Alexandria Engineering Journal (2016) **55**, 2919–2931

HOSTED BY

ELSEVIER

Alexandria University

Alexandria Engineering Journal

www.elsevier.com/locate/aej
www.sciencedirect.com

ORIGINAL ARTICLE

A new tool for risk analysis and assessment in petrochemical plants

El-Arkam Mechhoud [a,*], **Mounira Rouainia** [b], **Manuel Rodriguez** [c]

[a] *Automatic Research Laboratory, Department of Electrical Engineering, Faculty of Technology, University of Skikda, Algeria*
[b] *Chemical Engineering and Environment Research Laboratory, Department of Petrochemistry and Chemical Engineering, Faculty of Technology, University of Skikda, Algeria*
[c] *Autonomous Systems Laboratory, Technical University of Madrid, Spain*

Received 9 October 2015; revised 31 March 2016; accepted 11 May 2016
Available online 9 June 2016

KEYWORDS

Industrial plant;
HAZOP;
FMECA;
Automated risk analysis;
Risk assessment;
High density polyethylene

Abstract The aim of our work was the implementation of a new automated tool dedicated to risk analysis and assessment in petrochemical plants, based on a combination of two analysis methods: HAZOP (HAZard and OPerability) and FMEA (Failure Mode and Effect Analysis). Assessment of accident scenarios is also considered. The principal advantage of the two analysis methods is to speed-up hazard identification and risk assessment and forecast the nature and impact of such accidents. Plant parameters are analyzed under a graphical interface to facilitate the exploitation of our developed approach. This automated analysis brings out the different deviations of the operating parameters of any system in the plant. Possible causes of these deviations, their consequences and preventive actions are identified. The result is risk minimization and dependability enhancement of the considered system.

1. Introduction

There are many kinds of equipment in the petrochemical plants and petroleum refineries, usually presenting complex structures and several parameters. In such plants, it is important to consider different and critical types of risks, such as explosions, fire and toxic release which may cause serious damage either to human lives or to the environment. Fires and explosions are potential initiators of major accidents in these industry installations. In petrochemical industry, explosion risk must be analyzed for every component in the plant, and all tools must be used to minimize this threat. The quantitative risk analysis, in essence, should predict the extent and movement of the gas cloud and calculate the overpressures generated if the cloud is ignited inside a congested area.

Since real processes are not always operated within the control range because an abnormal situation happened, accidents may occur such as valve damage, pump damage and pipe leakage [1]. HAZOP is the method recommended for identifying hazards and problems which prevent efficient operation. Once the hazards and problems are identified, possible solutions and modifications can be proposed to avoid and get rid of these hazards and problems, that is, HAZOP is a prevention tool.

---

[*] Corresponding author at: B.P. 26 route El-Hadaiek, Skikda-Algérie 21000, Algeria. Tel.: +213 669348764.
E-mail addresses: mechhoud.elarkam@uni-skikda.dz, elarkam_mechhoud@yahoo.fr (E.-A. Mechhoud).

Peer review under responsibility of Faculty of Engineering, Alexandria University.

http://dx.doi.org/10.1016/j.aej.2016.05.013
1110-0168

FMEA analysis allows the determination of all failure modes, causes and consequences of each component in the process and the localization of the damage. Our contribution in this context is an automated risk analysis and assessment by combining the HAZOP and FMEA methods and assessing the consequences of the accident scenarios. The combination will enable to localize the problem and its cause in every component, besides fastening hazards identification.

Traditional risk analysis has been a time consuming and error prone task. Many research works present automated tools for risk analysis and assessment exist in the world such as a TORAP [2] a HAZOPExpert [3], PHASuite [4], Functional HAZOP assistant [5], Automating HAZOP studies using D-higraphs [6]. In [1] C. Jeerawongsuntorn proposed an automated approach developed under an interface Human–Machine using the HAZOP study to identify all deviations in the biodiesel production. However, this method cannot localize exactly the failure, or simulate the accident scenario when it is important to predict the release rate of hazardous material, the flashing degree, and the evaporation rate, into techniques and methodologies for risk analysis in chemical process industries by Authors of [2] "TORAP "makes a rapid and quantitative risk assessment of a typical petroleum refinery, and quantifies the accident consequences such as the BLEVE, VCE, UVCE, but without proposing any recommendations helping the operators to make a decision.

Our proposed Tool for Risk Analysis and Assessment (TORANAS) is developed to enable a more global risk analysis, accident simulation and potential damage estimation in operating petrochemical plants. The developed analysis provides recommendations allowing the increase in system reliability and safety. The software has been developed in the form of a graphical interface using Matlab as a coding tool. Our method includes deviations and failure modes identification, and localization of their causes. TORANAS will heal to decrease human errors and will assist the operator to make a good and safe decision. As a case study, we have considered the High Density PolyEthylene (HDPE) plant in Skikda-Algeria- (CP2K-Skikda petrochemical plant).

2. Dependability analysis

The dependability analysis of an industrial system can be divided into two steps:

- Functional analysis
- Dysfunctional analysis, qualitative and/or quantitative.

2.1. Functional analysis

Functional analysis performs a functional decomposition of an industrial plant under design or operation. The aim was to identify, characterize, classify, prioritize and valorize all the system's functions. Numerous methods of functional analysis have been developed since the end of the Second World War. All of them have been derived from the value analysis method developed by LD Miles in 1947 [7].

Functional analysis provides a synthetic description of a system operating modes and knowledge of functions. It establishes systematic and exhaustive functional of this system.

Among these methods, we have the SADT method (Structured Analysis and Design Technical), RELIASEP method also called the tree functional calculus, D-higraphs as a modeling technique that merges functional and structural information of the system modeled (Rodriguez 2009), and multilevel flow modeling (MFM) is used to represent the knowledge of plant functions (Lind 2010). This last method presents the whole set of the connections between the functions, performances, constraints and characteristics of materials using a tree structure [7].

2.2. Dysfunctional analysis

Dysfunctional analysis is to identify the conditions that can lead to failures and predict their impact on reliability, maintainability, availability, integrity, and security of systems under development or already operational.

According to the standard (Aero RE 701 November 11, 1986), the principle of these methods is based on a cause of abnormality (failure, human error, external aggression, etc.) and determines the resulting scenarios and/or all of its possible consequences. The main inductive methods used in the domain of accidental risks are as follows: preliminary risk analysis (PRA), Failure mode and effect analysis (FMEA), HAZOP (Hazard and operability) What if, Event tree analysis (ETA), ...etc. And the only deductive method is the Fault tree analysis (FTA). In our work we use two inductive risk analysis methods HAZOP and FMEA.

2.2.1. Failure mode and effect analysis (FMEA)

FMEA is a structured method used to identify potential failures of a product or service and determine the failure frequency and impact. This method is often referred to as a "bottom up" approach and it is based on the identification of a particular cause or failure mode within a system in a fashion that traces forward the logical sequence of this condition through the system to the final effects [8]. When the criticality ranking is included the analysis is usually called Failure Mode, Effect and criticality Analysis (FMECA). This is a procedure that is performed after a failure mode effect analysis to classify each potential failure effect according to its severity, probability of occurrence and Detection. A typical FMECA incorporates some method to evaluate the risk associated with the potential problems identified through the analysis. The two most common methods are Risk (R) Priority (P) Numbers (N) and Criticality Analysis. FMECA takes three parameters into consideration: Severity (S), Occurrence frequency (F) and Detection (D). A scale of 1 (without adverse effects) to 4 (immediate danger to personnel and installation, requiring emergency shutdown) has been suggested to rate the severity of the failure mode (AIChE/CCPS, 1985), with levels 2 and 3 corresponding respectively to low-risk situations, which do not require shutdown, and those of higher risk levels, which require normal shutdown [9]. The RPN is a measure used to identify critical failure modes associated with process. It's obtained by multiplication of the three FMECA parameters:

$$\mathrm{RPN} = \mathrm{F} \times \mathrm{S} \times \mathrm{D}. \tag{1}$$

The RPN provides a relative priority for taking action – the bigger the RPN, the more important to address the corresponding failure being assessed. RPNs should be recalculated after the corrections to see whether the risks have gone down, and to check the efficiency of the corrective action for each failure mode [10].

2.2.1.1. Advantage and limit of the FMEA. FMEA is useful mostly as a survey method to identify major failure modes in a system. It is not able to discover complex failure modes involving multiple failures or subsystems, or to discover expected failure intervals of particular failure modes. For these, a different method called fault tree analysis is used. Its structured analysis evaluates processes before implementation. Time and resources for FMEA are allocated during development, when changes are easier and less expensive to make [11].

Hazard and Operability Study (HAZOP)

A HAZOP study is a highly disciplined procedure that identifies how a process may deviate from its design intent [12]. It is defined as the application of a formal, systematic critical examination of the process and the engineering intentions of new or existing facilities to assess the malfunctioning potential of individual components of an equipment, and the consequential effects on the facility as a whole. This method's success lies in its strength in analyzing a system's Piping & Instrumentation Diagrams (P&IDs), breaking the design into manageable sections with definite boundaries called nodes, so as to ensure the analysis of each equipment piece in the process.

A small multi-disciplinary team undertakes the analysis, whose members should have sufficient experience and knowledge to answer most questions on the spot. The members are selected carefully, and are given the authority to recommend any needed changes in the design [12].

Executing the method relies on using guidewords (such as no, more and less) combined with process parameters (e.g., temperature, flow, pressure) that aim to reveal deviations (such as less flow, more temperature) of the process intention or normal operation guideword + Parameter = Deviation [13]. This procedure is applied in a particular node as a part of the system characterized for a nominal intention of the operative parameters. Having determined the deviations, the expert team explores their possible causes and their possible consequences [14].

HAZOP is useful to apply to systems that involve human performance and behavior or any system that involves hazards that are hard to quantify or detect. On the other hand, HAZOP does not take into account the cognitive ability of human as of why they would commit an unsafe act, which is a weakness of HAZOP. Thus, HAZOP analysis is not standardized worldwide; hence, the analysis is performed differently with variation in results for the same system [15]. Moreover, HAZOP study does not take into account the interaction between different components in a system or a process [16], and it also can be lengthy, time consuming and expensive [17].

However, HAZOP is time consuming. According to one evaluation [18], for a process with many P&ID ranging from simple or complex drawings, a team of five people led by an experienced team leader needs more than 400 man-hours for the finalization of the HAZOP analysis, and the overall spent time is about 8 weeks. So an automated analysis is helpful in reducing time, minimizing the errors and can be used as an aid for human expert.

3. Tool for Risk Analysis and Assessment proposed approach: (TORANAS)

Our proposed tool for Automated Risk Analysis and Assessment (TORANAS) is developed to enable a more global risk analysis, accident simulation and potential damage estimation in the petrochemical industries. The software has been developed in graphical interface using Matlab as a coding tool.

The proposed concept involves the combination of HAZOP and FMECA to analyze the risk and to evaluate the accident consequences by using the Sadovsky model used to calculate blast wave from explosion [19] to see the mean parameter of each consequence (as the impact radii of explosion or fire, the overpressure intensity,...etc) in order to make a good, perfect analysis and to make a safe system. Both automated techniques are used to support the decision-making process. In this framework the TORANAS process involves creating two interlinked evaluation models. The first model is evaluated by the criticality matrix extracted from the HAZOP and FMECA analysis by the severity level implemented in the HAZOP and FMECA analysis and the second by the accident scenarios model extracted from the distance effect (domino effect) and blast wave. TORANAS consists of four major elements (Fig. 1): description and definition of the system, identification of hazards, Risk assessment and decision making.

- *Description and definition of the system:* The purpose of the first stage was to determine the system with all equipment and operating parameters by a decomposition of the global system into sub systems, and usually HAZOP is done with the P&ID. We use a structural tree to identify all the equipments which builds the system.
- *Hazard identification:* In this stage we proceed to hazard identification and localization. HAZOP study is proceeded to identify the deviations, their causes and their consequences in the plant. Then the FMECA analysis will localize the problem by identifying all failure modes, their causes and their consequences in each sub-system elements.
- *Consequence assessment:* The third stage helps to identify the accident scenarios. It includes an assessment of geographical areas likely to be affected by the consequences of the possible accidents types. But before this, we need to input the chemical properties and the material parameters. We use the Sadovsky model to simulate the different accident scenarios. This stage helps the operator to prevent accidents and also cushions any adverse impacts.
- *Decision Making:* After the analysis and evaluation of the risks by TORANAS, the user will be able to effectively localize the problem and to realize how much influence each evaluation criterion will have on the decision-making process and on the system safety.

3.1. Case study

3.1.1. Description of the CP2K Skikda plant

HDPE complex is located in the Skikda industrial area, with a surface of 166,800 m^2, from which 10% are built. HDPE project is located on the coast at 06 km east from Skikda city center and an average height of about 06 m above sea level. The position is delimited as follows: (North: Mediterranean

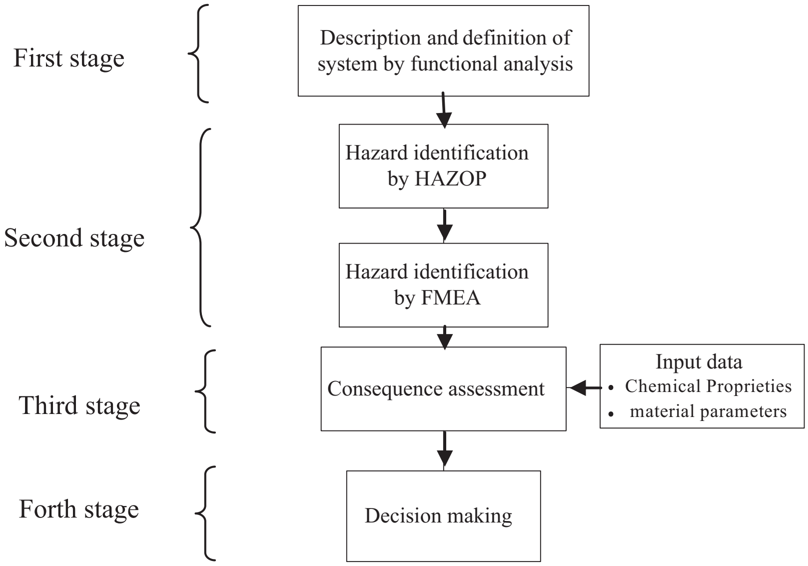


Figure 1 Flowchart of TORANAS.

Sea, South: the main road of the industrial area, East: The Intervention and Reserve Force, West plastic material plant).

Skikda CP2K plant was put in exploitation in 2005. It is an Operational Unit of the national Company SONATRACH. It is located in the industrial area ‘‘Oil-rig SKIKDA’’. The production of high-density polyethylene from ethylene as the main raw material is based on the PHILLIPS PETROLEUM COMPANY process (particles process). It consists essentially of the catalytic polymerization of the ethylene in a closed continuous tubular reactor, in liquid phase (forming suspension in isobutane). The highly exothermic chemical reaction (800 kcal/kg approximate.) occurs at a temperature in the range [85–110] °C and under a pressure of 42–44 kg/cm^2 (Fig. 2) [20].

This unit is divided into four areas (Fig. 3). The first, named ‘‘off-site’’ stores the raw material (hexane, i-butane and hydrogen) while in the second ‘‘humid area’’ the raw material preparation and reaction are proceeded. The third area ‘‘Drying area’’ is the one where the finished product is stocked up and conditioned. The last area is the building area which is devoted to department offices.

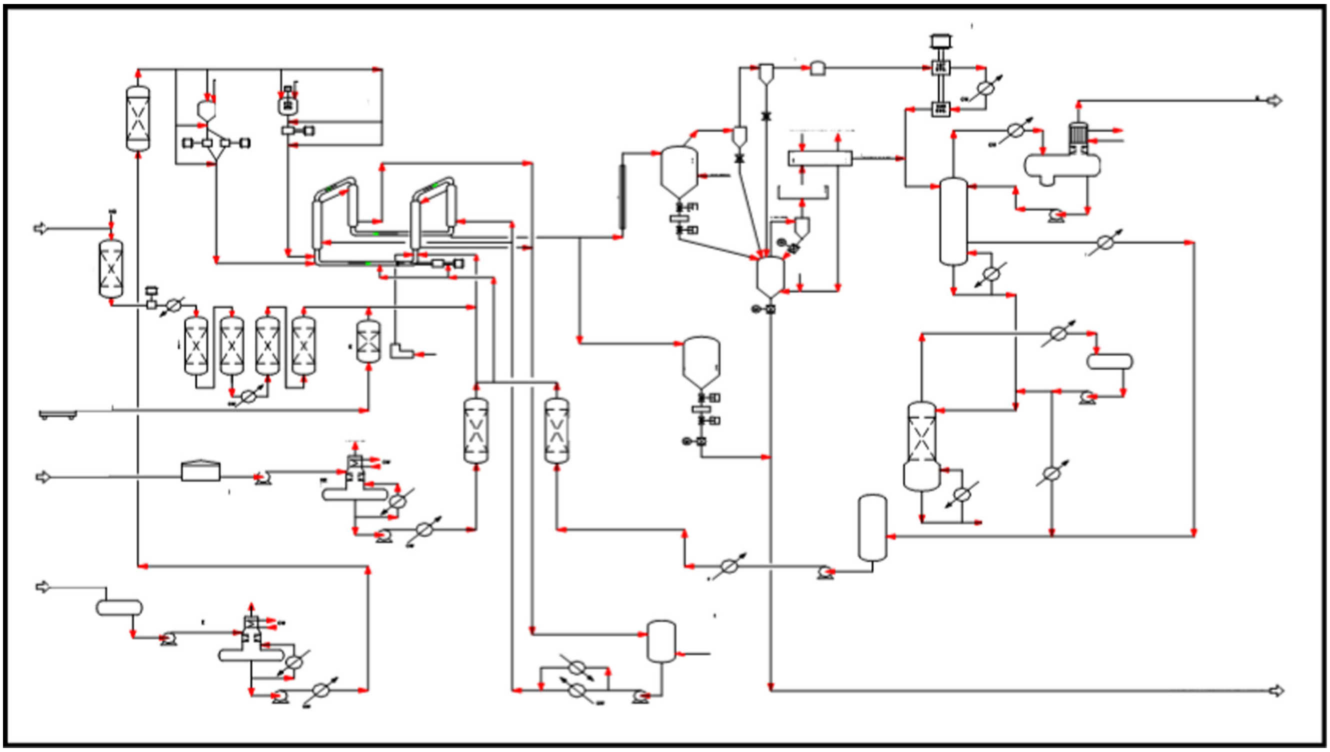
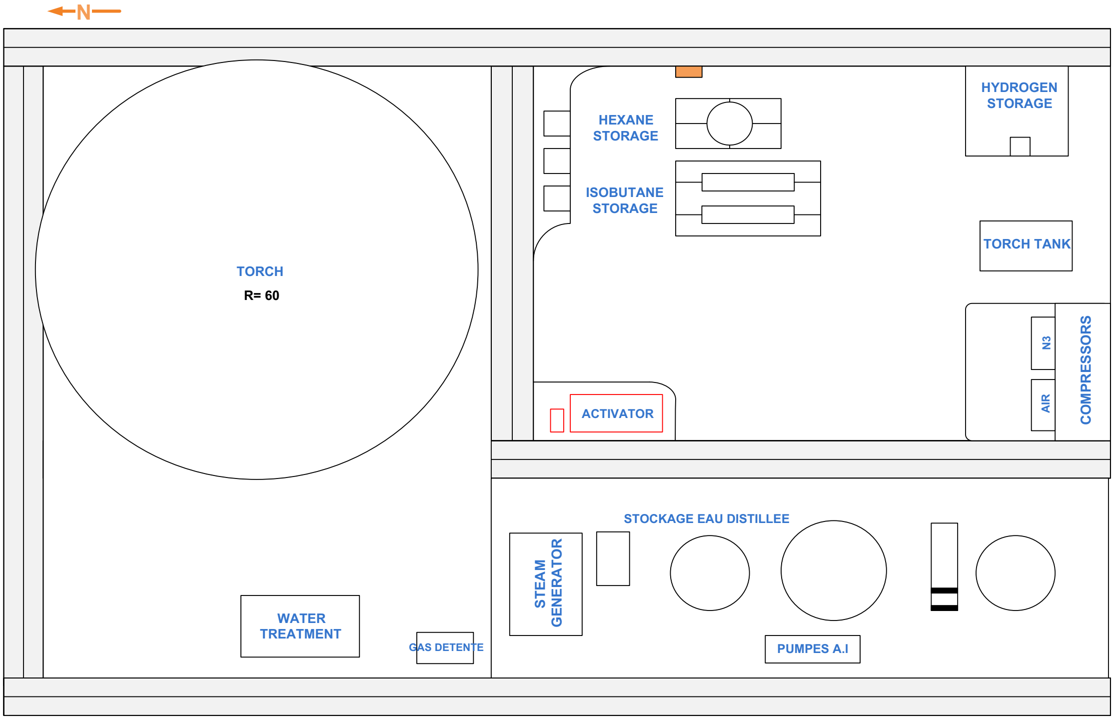
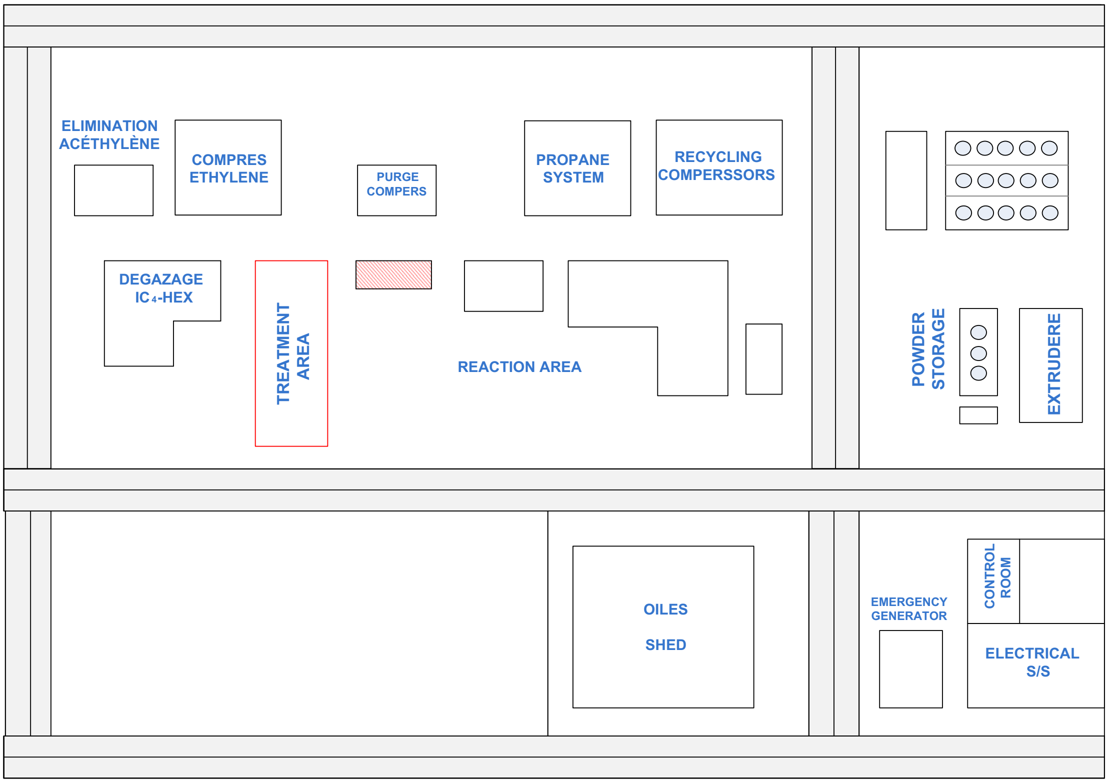


Figure 2 PFD of the HDPE process.



(a) The off-site area



(b) The humid, drying and building areas

Figure 3 CP2K unit Skikd.

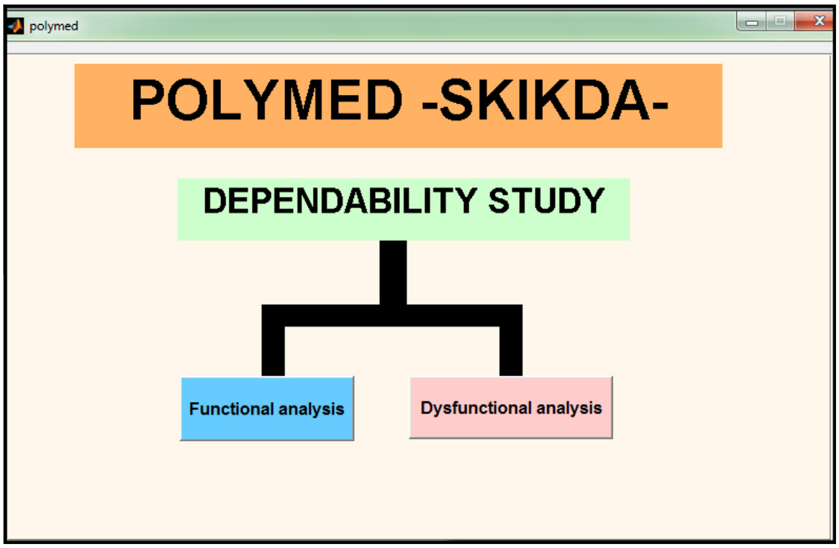


Figure 4 Graphical user interface – flyleaf.

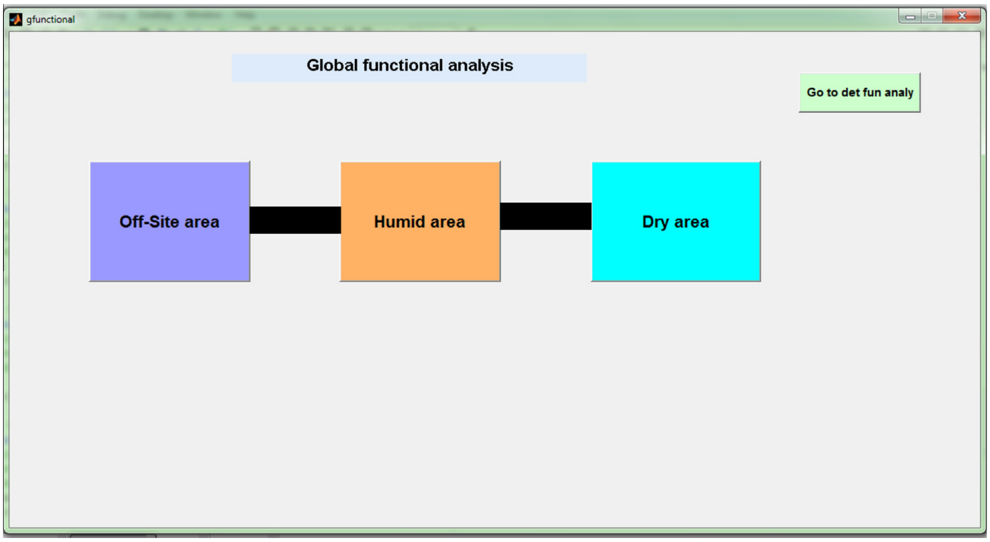


Figure 5 Graphical user interface- Functional analysis.

- The off-site area is composed of the following: Torch system (Flare stack system), storage hexane (hexane tank 950-461), i-butane and hydrogen, waste water treatment and catalyst activator.
- The humid area is composed of the following: the different caterers, reactor, compressors and capacities.
- The drying area is composed of the following: extruder, blower, silos to store the finished product, and bagging.
- The building area is composed of the following: control room and laboratory, security block and infirmary, substation high and low tension, ADM and finance block, workshop and replacement part store [21].

The reactor feed streams (ethylene, isobutane, hydrogen and hexane, in the case of the production of copolymers) require a high degree of purity, for this; they are in advance treated to remove any catalyst poison (basically acetylene, oxygen, and water) until no harmful residual contents. This is accomplished in suitable catalytic caterers, in the case of ethylene, degassing columns, isobutane and hexane, and specific dryers for all currents. The reactor is fed with the raw materials processed at the treatment area. Recycled isobutane, hydrogen, hexane and ethylene arrive at the reactor through the main supply line to the reactor. Hexane and recycled isobutane are mixed in the static mixer isobutane/hexane. Hydrogen is mixed with the ethylene and it is added to the stream of recycled isobutane/hexane at the mixer output. The feed to reactor at different flows is adjusted based on certain variables. The isobutane-ethylene-polyethylene mixture flows into the reactor through the reactor pump [22].

3.1.2. Application

The effects of temperature, pressure and flow on the HDPE reactor are determined, and the operating condition for each

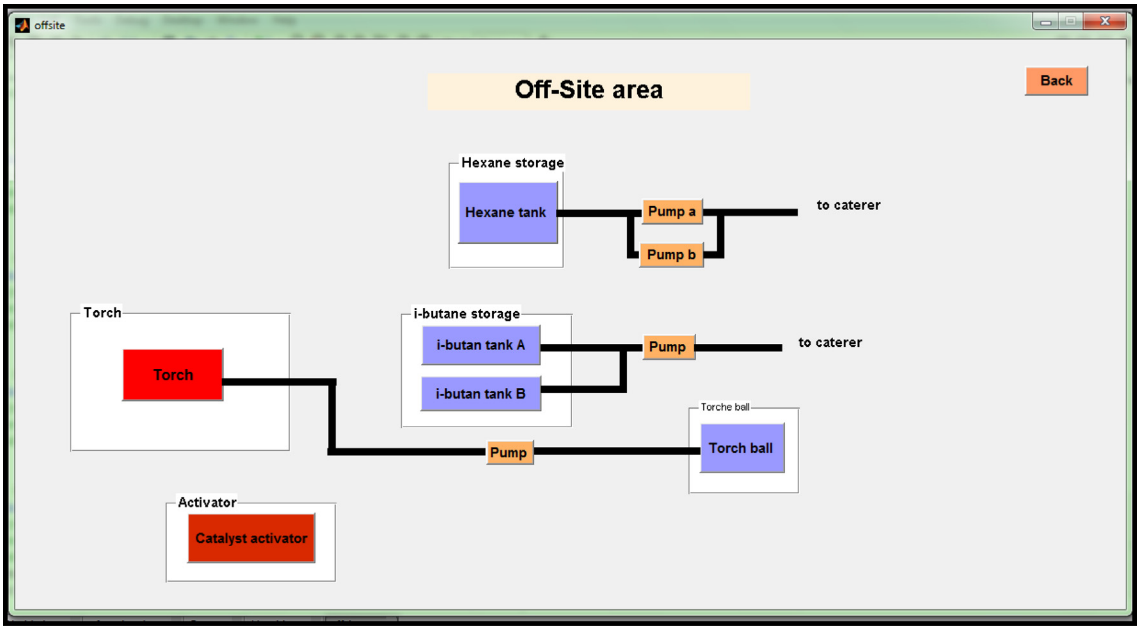


Figure 6 Graphical user interface- Functional analysis Off-Site area.

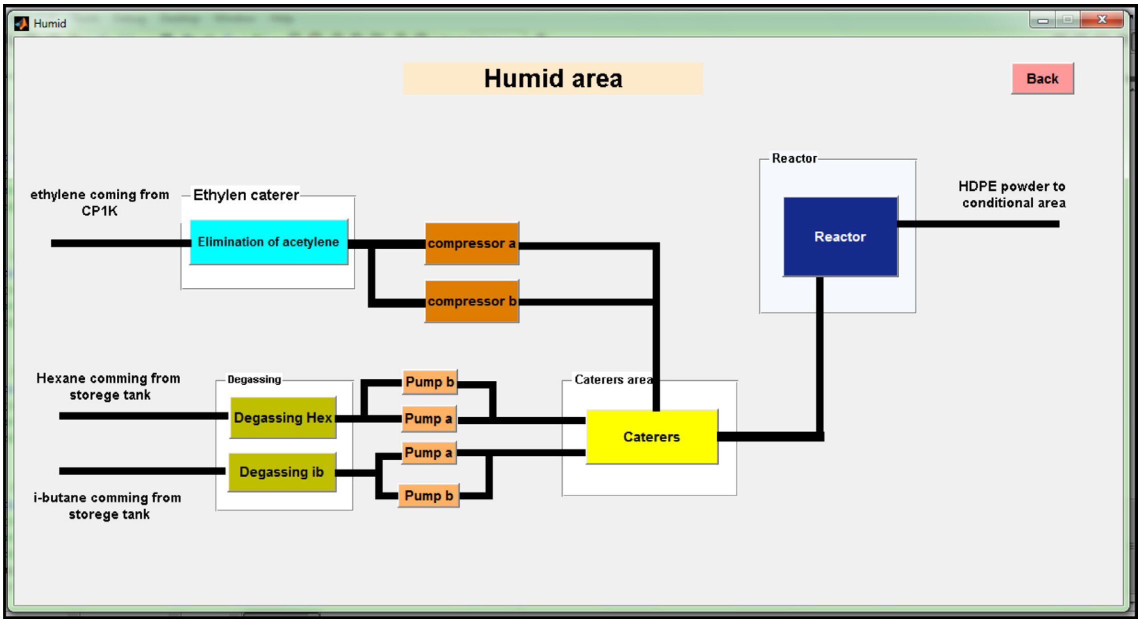


Figure 7 Graphical user interface- Functional analysis Humid area.

case is selected. When we have a deviation in a parameter, the HAZOP and FMECA analysis is performed. The analysis will show the severity of the hazard level. A human machine interface is constructed to automatically operate the HDPE process using HAZOP and FMECA. This helps decreasing the hazards and increasing production as well as the reliability of the process.

Our analysis approach incorporates the HDPE plant modeling with functional analysis and safety analysis (dysfunctional analysis). It can be divided into two parts. The first part is devoted a functional analysis to the decomposition of the plant into three areas, as that the safety is done using it, each one having many installations and equipment, while safety analysis is performed in the second part. A decomposition of the CP2K plant is performed using graphical interface developed under Matlab software. The safety analysis is preceded by a combination of a HAZOP and an FMECA analysis. The analysis results are shown on the graphical interface. The HAZOP analysis is used to identify all the deviations, their causes and consequences in the installation nodes, while the FMECA analysis is applied to identify all failure modes, causes and consequences in each equipment.

Our developed graphical interface contains two modules: the functional analysis and the dysfunctional analysis. Fig. 4 shows the flyleaf of the interface. It consists of 2 parts.

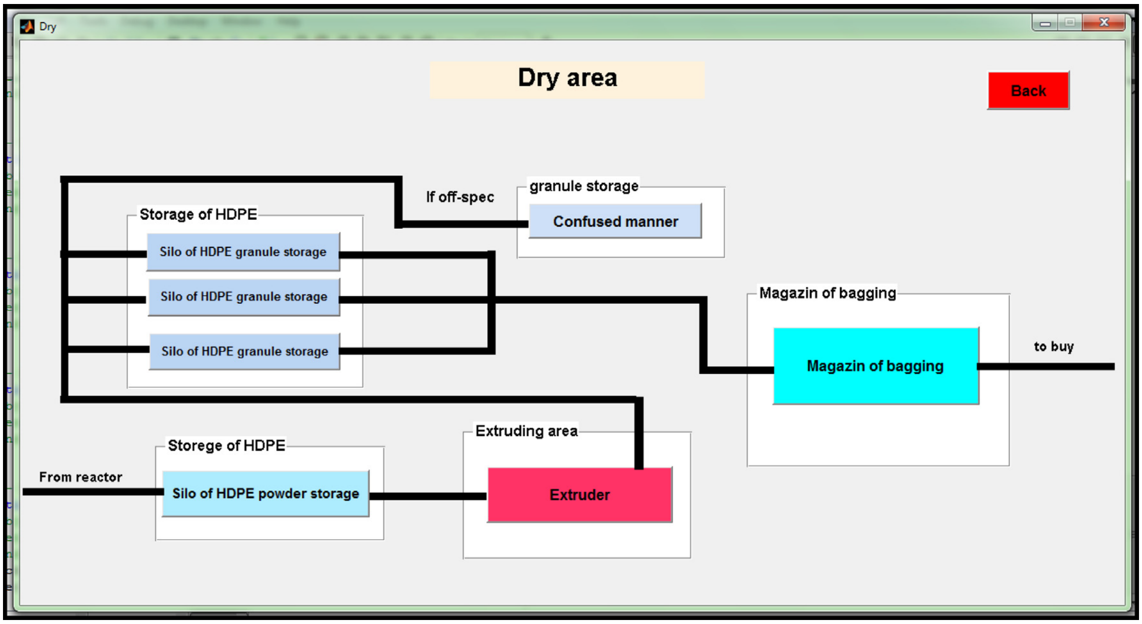
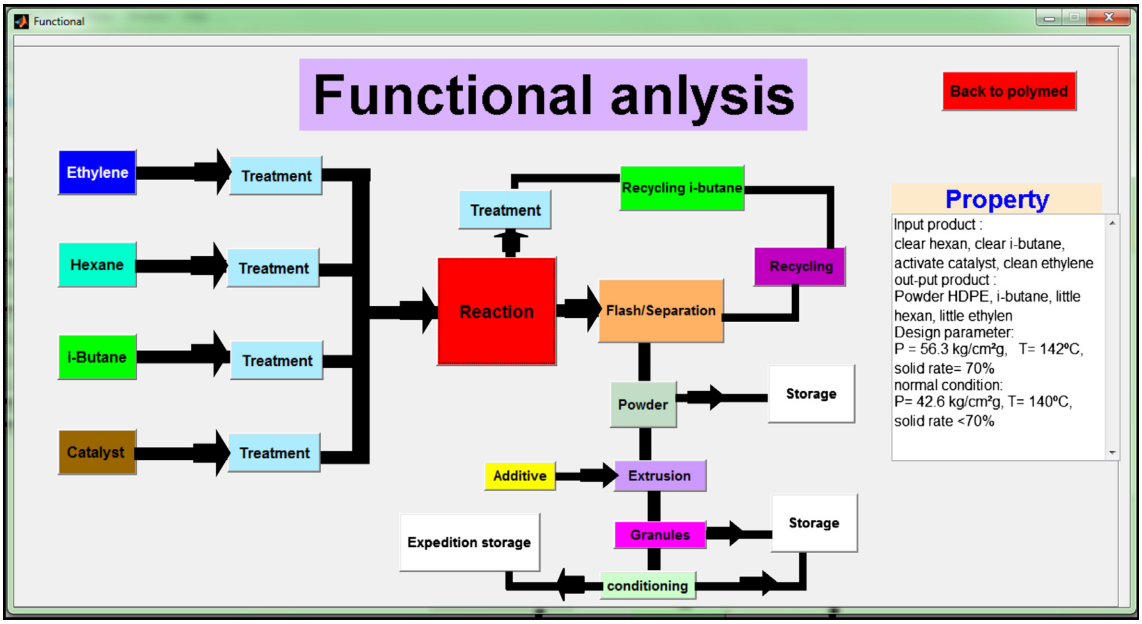


Figure 8 Graphical user interface- Functional analysis Dry area.



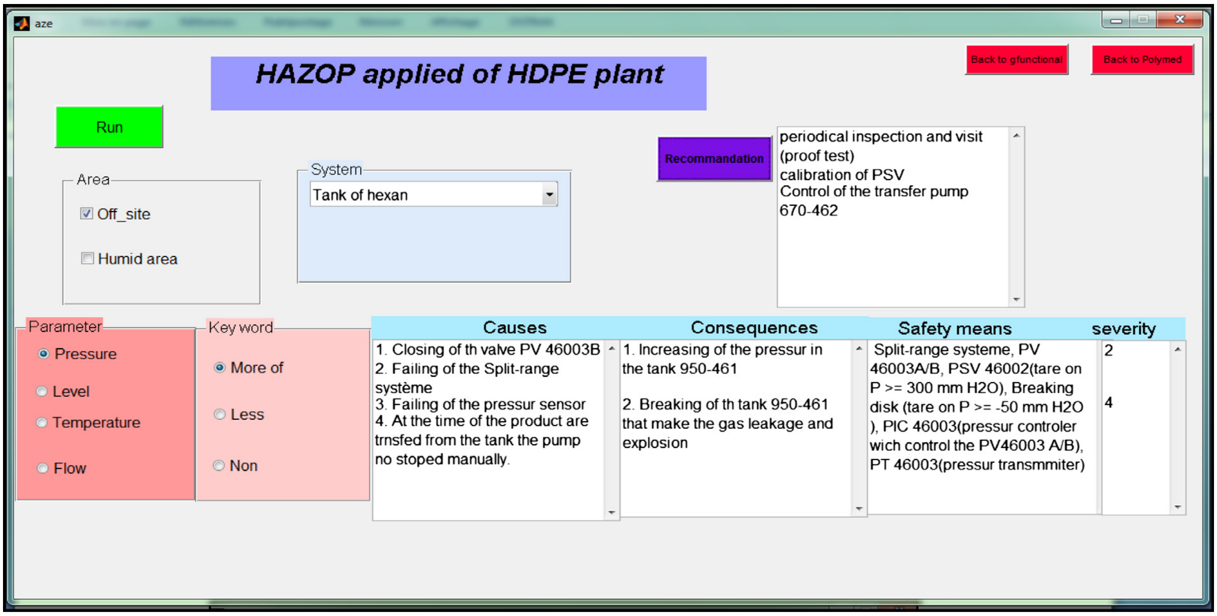
Input product :
clear hexan, clear i-butane,
activate catalyst, clean ethylene
out-put product :
Powder HDPE, i-butane, little
hexan, little ethylen
Design parameter:
P = 56.3 kg/cm²g, T= 142ºC,
solid rate= 70%
normal condition:
P= 42.6 kg/cm²g, T= 140ºC,
solid rate <70%

Figure 9 Graphical interface-HDPE process modeling.

- Part 1 is the functional analysis command click. Clicking on it will show the results of the process identification and its decomposition into sub-system (areas, unit, equipment, components,...etc.). This analysis describes the process functionality and identifies all operating parameters (Figs. 5–9).
- Part 2 is the dysfunctional analysis command click. Clicking on it will show the result of the HAZOP analysis including identification of the hazardous events which may happen in the process. Guide words are introduced for generating the process variables. When the guide words are applied to the process variables of each unit, their deviations are considered. The result of the HAZOP analysis is proposed in a safety table (Fig. 10).

Fig. 5 shows the functional analysis. It considers the three areas of the plant HDPE [23]. Each area is presented by a command click which shows, all existing components and equipment in this area (Figs. 6–8 show the results for the off site, the humid and the dry site respectively).

For example, in Fig. 6 we can see the off-site decomposition: storage tanks, catalyst activator, torch system, pumps and compressors. Clicking on the compressor button will show



Area
☑ Off_site
☐ Humid area

System
Tank of hexan

periodical inspection and visit (proof test)
calibration of PSV
Control of the transfer pump 670-462

Parameter
● Pressure
○ Level
○ Temperature
○ Flow

Key word
● More of
○ Less
○ Non

Causes	Consequences	Safety means	severity
1. Closing of th valve PV 46003B 2. Failing of the Split-range système 3. Failing of the pressur sensor 4. At the time of the product are trnsfed from the tank the pump no stoped manually.	1. Increasing of the pressur in the tank 950-461 2. Breaking of th tank 950-461 that make the gas leakage and explosion	Split-range systeme, PV 46003A/B, PSV 46002(tare on P >= 300 mm H2O), Breaking disk (tare on P >= -50 mm H2O), PIC 46003(pressur controler wich control the PV46003 A/B), PT 46003(pressur transmmiter)	2 4

Figure 10 Graphical user interface –Dysfunctional analysis HAZOP.

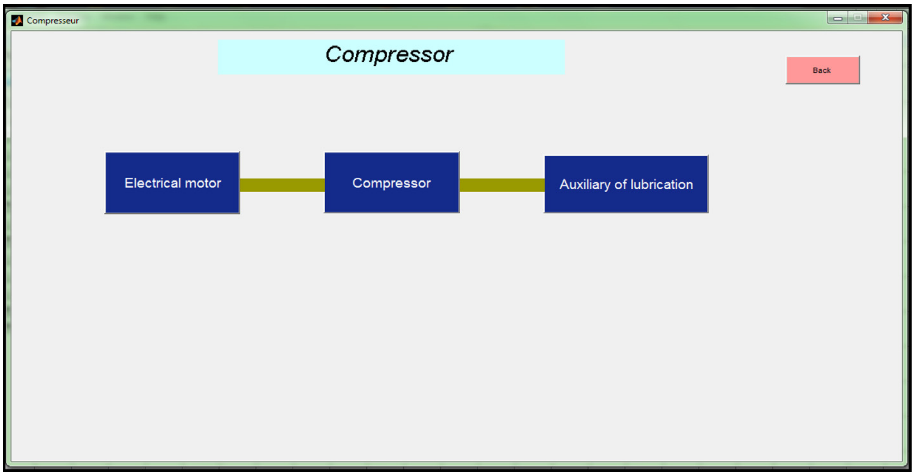
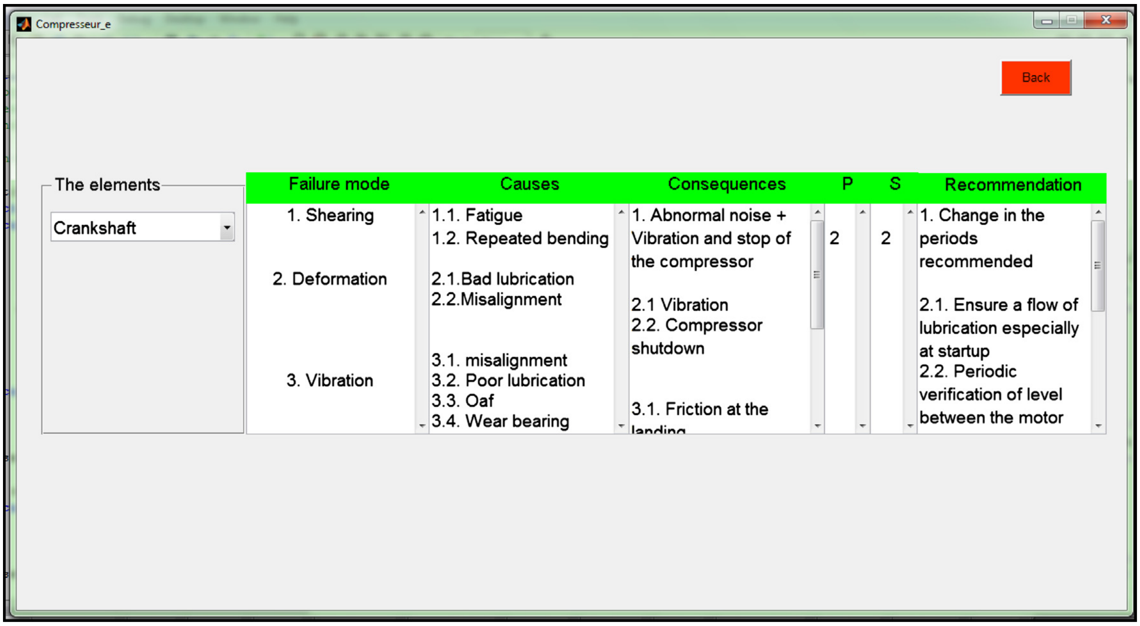


Figure 11 Graphical user interface – The compressor functional analysis.

the decomposition of this equipment into the following: compressor, motor and the lubricator (Fig. 11). Clicking on the "compressor" button will show the FMEA analysis results including identification of the failure modes that may occur in the unit, their causes and consequences (Fig. 12).

Fig. 9 shows the HDPE process modeling by clicking on the "Go to det fun anly" (Fig. 5). It includes many commend click, when the user clicks on any commend click, will show the properties of this component in the part "Property". Temperature is an important variable in the process. The severity of the hazard for temperature deviation is divided into four levels. Level 1 is determined when the temperature is more than 110 °C or less than 85 °C. The reaction rate will be lost if the temperature is less than 85 °C. In addition, the fouling problem appears when the temperature exceeds 110 °C. The reaction will not be complete because more rate of anti static agent (ASA), thus Product out of specification. Level 4 is reached when the temperature is higher than 142 °C. This situation is critical. It could cause a fire and explosion in the plant. In this work, TORANAS is used to help the operator in order to ensure the control of the operation when the severity level is 4.

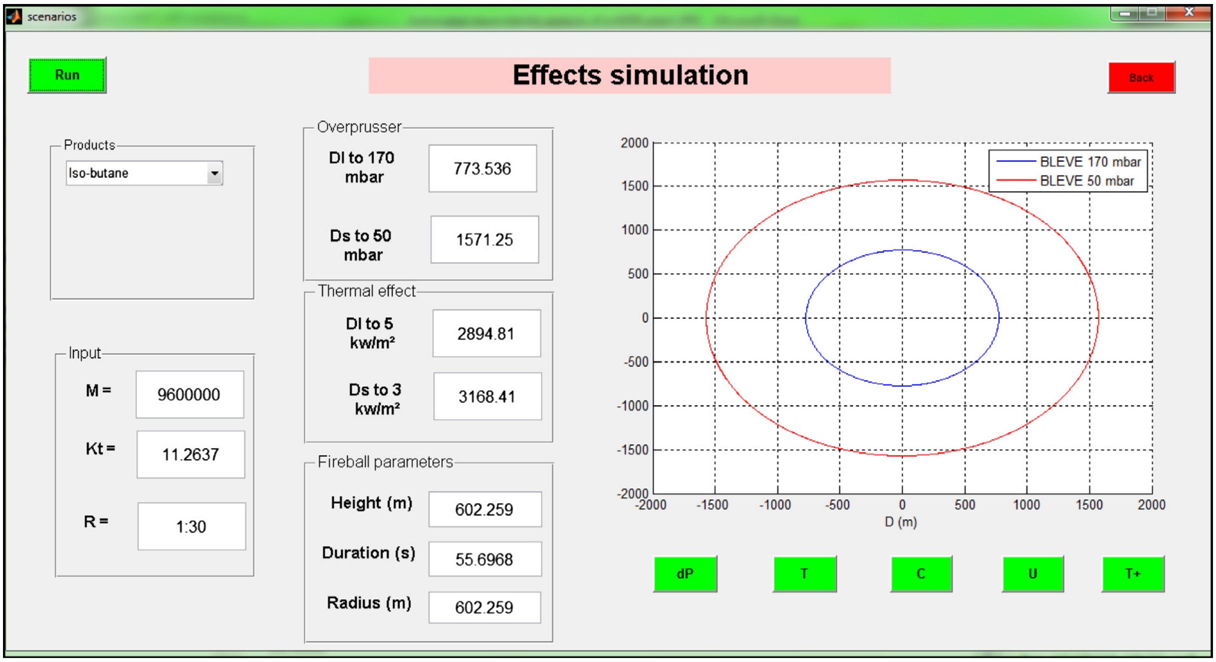
Pressure is an insignificant parameter in the process. In the Philips high density polyethylene production process, the operating condition is 42–44 kg/cm^2 g. The severity level for pressure is defined as 1, 2, 3 and 4. When the pressure is greater than 44 kg/cm^2 g or less than 42 kg/cm^2 g, it is classified as severity level 1. In an HDPE reactor, the reactor can sustain a maximal pressure of 56.3 kg/cm^2 g. If the pressure in the reactor is greater than 56.3 kg/cm^2 g, the reactor will rupture. This situation is designated as severity level 4 because the plant may need to be shut down and could cause an explosion in the plant. The operating conditions for the Philips process of



The elements: Crankshaft

Failure mode	Causes	Consequences	P	S	Recommendation
1. Shearing	1.1. Fatigue 1.2. Repeated bending	1. Abnormal noise + Vibration and stop of the compressor	2	2	1. Change in the periods recommended
2. Deformation	2.1.Bad lubrication 2.2.Misalignment	2.1 Vibration 2.2. Compressor shutdown			2.1. Ensure a flow of lubrication especially at startup 2.2. Periodic verification of level between the motor
3. Vibration	3.1. misalignment 3.2. Poor lubrication 3.3. Oaf 3.4. Wear bearing	3.1. Friction at the landing			

Figure 12 Graphical user interface –Dysfunctional analysis FMECA.



Products: Iso-butane

Input
M = 9600000
Kt = 11.2637
R = 1:30

Overprusser
Dl to 170 mbar: 773.536
Ds to 50 mbar: 1571.25

Thermal effect
Dl to 5 kw/m²: 2894.81
Ds to 3 kw/m²: 3168.41

Fireball parameters
Height (m): 602.259
Duration (s): 55.6968
Radius (m): 602.259

Figure 13 Graphical user interface –BLEVE impact distance overpressure and thermal effect.

HDPE are summarized in the property part that is shown in Fig. 9.

The results of the HAZOP analysis can be seen by clicking on the "Dysfunctional analysis" button (Fig. 4) or clicking on any button like "Hexane tank" button (Fig. 6). Results of HAZOP analysis are shown in Fig. 10. When we choose the area by checking on the "Area" check box (Off-site or Humid area), system by clicking on the "System" pop-up menu, parameters by clicking on the "parameter" radio button, key words by clicking on the "key word" radio button, we obtain the HAZOP analysis result causes, consequences and severity of deviation are shown by clicking on the "Run" button. In this situation, if the pressure in the hexane tank is higher than the operating condition, or if the split-range in the roof tank fails, it will cause an increase of pressure in the tank or an explosion hazard (severity levels 2 and 4, respectively). The proposed recommendations can be seen by clicking on the "Recommendation" button.

Fig. 12 shows the result of the FMECA analysis when the pressure increases in the reactor due to the ethylene flow increasing. This flow increases because the compressor failure, inadequate conditions of exploitation due to the malfunction

Table 1 The thermal radiation impact zones.

Zone 1	Zone 2
• It extends the center of the bowl over a radius of more than 2894 m • Important risk of fatality for persons in this range if they are not evacuated in the 40 s that follow the outbreak of fire • Likely Damages for the tank security system (anti fire system) tank • Deformation of neighborhood tank or tank explosion (domino effect)	• It extends beyond the Zone 1 and exceeds 3168 m • All the persons in this area will be exposed to: pain after 12 s, the formation of blisters after 30 s and 60 s lethal for minimum flows • All neighboring tanks are affected

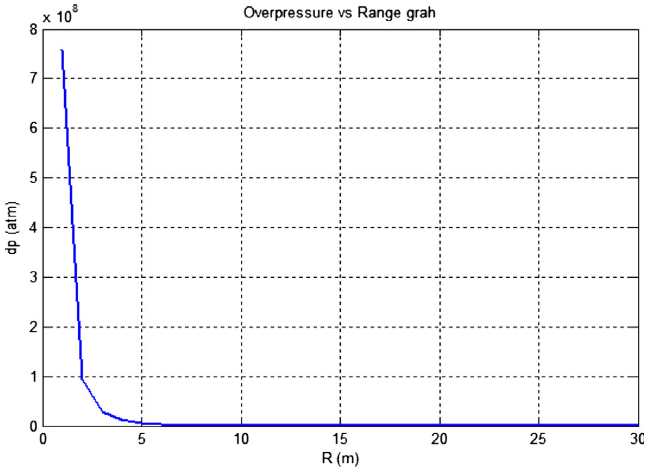


Figure 14 The intensity of overpresser vs distance.

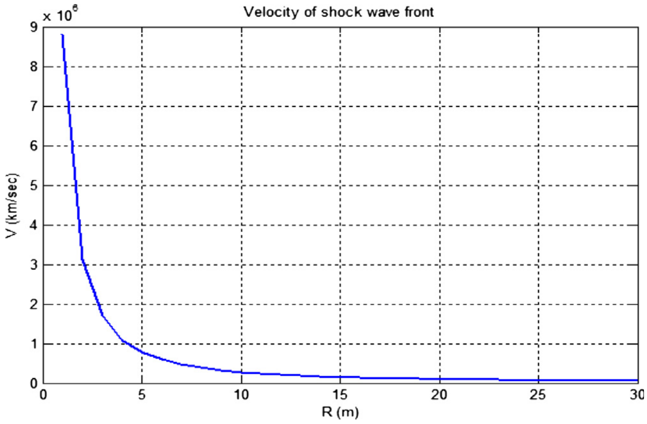


Figure 15 The velocity of shockwave front vs distance.

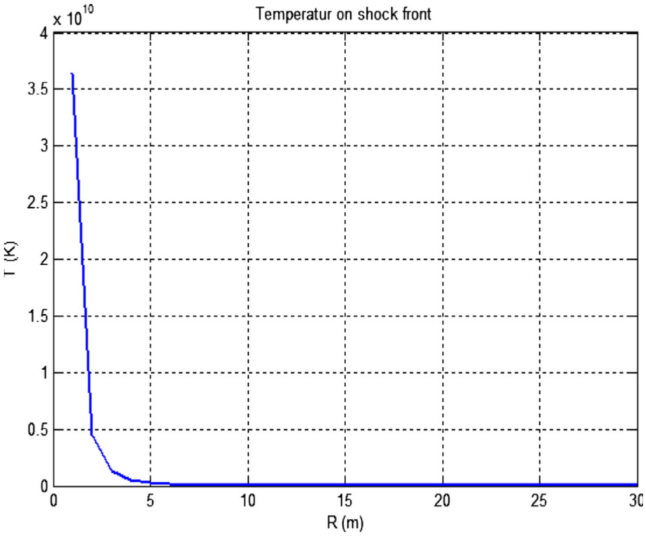


Figure 16 The temperature on shock front vs distance.

Table 2 Output of the graphical interface for an accident scenario (BLEVE) in an ethylene storage vessel.

BLEVE parameters	Values
• The overpressure distance corresponding to the lethality threshold (170 mbar)	773.54 m
• The overpressure distance corresponding to the significant effects threshold (50 mbar)	1752.54 m
• The thermal effect distance corresponding to the lethality threshold (5 kw/m^2)	2894.81 m
• The thermal effect distance corresponding to the significant effects threshold (3 kw/m^2)	3168.40 m
• Radius of the fireball	602.26 m
• Height center fireball	602.26 m
• Duration of the fireball	55.70 s
• Power of the fireball	8135008976.67 W

of the instrumentations (sensors, control loop, control valve,... etc.). In order to localize the problem (identify where is the problem exactly or in which part?) we use the FMECA analysis by clicking on the “Compressor” button (Fig. 7) to see the decomposition of the ethylene compressor (Fig. 11) and then the FMECA results (Fig. 12). The aim of applying the FMECA analysis after the HAZOP analysis was to identify and localize the problem in the compressor, and to enhance and complete the necessary recommendations. Results of the two combined analysis will enable the user to effectively localize the problem and to realize how much influence each evaluation criterion will have on the decision-making process and on the system safety. The “elements” pop-up menu shows all the components in the system, selecting a component will show the results of the FMECA analysis concerning this component.

Fig. 13 shows the results of consequences assessment (the thermal radiation and the overpressure), and it consists of six parts:

- products unit: it has the three principal products (Ethylene, Hexane, Isobutane)
- input unit: it considers the input data (Product mass M, TNT equivalent Kt, Radius R)
- overpressure unit, it considers the explosion impact radius values of 170 mbar and 50 mbar,

- thermal effect unit, it considers the thermal effect distance values of 5 kW/m^2 and 3 kW/m^2
- The fireball parameters, it considers the height, the radius and the duration of the fireball.
- The axes effect which traces the different curves:
  - The thermal radiation intensity is a maximal at the center of the fire and decreases with the distance. The curve presented in Fig. 10 shows the different levels of the ethylene tank thermal radiation while the impact zones are shown in the following table:The overpressure effects after the ignition of vapor cloud is presented as flow:
  - The first area corresponds: to overpressure greater than or equal to 170 mbar causing the destruction of buildings, it exceeds 773 m.
  - The second area corresponds to overpressure greater than or equal to 50 mbar. At this pressure we have very probable and serious injuries, it exceeds 1571 m. People being in this area may undergo serious injuries (see Table 1).

When we click on the "dP" button we can see that the overpressure intensity in function of the distance (Fig. 14) (i.e.) the pressure is higher at the explosion origin (where $dP \approx 7.7 \times 10^8$ atm) and it decreases with the distance to $dP = 0$ atm at $R \approx 6$ m.

Clicking on the "U" button will show the velocity of shock wave front (Fig. 15). This velocity is maximum at the center of the explosion ($V \approx 9 \times 10^6\ km/s$) and it decreases with the distance.

When we click on the "T" button we obtain the graph representing the temperature on shock front (Fig. 16). The temperature is max $T \approx 3.6 \times 10^{10}\ K$ at a distance $R \approx 1.5\ m$ from the explosion origin and it decreases with the distance to $T = 0\ K$ at $R \approx 6$ m (see Table 2).

The different results of the consequences (BLEVE parameters) are summarized in the following table.

4. Conclusion

In this paper, we presented an automated risk analysis and assessment approach for implementation in petrochemical plants. Built in a graphical interface, the proposed method analyzes the dependability of the principal systems in the plant. Our approach includes system analysis in degraded mode – realized by a proposed combination of HAZOP and FMECA methods, and assessment of the accident scenarios. This analysis brings out the different deviations of the operating parameters on any system in the plant (Pressure, Flow, and Temperature). Possible causes of these deviations, their consequences and preventive actions are identified and presented in the interface so as the user can easily operate them, like in the case study when we looked an alarm of high pressure in the reactor, we need to see where is the failure and the element that caused this deviation by using the combination of HAZOP and FMECA, contrariwise the TORAP couldn't make that or HAZOP expert.

The major contribution of our proposed approach is that, beside the combination of the two analysis methods HAZOP and FMECA which enhance risks assessments, it decreases the time utilization in hazard identification. The time consumption is reduced compared to manual calculation thanks to the use of a graphical interface which performs an online analysis. Results of the automated analysis and assessment by combined HAZOP and FMECA analysis will enable the user to effectively localize the problem and to realize how much influence each evaluation criterion will have on the decision-making process and on the system safety. This approach of risks analysis and dependability study will be refined by the definition and propositions of the prevention means (safe guards) for maximum reduction in these risks.

References

[1] C. Jeerawongsuntorn, N. Sainyamsatit, T. Srinophakun, Integration of safety instrumented system with automated HAZOP analysis: an application for continuous biodiesel production, Loss Prevent. Process Ind. (2011) 412–419.

[2] I. Khan, S.A. Abbasi, TORAP—a new tool for conducting rapid risk assessment inpetroleum refineries and petrochemical industries, J. Loss Prev. Process Ind. 12 (1999) 299–313.

[3] V. Venkatasubramanian, J. Zhao, S. Viswanathan, Intelligent systems for HAZOP analysis of complex process plants, Comput. Chem. Eng. 24 (9–10) (2000) 2291–2302.

[4] C. Zhao, M. Bhushan, V. Venkatasubramanian, PHASuite: an automated HAZOP analysis tool for chemical processes. Part I. Knowledge engineering framework, Process Saf. Environ. Prot. 83 (6) (2005) 509–532.

[5] N.L. Rossing, M. Lind, N. Jensen, S.B. Jørgensen, A functional HAZOP methodology, Comput. Chem. Eng. 34 (2) (2010) 244–253.

[6] Manuel Rodríguez, José Luis de la Mata, Automating HAZOP studies using D-higraphs, Comput. Chem. Eng. 45 (2012) 102–113.

[7] H. Liu, L. Lui, N. Liu, Risk evaluation approaches in failure mode and effects analysis: a literature review, Expert Syst. Appl. 40 (2013) 828–838.

[8] B. Almannai, R. Greenough, J. Kay, A decision support tool based on QFD and FMEA for the selection of manufacturing automation technologies, Roboticsand Comput.-Integr. Manuf. (2008) 7.

[9] Mohamed N. Lakhoua, Application of analysis on aFunctional SCADA system of a thermal power plant, Robotics Comput.-Integr. Manuf. (2009) 11.

[10] Esra Bas, An investment plan for preventing child injuries using risk priority number of failure mode and effects analysis methodology and a multi-objective, multi-dimensional mixed 0-1 knapsack model, Reliab. Eng. Syst. Safety 96 (2011) 748–756.

[11] B. Debray, S.Chaumette, S. Descouriere, V. Trommeter. Méthode d'analyse des risques générés par une installation industrielle Ω-7. Rapport d'étude, No 46055-CL47569, INERIS-DRA, 2006.

[12] P.K. Marhavilas, D. Koulouriotis, V. Gemeni, Risk analysis and assessment methodologies in the work sites: on a review, classification and comparative study of the scientific literature of the period 2000–2009, J. Loss Prev. Process Ind. (2011) 47.

[13] L. Froquet, Contribution à l'analyse des risques: Proposition d'une méthode par scénarios et capitalisation de la connaissance". Thèse de doctorat de laboratoire d'automatique de Grenoble dans le cadre de l'école doctoral électronique, électrotechnique, automatique, télécommunication, signal, France, 2005.

[14] J. Dunjó, V. Fthenakis, Juan A. Vílchez, J. Arnaldos, Hazard and operability (HAZOP) analysis. A literature review, J. Hazard. Mater. (2010) 19.

[15] M. Santamarfa Ramiro, Risk Analysis and Reduction in the Chemical Process Industry, Springer Science + Business Media, Dordrecht, 1998, Originally published by Chapman & Hali in 1998.

[16] M. Perez-Marín, M. Rodríguez-Toral, HAZOP local approach in the Mexican oil & gas, J. Loss Prev. Process Ind. (2013) 936–940.

[17] Product Quality Research Institute. (2013, May 11). PQRI. Retrieved 2013, from < http://www.pqri.org/publications/index.asp > < http://www.pqri.org/pdfs/MTC/HAZOP_Training_Guide.pdf > .

[18] C. Zhao, M. Bhushan, V. Venkatasubramanian, Phasuite: an automated hazop analysis tool for chemical processes, Trans IChemE, Part B, Process Safety Environ. Protection 83 (B6) (2005) 509–532.

[19] Gelfand Boris. TRANSLATION FROM RUSSIAN TO ENGLISH THE BOOK “BLAST EFFECTS CAUSED BY EXPLOSIONS” AUTHORED BY B. GELFAND AND M. SILNIKOV Final Technical Report. 2004. Standard Form 298 (Rev. 8–98).

[20] Operation manual PHILIPS (CP2K).

[21] El Arkam Mechhoud, Mounira Rouainia, Dependability analysis of HDPE reactor, in: 7th International Symosiom on Hydrocarbon and Chemistry Boumerdes- Algeria, 2014.

[22] El Arkam Mechhoud, Mounira Rouainia. Application de la méthode HAZOP su le réacteur PEHD. 9ème Congrés Francophon de Gènie des Procédés, Agadir- Marroc, 2014.

[23] El. Mechhoud, M. Rouaïnia, Automated dependability analysis of a HDPE reactor, in: 48th ICCST-IEEE-. 13–16 October 2014, Rome- Italie, 2014.