# Study of the Incidence of Human Error in Accidents and Incidents at Petroleum Refineries

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*Abstract*—**In the last 20 years, there has been a growing interest in biofuels as an alternative to fossil fuels. However, petroleum refining industry will continue playing a crucial role as the main source of fuel in the world's economy. Although these kind of industries are very different in terms of complexity in their processes, at both, accidents with numerous deaths and injuries have been registered and human error plays an important role in their occurrence. The objective of the present article is to determine the incidence of human error in the accidents occurring at petroleum refineries, and to compare results to those obtained for biofuel plants. As complementary information, the number and type of accidents and their consequences will be determined for each type of industry, in the period 1998-2018.**

*Index Terms*—**Human Error, Biofuel Plants, Oil Refineries, Biodiesel, Ethanol, Accidents, Incidents.**

## I. Introduction

Since more than a century, petroleum has been the most used fuel in the world. It plays a vital role as the main source of fuel in the world's economy [1]. However, during the last fifty years there have been a growing interest in alternative and renewable energy sources due to the increase of oil prices, the exhaustion of petroleum reserves, the worries about carbon dioxide emissions due to the use of fossil fuels, and the limitations stablished by regulations and protocols on the amount of emissions [2]- [5]. Biodiesel and Ethanol industries emerged as an alternative for fossil fuels.

Biodiesel has been defined as monoalkyl esters of long chain fatty acids derived from a renewable lipid feedstock [6]. It can be used pure or mixed with petroleum-based diesel, with little or no adequacy of engines.

Ethanol has been defined as an alternative fuel based on alcohol, produced by the fermentation and distillation of feedstock with high content of sugars and starch [7]. It can also be obtained from lingo-cellulosic biomass although the process is more complex than one needed for starch [8]. It can be mixed in different proportions with unleaded gasoline to be used in gasoline-fueled cars or, in Flex-fuel vehicles (FFV).

The most used technique to produce biodiesel is the transesterification of vegetable oils or animal fats. It is a simple process compared to that to obtain fossil fuels. It consists in the reaction of oil with an alcohol such as methanol, in presence of a catalyst, generally a strong base, such as sodium or potassium hydroxide. Once the reaction is completed, the glycerol is removed from the methyl esters. Following, the methyl esters enter a neutralization step and then pass through a methanol stripper before water washing. Finally, remaining water is removed from biodiesel through a vacuum flash process [9].

Although biodiesel production process is simple, significant risks are involved in operations if expert knowledge and safety technologies are not applied. Main risks are associated to: the handling and storage of flammable and toxic raw materials, the lack of expert knowledge and safety technologies, the performing of unsafe procedures (e.g. welding methanol tanks without previous checking) or poor knowledge about them (e.g. mixing glycerin and sulphuric acid in an improper ratio) [10], [11].

The most common method to obtain ethanol is the fermentation of sugars. When using sugar cane or sugar beet as raw material, removal of sugars is made by extraction through pressure or diffusion. If the raw material is corn, there are two ways in which the process can be performed: wet and dry milling. The first one produces starch and the second a mash (milled corn and water). In both cases, enzymatic hydrolysis is made to obtain simple sugar. Once the fermentable mash is obtained, yeast is added to obtain alcohol, carbon dioxide and other organic compounds in minor quantities. The fermented mash goes to a distillation step in order to separate the alcohol from solids and water. Then, the alcohol is submitted to dehydration to remove residual water. Finally, pure ethanol is denatured. Besides CO2, other co-product from dry milling process is the distiller's dried grains with solubles, known as DDGS [8], [12]- [14]. When using lignocellulosic biomass as raw material, due to its complex structure, a pretreatment is required and consists in crushing, followed by acid or enzymatic hydrolysis [15].

Currently, dry milling is the process used to obtain most fuel ethanol (67%) [3]. Main risks at ethanol installations are related to: handling and storage of ammonia (used for controlling pH and providing nitrogen for yeast) and ethanol due to its flammability, and to grain dust that can create explosive atmospheres in presence of oxygen. Other potentially hazardous situations are associated with grain

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engulfment and outsourced works, because the lack of safety orientation at the plant may result in an accident [16].

On the other side, petroleum refineries separate crude oil into a diverse type of petroleum products applying sequences of physical and chemical separation techniques. The five major processes involved can be briefly describes as follows:

- *Separation processes*: applied to separate the different fractions/ hydrocarbon compounds that make up crude oil based on their boiling point differences. Crude oil generally is composed of the entire range of components that make up gasoline, diesel, oils and waxes. Atmospheric and vacuum distillation are commonly used to achieve these physical processes.
- *Conversion processes*: used to break down large longer chain molecules into smaller ones by heating or using catalysts. They allow to break down the heavier oil fractions into other light fractions to increase the fraction of higher demand components (gasoline or diesel fuels). Cracking, reforming, coking, and visbreaking are conversion processes.
- *Treating processes*: used to separate the undesirable components and impurities (sulfur, nitrogen and heavy metals) from the products. This involves processes such as hydrotreating, deasphalting, acid gas removal, desalting, hydrodesulfurization, and sweetening.
- *Blending/combination processes*: applied to create mixtures with the various petroleum fractions to produce a desired final product. For example, combining different mixtures of hydrocarbon chains to produce lubricating oils, asphalt, or gasoline with different octane ratings.
- *Auxiliary processes*: involve other processes and units that are vital to operations by providing power, waste treatment and other utility services. A few of these units are boilers, wastewater treatment, and cooling towers [17]- [19].

Main risks associated to these facilities are explosions and fires as consequence of equipment failure, maintenance mistakes and human error, and release of toxic and/or dangerous substances [20]- [22].

Although these kind of industries are very different in terms of complexity in their processes, at both, accidents with numerous deaths and injuries have been registered. Human error plays a significant role in the accidents not only in the direct action but also in an inadequate design [23]. According to a study of equipment failures in the process industries [24], human and organizational errors constitute the major cause of accidents.

The objective of the present work is to determine the incidence of human error in the accidents occurred at petroleum refineries and to compare obtained results to those obtained for biofuel production facilities.

## II. Human Error

Human error plays a large role in causing process plant accidents, including major hazards accidents. However, in contrast to the situation in the nuclear and aerospace industries, very little Human Error Analysis (HRA) is carried out in the petroleum industries. Several human facts and reliability studies related to perforation activities and offshore platforms have been found, but scarce are those referred to oil refineries. Something similar occurs at biofuels facilities [5].

Where HRA is performed, it is largely unrelated to the Hazard and operability (HAZOP) study and Quantification Reliability Analysis (QRAs) which are the heart of process plant safety assessment. Some of the reasons for this are:

- a considerable effort from already hard pressed engineers,
- lack of mesh between exiting methodologies and safety analysis practice,
- lack of operations descriptions and procedures (often at new plants),

The problem is that if human error is not taken into account, there is no incentive, and very little possibility, of applying risk reduction techniques [25].

According to the authors Boring y Øien [26], as the nuclear energy case, petroleum extraction and refining is an activity in which safety is a critical aspect. Consequences of the human action can be severe, impacting on the people, the environment and the economy. Frequency of occurrence of adverse events is low but the magnitude of consequences is high. Because of that, there are multiple safety barriers to avoid failures or, in case they occur, their effects be quickly reduced [27]. However, risk analysis of severe accidents at oil refineries does not involve human reliability analysis and human error study [28]. This fact shows a weakness, since most part of severe accident scenarios depend on human action, not only in the cause but also in its mitigation. Being a very complex system, human intervention is crucial to carry it out but it can lead to the occurrence of error at any moment.

While it is true that biofuel facilities involve more simplex processes compared to oil refineries, under certain considerations, human error is the cause of accident in the 70% of the cases [29]. The handling, storage and use of flammable chemicals, the lack of procedures and expert knowledge have created different error scenarios [5], [10], [11], [30]. Further, when operators or maintenance technicians are the cause of accidents, they are almost always present, so that the risk to employees is higher because of higher exposure [25].

Based on the described situation, it is very important the study of human error in this kind of industries.

## III. Data Collection

### A. Biodiesel and Ethanol Plants

Data about accidents occurring at biodiesel and ethanol production facilities were obtained from the *Database for accidents and incidents in the biodiesel industry* [5] and from the *Database for accidents and incidents in the fuel ethanol industry* [30]. They are organized and unified registers, based on different documental sources, that contain general information about adverse events, its sequence, mitigation, causes, and human, environmental and material consequences occurring at biodiesel plants during a period of ten years (2003-2013) and at ethanol plants for a period of sixteen years (1998-2014).

For the present work, information provided by both databases was updated and completed for the period from

2014 to 2018 in the case of biodiesel, and for the period 2015-2018 in the case of ethanol. Procedure involved collection, analysis, and cross checking of the data founded in different sources such as: Occupational Safety and Health Administration [31], Biodiesel Magazine [32], Ethanol Magazine [16] and national and local newspapers publications.

*B. Petroleum Refineries*

Information about accidents and incidents at oil installations was collected from the following sources:

- Databases: FACTS, Hazardous Material Accidents Knowledge Base; Pondicherry University Process-industry Accident Database (PUPAD);
- Industrial Reports: "The 100 Largest Losses 1972-2001" [33] and "The 100 Largest Losses 1974-2013" [34].
- Technical Reports: OSHA [31], Safety Bulletin- U.S. Chemical Safety and Hazard Investigation Board [35]-[37].
- Journal articles and videos.

Information was also gathered and evaluated, making a cross checking of data in order to obtain a complete and a unified register.

## IV. Data Analysis

To perform the present study, data were organized as follows. Information provided by the biodiesel accidents database and by the ethanol accident database was put together in a unified *Biofuel* accidents database. As a result, it was obtained a database with a total of 230 accidents and incidents occurred at Biofuel production facilities for the period from 1998 to 2018. In this way, comparison with what happened at oil refineries is viable and relevant.

Regard to the database of accidents and incidents occurring at oil refineries, it was developed for the period 1971-2018. However, to perform the analysis, it was only considered the period from 1998 to 2018 covering a total of 258 adverse events.

The number of accidents and incidents per year for each kind of production facility is shown in Fig. 1.

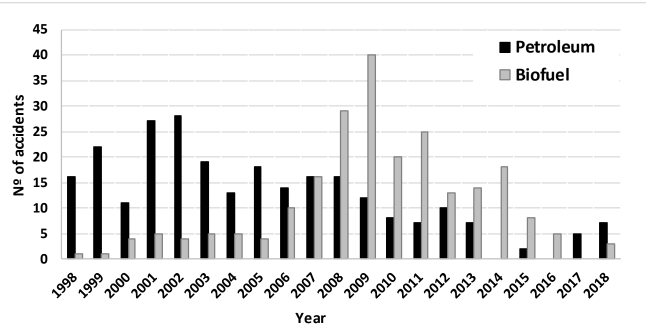


Fig. 1. Number of accidents and incidents vs. Year at Petroleum and Biofuel production facilities. Period 1998-2018.

Incident and accident reports include: mainly industrial accidents (spill or releases, fires and explosions), occupational incidents (slips, falls, burnings and cuttings) and other adverse events affecting the installation. It can be seen that the major number of accidents and incidents at petroleum refineries (28) was registered in the year 2002, while at biofuel plans, the major number (40) was registered in the year 2009.

The following figures (Fig. 2 and Fig. 3) show the number of accidents by type. The types of incidents and accidents are classified into: "Fire", "Explosion", "Release", "Occupational Incident", and "Other" (involving meteorological phenomena, structural collapse, etc.). It is important to clarify that an accident can belong to more than one classification (e.g. an explosion may result in a fire, a release can lead a fire, or an explosion, a fire and a release can take place once the accident has been initiated).

At first glance it can be determined that the major type of accidents that occur at both biofuel production facilities and oil refineries are fires, involving 64% and almost 40% of the cases respectively. Releases are more common at oil refineries (17,3% of the cases) than at Biofuel plants (8,0% of the cases). Something similar happens with Occupational Incidents, they are more frequent at oil refineries (almost 20% against 2% at Biofuel installations).

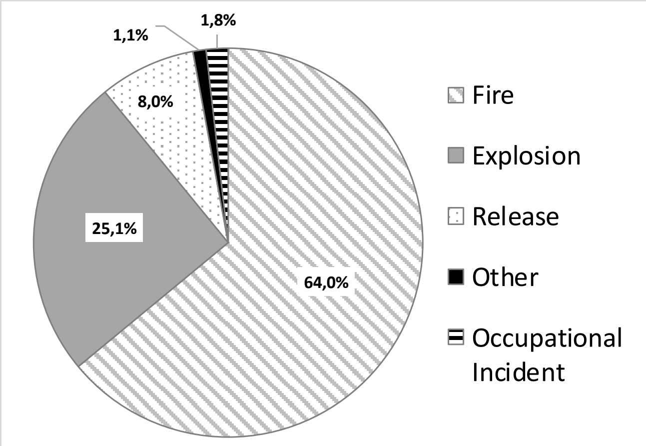


Fig. 2. Type of accidents at Biofuel Production Facilities for the period 1998-2018.

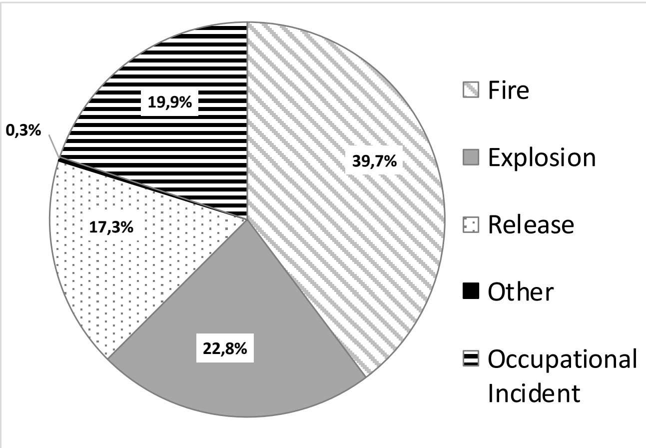


Fig. 3. Type of accidents at Petroleum Refineries for the period 1998-2018.

Fig. 4 show the immediate causes of accidents and incidents for the industries under analysis for the period 1998 to 2018. It shows that in the 33% of the accidents occurred at biofuel plants (75) and in the 31% of the accidents at oil refineries (80) there is not information about event immediate causes. Almost a 22% and 3% is under investigation respectively, resulting in a lack of knowledge about the causes in more than half of the cases for biofuel plants.

Concerning the adverse events for which causes are known, the most frequent causes at both industries are Equipment-Mechanical failures, with 49 cases (20% of the total) at biofuel production facilities and 45 (19% of the total) at oil refineries.

Human Factor Operator Error is the second more frequently cause at oil refineries (47 cases that represent a 18%). Instead, the second more frequently cause at biofuel plants is ignition (29 cases that represent a 13%). This last percentage has to be with the fact that flammable substances are handled and used at biofuel production facilities.

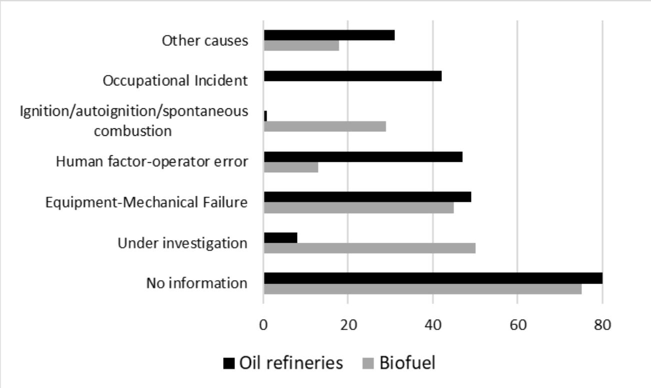


Fig. 4. Immediate causes of accidents and incidents at Biofuel and at Petroleum production facilities. Period 1998-2018.

The number of injured at installations under analysis is shown in Fig. 5. It can be seen that the major number of injured people was registered in 2005 for oil refineries and in 2001 for biofuels plants, reaching values 186 y 18 respectively. The biggest number of injured in the year 2005 is one of the consequences of the explosion and fire at BP Texas Refinery, one of the worst industrial disasters in recent United State history [35].

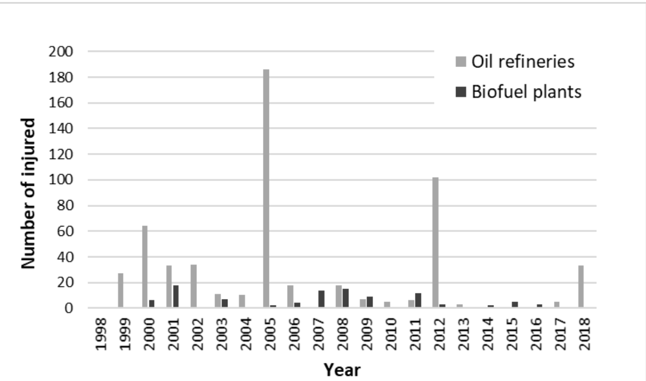


Fig. 5. Number of injured people vs. Year at Biofuel and at Petroleum production facilities. Period 1998-2018.

According to Fig. 6, the major number of deaths was registered in 2012 and grow up to 53 people for oil refineries. The great number of deaths in 2012, has to be with a very powerful explosion that took place in a refinery at Venezuela [34].

Instead, the year 2011, was the most catastrophic for biofuel industry, registering 33 deaths. It is shown that for both industries, the number of deaths have decreased significantly over the following years.

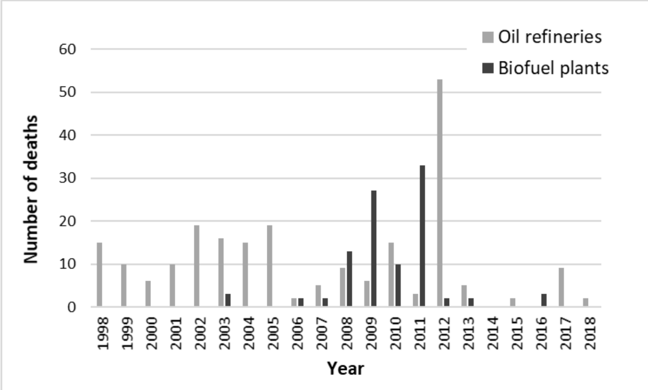


Fig. 6. Number of deaths vs. Year at Biofuel and at Petroleum production facilities. Period 1998-2018.

## V. Discussion of results

The annual distribution of accidents at biofuel plants in Fig. 1, that not means necessarily that the number of accidents have increased during the analyzed period, but it is rather a demonstration that there is more availability and access to information. Other factors that have influenced the number of accidents are technology improvements and safety normatives.

Fires and explosions are the most common type of accident at both industries since complex chemical processes, storage, handling and/or use of flammable substances are involved.

Studying the incidence of human error as the immediate cause of the accident, statistical analysis shows that 18% of the accidents and incidents occurring at oil refineries are caused by human error. It is important to note that if accidents caused by equipment- mechanical failures could be analyzed in depth, the contribution of human error would be probably higher since operators are involved on corrective and preventive maintenance tasks. Under these considerations, human error could be the root cause of almost 40% of the cases.

According to obtained results, and, as authors have exposed at previous works, necessary information is not complete as required. Thus, a great effort is needed to generate exhaustive reports that make possible risk analysis, human error quantification, human reliability analysis, etc.

## VI. Conclusion

Following the research line of the authors, this is a comparative study to determine the incidence of human error at energy industries, in particular, at biofuel and oil refineries plants. It was determined that human error is the cause of the 18% of the accidents occurring at oil refineries and the cause of only 6% of those occurring at biofuel plants. However, a deep analysis of causes, could show that the contribution of human error to accidents is higher.

The main objective of this work is to extend knowledge about human error at oil refinery industry. However, lack of information limit the study.

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According to firstly exposed, there are scarce studies on human error at petroleum refineries. Based on obtained results, it is crucial its study in order to diminish the magnitude of consequences. The present work is a contribution to the existent gap.

Finally, it also contributes to the identification of the different types of human error, allowing to determine what tools, models or methodologies could be applied in order to diminish their occurrence.

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