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# Recommendations Generated about Human Reliability Analysis on Biodiesel Plants

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***Abstract*—This paper presents a set of recommendations generated from the review of different methods used. They have been selected taking into account research on documented biodiesel plant accidents. It provides a summary of those tools and methods considered to be of potential use to analysts undertaken a Human Reliability Analysis in the Biodiesel plant industry. This potential use is based on a review on published research material about accidents reported and together with previous work allowed to extract the main considerations identified to date. As a result of this work a set of recommendations were generated for use in the biodiesel industry.**

***Index Terms*—risk analysis, risk assessment, human reliability assessment, biodiesel plants**

## I. Introduction

BIODIESEL is an alternative considered to replace petroleum. Life cycle analysis [1]-[3] is a systematic evaluation of the environmental and resource consequences of a particular product, process, or activity. The analysis may evaluate improvements such as changes in product design, raw material substitution, industrial process improvements, or waste management methods. As a result of these analyzes biodiesel is not cheaper than oil. It is because the raw material of these does not have to be produced.

In an industry an accident can be fatal and biodiesel plants are not exempt [4]. Being an industrial facility, risks and dangers exist related to transport, storage and use of great amount of toxic chemical substances. Flammable and highly polluting vegetal oil tanks contribute too.

Like other industries, it is necessary to improve the reliability of operation processes, inspection, maintenance and projects during assembly of equipment [5]. According to some authors [6] the contribution of human error is between 60 and 80% in technological accidents. The relevant accidents occurred in the biodiesel industry in the last decades have been presented and analyzed in the open literature [4]-[7]-[9]. Results show that methanol and methoxides fires or explosions are essentially related to transportation activities, maintenance operations and the tank farm area.

Dangerous materials like methanol can be spilled and generate explosions if it is not have adequate management of them. It is important take into account the lack of training in safety of the personnel. Frequently, safety is omitted due to the simplicity of the process. It is necessary apply secure technology and expert knowledge.

According to LEA S.A. [10] the amounts of methanol in the production area should be limited to the fullest. Biodiesel is a methyl-ester of fatty acids with close to flash point 100 °C. The fire risk of biodiesel is equivalent to the risk of oil mineral, however, rags soaked with oil fires usually generate by combustion.

Since the methanol vapors generated, it is important that environments are well ventilated and that from a careful area classification, electrical panels are located outside the area where you can create explosive dust clouds. The nitrogen blanketing desirable both to avoid the formation of explosive atmospheres inside equipment to prevent oxidation of the product. For the extinction, biodiesel plants should have at least fire facility with the following features:

- water source (tank and pumps) of adequate reliability and flow
- cooling tank
- extinguishing system based on polar solvent foam
- extinguishing system based on water

In relation to protecting the environment, the risks are lower than that generated hydrocarbons as the remediation is less expensive. Care environmental authorities require security monitoring systems and less demanding than for petroleum oils, but are necessary double containment and contingency plans.

The lower stability of the product in respect of oil (the product oxidized) increases the risk of liability for products.

In many cases the biodiesel plants are integrated plants oil extraction with solvents, which have other risk factors critical vapors associated with hexane and the self-combustion of the feedstock (sunflower seeds, soybeans, corn, etc.)

Plants with capacity larger than 100,000 tons per year has been proved [9] to be the only processes economically feasible with higher-value virgin oil, yielding higher net annual profit and lower break-even price. The growing plant capacity clearly enhances the hazard of biodiesel production.

The consequences of accidental scenarios are due to the increased complexity of plants, due to the number and

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dimension of equipment and due to the larger inventory of chemicals.

According to [7] economic reasons have addressed to the use of sulphuric acid in the neutralization process of glycerol by-products, thus introducing new risks, due to the pressurization of the reactor when excess acid is used. To this regard, it is important to note that, in general, several operations involving large use of chemicals and large consumption of energy are necessary for the purification of transesterification products, and that these problems are mainly addressed by the use of homogeneous catalysts, which are not easy to remove from the reaction products. A solution is the use of heterogeneous catalysts but, to the author's knowledge, only one process by the Institute Français du Petrole (IFP) is operative in the world. When heterogeneous catalysis is adopted, neutralization step, biodiesel washing and glycerol distillation may avoid or simplified. On the other hand, the process is more hazardous for the higher pressure (200°C – 250°C, 40 bar – 70 bar) and temperatures adopted. Further analyses are required for effective advantages, in terms of risks, for the two catalytic options. According to the above showed, is highly recommended to do an FMEA in order to improve the safety of the facility and to diminish the human error to implement reliability human analysis.

## II. Human Reliability

The presumption of human error [39] generally occurs when various types of committed or omitted human actions appear, when viewed in retrospect, to be linked to undesirable consequences, although unwanted consequences do not necessarily imply the occurrence of human error. Human error also subsumes actions whose unwanted outcomes may occur at much later points in time or following the interjection of many other actions by other people. The situation becomes more blurred when humans knowingly implement strategies in performance that will result in some degree of error.

According to [40] a study of 500 incidents involving pipework failure and subsequent chemical release (in the United Kingdom, the USA, the Netherlands, and Finland) for the UK's Health and Safety Executive, "responsible in 30.9% of the incidents, operator error was the largest contributor to pipework failures among known direct causes". This study has concluded and recommended "human factors reviews of maintenance and operations personnel and functions" as one of the four critical areas where management of oil, gas, and chemical companies should concentrate their efforts.

### A. *Human behavior process*

According to [13] hundreds of studies affirm that human behavior cannot be assumed as a serial process; however, it starts with a sensorial activation and ends with a manipulation of the environment. The result of activation is the sensorial process; this process sends relevant information from the environment into the perceptive system.

The result of the perceptive process is the recognition of the sensorial stimulus and its assignation to a perceptual category [29]. The recognition initiates the cognitive process, which decides what to do with the perceived information. The human behavior process can start [13] with the sensorial or the cognitive process and human response can also be the result of any of the three processes: cognitive, sensorial and perceptive.

### B. *Human Error*

According to [11] until the 1980s, human reliability analysis focused upon individual erroneous actions. More recently, attention has shifted to the managerial and organizational contexts that create the latent conditions for such failures.

Recent years have changed our understanding of human error. Investigations into various accidents [4]-[11] focus upon managerial factors rather than the individual's contribution through erroneous actions. Recent accidents have shown that many industries must still learn the more fundamental lessons of human cognition, physiology and perception [12].

According to [13] the studies of human reliability assessment try to determine the tendency of committing errors during professional activity and there are a lot of techniques based on human behavior but none of them have general acceptation or either proves to be sufficiently comprehensive. The two fields of human behavioral science and engineering have not been integrated sufficiently. Despite this, human error analysis is useful and there are a lot for research.

### C. *Standards and methods*

There are a lot of tools that can be classified as first, second and third generation and expert judgment methods [14]. First generation methods were developed to help risk assessors predict and quantify the likelihood of human error. Second generation methods attempt to consider context and errors of commission in human error prediction. Expert judgment methods provide a structured means for experts to consider how likely an error is in particular scenario.

Some old techniques have incorporated fuzzy approaches but they represent one of the present models. It is necessary a new model that includes different point of view, identify the uncertainty associated with them and facilitate the implementation of the most appropriate technique for its treatment [15].

Nowadays, new studies are arising with focus on a unified human reliability model. Following this line, they include the cognitive aspects, the last conception of the human cycle and fuzzy logic.

### D. *Human Errors in Biodiesel Plants*

Biodiesel safety is mainly related to methanol fires and explosions [4]-[7]. Some anomalies result if considering the entire process and more in particular the neutralization steps. Indeed, several large accidents have occurred after using sulphuric acid as neutralization agent of glycerol-based by-products, either before after the distillation operation for methanol separation or after the same operation.

All accidents are due to the belief that in such simple process is impossible to have troubles. This belief is a constant in all kind of industries and much more in biodiesel

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plants where the lack of experience and the simple process are combined to prepare the environment to produce errors. It is important take into account the lack of training in safety of the personnel. Frequently, safety is omitted due to the simplicity of the process. It is necessary to implement secure technology and expert knowledge.

### *E. Factors affecting Human Reliability*

Some factors may influence human reliability within process plants. These factors are referred to as Performance Shaping Factors (PSFs).

Performance Shaping Factors [16] are those factors which influence human error rates. Typical PSFs include level of training, quality/availability of procedural guidance, time factors, etc.

A comprehensive hazard analysis consists of first understanding different factors that would lead to an unwanted event. Some authors [17] use a risk analysis framework and capture human and organization factors that influence the operator performance in order to identify the actual error producing conditions that lead to basic events.

A risk assessment must be associated with the operation of the plant. Hazards from storage of biodiesel, methanol, gas oil, sulphuric acid and phosphoric acid must be considered [8]. Releases may occur as a result of loss of containment from spontaneous failures of outdoor storage tank. It should be noted that most of accidents involving methanol have occurred in backyard utilities, where discontinuous operations are adopted, especially during maintenance activities [7].

The main factors [17]-[18] that contribute to human error are:

1) Available Time
2) Stress and Stressors
3) Complexity
4) Experience and Training
5) Procedures
6) Ergonomic and Human Machine Interaction
7) Fitness for Duty
8) Work process
9) Information
10) Job design
11) Supervision
12) Human-system-interphase design
13) Task environment
14) Workplace design
15) Physical characteristics
16) Attention/motivation
17) Skills and knowledge

It is accepted [19] that human error is affected by a wide range of factors. This leads to uncertainty as to how data can be applied from one situation to another where different factors may be relevant. These factors may vary for different situations at a plant, between plants and between countries. While there is no detailed guidance with which to assess the applicability of data to other situations or contexts, judgment can be used to assess this factor.

## III. Summary of Lessons Learned

In the following a summary of lessons learned are presented from [4]-[20].

It is necessary to spend time teaching people how to communicate properly and make sure that all instructions are clearly understood before actions are taken.

Design and construction errors may remain latent in a plant control system for a long time before discovery. Human errors occur during construction and maintenance, not only during operations.

It is essential to fully understand every detail of how the plant will be operated, including all of the “common sense” details which might not be written down in the procedures.

Training on the process operation and response may be more important and require more resources in highly automated plant because the operators, engineers and other personnel may not develop a good understanding of the plant operation through their normal work activities.

It is essential to analyze all operations in great detail when specifying the requirements for the computer control programs.

Errors in the specification of requirements for computer safety systems, or errors in implementation of those specifications in the actual computer code, may remain hidden until the process challenges the system.

Errors of commission, omission and neglected actions are the main cause of human errors.

At present, transporting biofuel, particularly methanol, via pipeline is not completely viable. Rail transportation is one of the simplest methods of moving biofuel. To get employees involved and to train them to use a simplified risk analysis as well as to make a simplified risk assessment is another very important step to prevent accidents, diseases and fires [21].

All the accidents are due to the belief that in such simple process is impossible to have troubles. This belief is a constant in all kind of industries and much more in biodiesel plants where the lack of experience and the simple process are combined to prepare the environment to produce errors. From this point of view is adequate to use methodologies that incorporate the contexts like generating sources of error [22].

In order to improve the design and operation of biodiesel plants a Failure Mode and Effect Analysis is a recommended practice [23]-[24].

## IV. Summary Tools Considered Useful

A comprehensive review [25] was made to identify the range of qualitative and quantitative HRA techniques available and to carry out an assessment of their strengths and weaknesses. A total of 72 potential human reliability related tools and acronyms were identified within the search timeframe. Of these, 37 were excluded from any further investigation and 35 were identified as potentially relevant. Of the 35 potentially relevant human reliability assessment tools, 17 are considered to be of potential use to major hazards directorates. From this potentially useful tools, are extracted 8 as shown in the following table.

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TABLE I
TOOLS POTENTIALLY USEFUL ON BIODIESEL PLANTS

| Tool | Domain |
|---|---|
| THERP<br>SPAR-H<br>ATHEANA<br>CREAM<br>SLIM-MAUD | Nuclear with wider application |
| HEART<br>APJ<br>PC | Generic |

THERP (Technique for Human Error Rate Prediction) [26]-[34] was developed by Swain and prepared by Swain and Guttmann in 1983. It was developed for probabilistic risk assessment of nuclear power plants but has been applied to other sectors such as offshore and medical.

SPAR-H (Standarized Plant Analysis Risk Human Reliability Analysis method) [25]-[35] was used in the development of nuclear power plant models and based on expertise gained in field-testing. It has been successfully applied to risk informed regulatory activities. No evidence was found of the method being used in other sectors but the underlying principles and HEP data are applicable to other domains.

ATHEANA (A Technique for Human Error Analysis) [22]-[25] has made a good attempt at dealing with subjects that first generation tools did not address such as error of commission. It has a good qualitative element but the quantitative element is lacking and relies on expert judgment. It was developed for the nuclear industry; however the approach is suitable for application in other industries.

CREAM (Cognitive Reliability and Error Analysis Method) [25]-[27] was developed for use in the nuclear industry, however the underlying method is generic and, therefore, it is suitable for use in other major hazard sectors. It is important to note this method is the most interest to psycologists and other more sophisticated errors.

SLIM-MAUD (Success likelihood index methodology, multi-attribute utility decomposition) [25]-[28] is an expert judgment methodology. SLIM is a flexible tools that is essentially a set of procedures for eliciting expert opinion. Therefore it is suitable for application in major hazard sectors.

HEART (Human Error Assessment and Reduction Technique) [25]-[36] is designed to be quick and simple method for quantifying the risk of human error. It is a general method that is applicable to any situation or industry where human reliability is important.

APJ (Absolute Probability Judgments) [25]-[37] has been used in the nuclear and offshore industries but requires experts, who must have detailed knowledge of the area they are being asked to assess, with at least ten years of practicing in their particular field or job. This method is suitable for a wide range of industries including those in the major hazards sectors.

PC (Paired Comparisons) [25]-[38] has been applied to the transport and nuclear industries. It is a generic one that can be applied to any sector. It is important remark that the usefulness of this technique relies heavily on the available of valid calibrators.

It is important to remark that exist other method (TESEO-Tecnica empirica stima errori operatori). It is an expert judgment method from 1980. It is recommended for chemical industries but some authors [25] question the theoretical background of this method and it is not considered to be accurate.

## V. SUMMARY OF BARRIERS TO USE HUMAN ERROR ANALYSIS

According to [11] the barriers are:

1) lack of agreed standards and methods
2) a reliance on subjective interpretation
3) poor support for "run-time" predictions
4) poor support for "design-time" predictions
5) focus on accidents and not incidents
6) focus on single users and single systems
7) focus on operation and not regulation
8) lack of integration between contextual analysis and requirements analysis
9) little regard for human error during requirements analysis

## VI. UNCERTAINTIES

The uncertainty becomes very valuable when considered in conjunction with other features of the model. In general, allowing more uncertainty tends to reduce the complexity and increase the credibility of the resulting model [30].

In many situations [31] human error risk analysis is a complex task which is of great uncertainty due to the complexity of human behavior and environment, lack of information and knowledge, insufficient human error data and the subjective judgments of experts.

A summary of works are shown by Szwarcman et al. [32]. They have contributed to human reliability research employing Fuzzy Set Theory and the concept of possibility of failure instead of probability of failure.

There are not many studies dedicated to the relative importance of human factors and according to [33] one way is by fuzzy cognitive maps approach.

New studies are trying to integrate models to minimize the total increase of uncertainty [13].

## VII. SUMMARY OF REVIEW AND CONCLUSIONS

From the literature referenced in this work, an analysis of reported accidents shows that most human errors are related to the confidence of the operators by the simplicity of the process.

Errors of commission, omission and neglected actions are the main cause of human errors.

The level of human reliability largely depends on the number of factors involved and that may constitute "latent failures".

Training and skills analysis task depend of the time used for training, periodic application test and exercises, the amount of practice and annual requalification of workers.

Workers experience is influenced by the frequency with which practices are carried out tasks related to processes important to safety. Just as the quality of the practices in

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simulators and implementation practices in areas of possible occurrences of incidents.

Motivation is influenced by the inclusion of training task assessing skills and abilities of the workers.

It is very important the existence of a clear commitment to the upper management in relation to the worker safety.

Are important features of the work place:

- the number of workers in the local emergency;
- The ease of physical access to the control room.
- The existence of indicators or registers away from view of the state of labels. Legends in the room control.
- The quality of the work place environment is influenced by temperature, humidity, air quality, lighting, noise and vibration.
- The amount of time that an operator has to diagnose and act upon an abnormal event can affect the operator´s ability to think clearly and consider alternatives.
- Stress can include mental stress, excessive workload or physical stress. It includes aspects of narrowed attentional field or muscular tension and can include general apprehension or nervousness associated with the importance of an event.

In general, a task with greater complexity requires greater skill and comprehension to complete successfully. Complexity refers to how difficult the task is to perform in the given context. The more difficult to perform and ambiguous the task is, the greater the chance for human error.

It is very important the existence and use of formal operating procedures for the tasks under consideration. A common problem is the ambiguity of steps.

The equipment displays and controls, layout, human machine interaction and quality and quantity of information available from instrumentation must be adequate to the interaction of the operator with the equipment to carry out tasks.

The individual performing task must be physically fit to perform the task at the required time.

The most type of operators is caused by common conditions surrounding a given operation [17].

It is important to consider human factors and potential errors throughout the life cycle of a chemical plant, starting with the initial plant design.

In this work 8 tools were identified as potentially useful on biodiesel plants. THERP and HEART are the simplest techniques. ATHEANA and CREAM are the most complex; the first technique uses Performance Shaping Factors and the second uses Knowledge Engineering.

All work related to uncertainties in the models of Human Reliability Analysis continue under research and therefore not is advised their use until they are validated.

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