat Zone | Orange Threat Zone | Yellow Threat Zone |
| Time: December 20,2020<br>Equipment: R-101<br>Chemical Name: Methanol<br>Wind: E<br>Model: ALOHA Gaussian | Toxic | 10 | Less than 10 m —<br>(7200 ppm = AEGL-3) | Less than 10 m —<br>(2100 ppm= AEGL-2) | 12 m —<br>(530 ppm= AEGL-1) | - | - | - |
| | | 25 | Less than 10 m —<br>(7200 ppm = AEGL-3) | 10 m —<br>(2100 ppm= AEGL-2) | 28 m —<br>(530 ppm= AEGL-1) | - | - | - |
| | | 150 | 27 m —<br>7200 ppm = AEGL-3) | 31 m —<br>(2100 ppm= AEGL-2) | 81 m —<br>(530 ppm= AEGL-1) | - | - | 5,764 |
| | Pool Fire | 10 | Less than 10 m —<br>(10.0 kW/$m^2$)<br>= potentially **lethal** within 60 s | Less than 10 m —<br>(5.0 kW/$m^2$)<br>= 2$^{nd}$ degree burns | Less than 10 m (2.0 kW/$m^2$)<br>= pain within 60 sec | - | - | - |
| | | 25 | Less than 10 m —<br>(10.0 kW/$m^2$)<br>= potentially **lethal** within 60 s | Less than 10 m —<br>(5.0 kW/sq m)<br>= 2$^{nd}$ degree burns | Less than 10 m —<br>(2.0 kW/$m^2$)<br>= pain within 60 sec | - | - | 231 |
| | | 150 | 23 m —<br>(10.0 kW/$m^2$)<br>= potentially **lethal** within 60 s | 33 m — (5.0 kW/$^2$)<br>= 2$^{nd}$ degree burns | 49 m — (2.0 kW/$m^2$)<br>= pain within 60 sec | 1,720 | 3,329 | 7,432 |
| | BLEVE | 10 | 187 m —<br>(10.0 kW/$m^2$)<br>= potentially lethal within 60 s | 270 m —<br>(5.0 kW/$^2$)<br>= 2$^{nd}$ degree burns within 60 s | 427 m — (2.0 kW/$m^2$)<br>= pain within 60 s | 109,856 | 229,563 | 572,460 |
| | | 25 | 187 m —<br>(10.0 kW/$m^2$)<br>= potentially **lethal** within 60 s | 270 m —<br>(5.0 kW/$^2$)<br>= 2$^{nd}$degree burns within 60 s | 427 m — (2.0 kW/$m^2$)<br>= pain within 60 s | 109,857 | 229,563 | 572,461 |
| | | 150 | 187 m —<br>(10.0 kW/$m^2$)<br>= potentially lethal within 60 s | 270 m — (5.0 kW/$^2$)<br>= 2$^{nd}$ degree burns within 60 s | 427 m — (2.0 kW/$m^2$)<br>= pain within 60 s | 109,857 | 229,563 | 572,456 |

### *3.1 Threat zone area in MARPLOT*

Table 8 shows the scenarios threat zone area for the methanol reactor, R-101 for E wind direction, and every leak diameter. Table 9 listed the scenarios threat zone area for the acetic acid reactor, R-102 for E wind direction, and every leak diameter. Table 10 presents the scenarios threat zone area for distillation, T-101 for E wind direction, and every leak diameter. Table 11 tabulated the scenario's threat zone area for Mix-100 for E wind direction and every leak diameter. Table 8

**Table 9**: Threat zone area on R-102 for each leaking diameter

| Parameters | Scenario | Diameter Leakage (mm) | Distance of Area Affected (m) | | | Area of Affected ($m^2$) | | |
|---|---|---|---|---|---|---|---|---|
| | | | Red Threat Zone | Orange Threat Zone | Yellow Threat Zone | Red Threat Zone | Orange Threat Zone | Yellow Threat Zone |
| Time: December 20, 2020 Equipment: R-102 Chemical Name: Acetic acid Wind: E Model: ALOHA Gaussian | Toxic | 10 | Less than 10 m — (250 ppm = ERPG-3) | 28 m — (35 ppm = ERPG-2) | 85 m — (5 ppm = ERPG-1) | - | - | 1,211 |
| | | 25 | 13 m — (250 ppm = ERPG-3) | 66 m — (35 ppm = ERPG-2) | 202 m — (5 ppm = ERPG-1) | 1,438 | 6,991 | - |
| | | 150 | 33 m — (250 ppm = ERPG-3) | 166 m — (35 ppm=ERPG-2) | 520 m — (5 ppm=ERPG-1) | - | 9,595 | 46,252 |
| | Pool Fire | 10 | Less than 10 m — (10.0 kW/$m^2$) = potentially **lethal** within 60 s | Less than 10 m — (5.0 kW/$m^2$) = 2nd degree burns | Less than 10 m — (2.0 kW/$m^2$) = pain within 60 s | - | - | - |
| | | 25 | Less than 10 m — (10.0 kW/$m^2$) = potentially **lethal** within 60 s | Less than 10 m — (5.0 kW/$m^2$) = 2nd degree burns | Less than 10 m — (2.0 kW/sq m) = pain within 60 s | - | - | - |
| | | 150 | 19 m — (10.0 kW/$m^2$) = potentially **lethal** within 60 s | 28 m — (5.0 kW/$m^2$) = 2nd degree burns | 43 meters — (2.0 kW/$m^2$) = pain within 60 s | 1,101 | 2,387 | 5,744 |
| | BLEVE | 10 | 145 m —(10.0 kW/$m^2$) = potentially **lethal** within 60 s | 215 m — (5.0 kW/$m^2$) = 2nd degree burns within 60 s | 345 m — (2.0 kW/$m^2$) = pain within 60 sec | 66,462 | 146,010 | 373,440 |
| | | 25 | 145 m — (10.0 kW/$m^2$) = potentially **lethal** within 60 s | 216 m — (5.0 kW/$m^2$) = 2nd degree burns within 60 s | 345 m — (2.0 kW/$m^2$) = pain within 60 sec | 66,461 | 146,002 | 373,414 |
| | | 150 | 145 m — (10.0 kW/$m^2$) = potentially **lethal** within 60 s | 216 m —(5.0 kW/$m^2$) = 2nd degree burns within 60 s | 345 m — (2.0kW/$m^2$) = pain within 60 s | 66,462 | 146,010 | 373,440 |

**Table 10**: Threat zone area on T-101 for each leaking diameter

| Parameters | Scenario | Diameter Leakage (mm) | Distance of Area Affected (m) | | | Area of Affected ($m^2$) | | |
|---|---|---|---|---|---|---|---|---|
| | | | Red Threat Zone | Orange Threat Zone | Yellow Threat Zone | Red Threat Zone | Orange Threat Zone | Yellow Threat Zone |
| Time: December 20, 2020 Equipment: T-101 Chemical Name: Acetic acid Wind: E Model: ALOHA Gaussian | Toxic | 10 | Less than 10 m — (250 ppm = ERPG-3) | 28 m — (35 ppm=ERPG-2) | 85 m — (5 ppm = ERPG-1) | - | - | 1,211 |
| | | 25 | 13 m — (250 ppm = ERPG-3) | 66 m — (35 ppm = ERPG-2) | 201 m — (5 ppm = ERPG-1) | - | 1,425 | 6,906 |
| | | 150 | 14 m — (250 ppm=ERPG-3) | 73 m — (35 ppm = ERPG-2) | 222 m — (5 ppm=ERPG-1) | - | 1,696 | 8,243 |
| | Pool Fire | 10 | Less than 10 m — (10.0 kW/$m^2$) = potentially lethal within 60 s | Less than 10 m — (5.0 kW/$m^2$) = 2nd degree burns | Less than 10 m — (2.0 kW/$m^2$) = pain within 60 s | - | - | - |
| | | 25 | Less than 10 m — (10.0 kW/$m^2$) = potentially lethal within 60 s | Less than 10 m — (5.0 kW/$m^2$) = 2nd degree burns | Less than 10 m — (2.0 kW/$m^2$) = pain within 60 s | - | - | - |
| | | 150 | 12 m — (10.0 kW/$m^2$) = potentially **lethal** within 60 s | 18 m — (5.0 kW/$m^2$) = 2nd degree burns | 28 m — (2.0 kW/$m^2$) = pain within 60 s | 358 | 802 | 2,013 |
| | BLEVE | 10 | 78 m — (10.0 kW/$m^2$) = potentially lethal within 60 s | 116 m — (5.0 kW/$m^2$) = 2nd degree burns within 60 s | 185 m — (2.0 kW/$m^2$) = pain within 60 s | 19,264 | 42,101 | 107,525 |
| | | 25 | 78 m — (10.0 kW/$m^2$) = potentially lethal within 60 s | 116 m — (5.0 kW/$m^2$) = 2nd degree burns within 60 s | 185 m — (2.0 kW/$m^2$) = pain within 60 s | 19,264 | 42,101 | 107,525 |
| | | 150 | 78 m — (10.0 kW/$m^2$) = potentially **lethal** within 60 s | 116 m — (5.0 kW/$m^2$) = 2nd degree burns within 60 s | 185 m — (2.0 kW/$m^2$) = pain within 60 s | 19,264 | 42,096 | 107,543 |

**Table 11**: Threat zone area on Mix-100 for each leaking diameter

| Parameters | Scenario | Diameter Leakage (mm) | Distance of Area Affected (m) | | | Area of Affected ($m^2$) | | |
|---|---|---|---|---|---|---|---|---|
| | | | Red Threat Zone | Orange Threat Zone | Yellow Threat Zone | Red Threat Zone | Orange Threat Zone | Yellow Threat Zone |
| Time: December 20, 2020 Equipment: Mix-100 Chemical Name: Acetic acid Wind: E Model: ALOHA Gaussian | Toxic | 10 | Less than 10 m — (250 ppm = ERPG-3) | 28 m — (35 ppm = ERPG-2) | 85 m — (5 ppm = ERPG-1) | - | - | 1,211 |
| | | 25 | 13 m — (250 ppm = ERPG-3) | 66 m — (35 ppm = ERPG-2) | 202 m — (5 ppm = ERPG-1) | - | 1,438 | 6,977 |
| | | 150 | 29 m — (250 ppm = ERPG-3) | 144 m — (35 ppm = ERPG-2) | 451 m — (5 ppm = ERPG-1) | - | 7,144 | 34,673 |
| | Pool Fire | 10 | Less than 10 m — (10.0 kW/$m^2$) = potentially **lethal** within 60 s | Less than 10 m — (5.0 kW/$m^2$) = 2[nd] degree burns | Less than 10 m — (2.0 kW/$m^2$) = pain within 60 s | - | - | - |
| | | 25 | Less than 10 m — (10.0 kW/$m^2$) = potentially **lethal** within 60 s | Less than 10 m — (5.0 kW/$m^2$) = 2[nd] degree burns | Less than 10 m — (2.0 kW/$m^2$) = pain within 60 s | - | - | - |
| | | 150 | 18 m — (10.0 kW/$m^2$) = potentially lethal within 60 s | 26 m — (5.0 kW/$m^2$) = 2[nd] degree burns | 41 m — (2.0 kW/$m^2$) = pain within 60 s | 989 | 2,150 | 5,226 |
| | BLEVE | 10 | 131 m — (10.0 kW/$m^2$) = potentially **lethal** within 60 s | 194 m — (5.0 kW/$m^2$) = 2[nd] degree burns | 310 m — (2.0 kW/$m^2$) = pain within 60 s | 54,001 | 118,558 | 303,140 |
| | | 25 | 131 m — (10.0 kW/$m^2$) = potentially **lethal** within 60 s | 194 m — (5.0 kW/$m^2$) = 2[nd] degree burns within 60 s | 310 m — (2.0 kW/$m^2$) = pain within 60 s | 54,002 | 118,561 | 303,150 |
| | | 150 | 131 m — (10.0 kW/$m^2$) = potentially **lethal** within 60 s | 194 m — (5.0 kW/$m^2$) = 2[nd] degree burns within 60 s | 310 m — (2.0 kW/$m^2$) = pain within 60 s | 54,002 | 118,561 | 303,161 |

to Table 11 indicated the area of the threat zone, the distance of area affected by the scenarios which are toxic release, pool fire, and BLEVE for 10 mm, 25 mm, and 150 mm leak diameter for each equipment, wind direction that moves towards residential areas and area affected footprint covered in $m^2$.

For the first equipment, which is the methanol reactor, R-101, the scenario with the largest area was BLEVE which covered 572,461 $m^2$ and with an affected distance of 427 meters. The areas affected by this scenario are only the facilities and the area nearby facilities.

For the second equipment, which is an acetic acid reactor, R-102, the scenario with the largest area was BLEVE which covered 373,440 $m^2$ and with an affected distance of 345 meters. The areas affected by this scenario are the post office and nearby facilities. For the third equipment, which is the distillation column, T-101, the scenario with the largest area was BLEVE which covered 107,543 $m^2$ and with an affected distance of 185 meters. The areas affected by this scenario are Udappi Lunch Home and nearby plant facilities.

For the last piece of equipment, which is the mixer, Mix-100, the scenario with the largest area was BLEVE which covered 303,161 $m^2$ and with an affected distance of 310 m. The areas affected by this scenarios are the facilities such as the post office, PCMC office, and nearby plant facilities.


**Fig. 4**: Affected area, intensity of the toxic threat zone of 150 mm leak diameter in all wind direction on R-102

If a tank holding liquid ruptures at a temperature above its ambient pressure saturation point, a BLEVE (boiling liquid expanding-vapor explosion) happens. The resulting BLEVE is explosive vaporization accompanied by combustion or eruption of a significant fraction of the vessel's contents. Due to its high radiation intensity and the production of overpressure waves, it has a potential impact, creating heavy damage to nearby equipment and structures.

By comparing all of the equipment, the methanol reactor, R-101 produced the largest threat zone areas and longest distances for the affected area. The behaviour of the material released because of containment loss depends on the physical characteristics of the material, the conditions of the contained material (pressure and temperature), the phase of the released material (liquid or gas), the inventory of the released material, the weather parameters (temperature, humidity, wind speed, atmospheric stability) and the material with a boiling point below the ambient condition.


**Fig. 5**: Affected area, intensity of the pool fire threat zone of 150 mm leak diameter in all wind direction on R-101

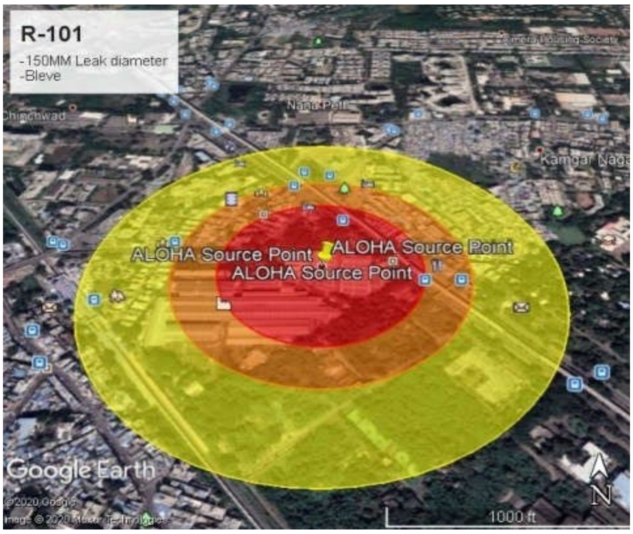


**Fig. 6**: Affected area, intensity of the BLEVE threat zone of 150 mm leak diameter in all wind direction on R-101

*3.2 Map of the Affected Area on Google Earth*

Example of selected scenario for toxicity, pool fire and BLEVE are illustrated in Fig. 4, 5, and 6. These figures presented the affected area and the intensity of the threat zone for scenario in R-102 and R-101. Figure 4 illustrated area affected for toxicity of acetic acid, leaked of 150 mm diameter. Only orange and yellow zone appear, suggest lower concentration of toxic of ERPG-1 and ERPG-2, which indicate mild impact, odor unacceptable for ERPG-1 and severe health effects that may impair the ability of a person for ERPG-2. Figure 5 presents affected area, resulting from pool fire threat zone of 150 mm leak diameter in all wind direction on R-101. In this Figure 5, chemical released are methanol, producing three threat zone of red, orange and yellow, which area covered of 1,720, 3,329, and 7,432 m$^2$, respectively. The radius of distance for yellow zone is within 49 meters, which can cause pain within 60 seconds. Figure 6 shows affected area of the BLEVE threat zone of 150 mm leak diameter in all wind direction on R-101. In this Figure 6, chemical released are methanol, producing three threat zone of red, orange, and yellow, which area covered of 109,587 m$^2$, 229,563 m$^2$ and 572,456 m$^2$ respectively. The radius of distance for yellow zone is within 427 meters, which can cause pain within 60 seconds.

## 4.0 Conclusions

Quantitative consequence analysis on Chemical Plant of Acetic Acid production using case study in India was performed. Consequence accident analysis was estimating worst case accident due to BLEVE scenario happen in methanol reactor, R-101. Distance of area affected in R-101 was 427 meters while area affected footprint covered 572, 461 m$^2$. Safety aspect of acetic acid production plant was successfully quantified, which the worst-case scenario occurred for every equipment in the plant has been identified and compared. Preventive measure on BLEVE, which is thermal radiation scenario must be prioritised such as installing safety alarm interlocks system and automatic fire suppression system (within process equipment) to minimise the impact of consequences scenario. Although distances and size of area affected for worst-case scenario was achieved, the study using different wind direction and frequency of accident analysis will be recommended for future work.

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