Latent Failures on Biodiesel Plants

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***Abstract*—The process to obtain biodiesel is simple, however it is a chemical process in which toxic and flammable substances are used or variables like temperature or pressure should be controlled to avoid any kind of incident. Literature report accidents where most human errors are related to the confidence of operators by this simplicity. Much of these accidents are influenced by a number of factors involved constituting latent failures. This paper presents a summary of latent failures identified on biodiesel plants and a description of their causes and the accepted practices to eliminate them.**

***Index B*iodiesel plants, human error, human reliability, latent failures**

I. INTRODUCTION

HUMAN RELIABILITY ASSESSMENT (HRA) is the common name for an assortment of methods and models that are used to predict the occurrence of human errors. HRA involves the use of qualitative and quantitative methods to assess the human contribution to risk.

Disasters and major system failures are frequently a sequence of events where one or more people have made a decision or taken some action while operating, maintaining or repairing some technological system.

According to [1] human reliability can be defined as maximizing the effectiveness of the decisions people make and the actions they take in response to those decisions while operating, maintaining or recovering from the failures of systems. Other constrain may apply, such as time limits for completing a task.

According to [2] some of the most important factors that can undermine the validity of an HRA include:

- Expert judgment.
- Impact of task context upon human error probabilities (HEP).
- Sources of data in HRA techniques.

Practically all HRA methods share the point of view that it is meaningful to use the concept of human error estimating human error probabilities. A new point of view takes into account how human performance is determined by the context or circumstances. The attention has shifted to the managerial and organizational contexts that create the latent conditions for such failures [1], [13].

In this point, it is important to distinguish two kinds of error: active errors and latent errors. Active errors are those whose effects are felt almost immediately. Latent errors are those whose adverse consequences may lie dormant within the system for a long time, only becoming evident when they combine with other factors to breach the system´s defenses [3].

II. HUMAN RELIABILITY ANALYSIS ON BIODIESEL PLANTS

Like other industries, it is necessary to improve the reliability of operation process, inspection, maintenance and projects during assembly of equipment [4].

An analysis of reported accidents shows that most human errors are related to the confidence of the operators by the simplicity of the process [5].

The relevant accidents occurred in the biofuel industry in the last decades have been presented and analyzed in the open literature. Errors of commission, omission and neglected actions are the main cause of human errors [5]-[8].

Human errors can be classified a number of ways [14]:

- errors of commission or omission. Errors of commission mean that someone did an act that resulted in an error. Errors of omission are where someone did not do something that created an error.
- Active or latent errors. In active errors the consequence is immediate, while a latent error ´s consequence is not.
- Random human error or where human factors are involved.
- Human errors can also be classified as to the reason the error was made. They are grouped into three broad categories: people-oriented errors, situation-oriented errors and system-oriented errors.

In this paper it is introduced a discussion about latent errors.

III. LATENT ERRORS

Most accidents in process industries are caused by operator errors. In most cases, they are affected by the failure of design and organization. They are known as latent errors [15].

It is not possible to design technological systems to eliminate all human errors during operation because people are involved in specifying, designing, implementing, installing, commissioning and maintaining systems as well as operating them. Even if systems can operate without human intervention, there is still the possibility of human error at

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other phases of the lifecycle [16].

It is essential to know what people did inappropriately in order to identify the latent causes, even though no-one wants to divulge this type of information [17].

According to [9], Performance Shaping Factors (PSFs) are those factors which influence human error rates. Typical PSFs include level of training, quality/availability of procedural guidance, time factors, etc.

In reviewing some of the techniques of human reliability analysis shows that there are uncertainties that have not yet been resolved. Component reliability principles and methods are used, which puts estimating human error probability at the same level as estimating failure probability.

These methodologies favoring psychologically based models remain anchored to the interior stage of the cognitive process and do not highlight the link with external conditions [18].

It is accepted that human errors is affected by a wide range of factors [5], [10]-[12]. Each technique reported in literature use a different terminology for contextual factors: Performance Shaping Factors, Factors, Common Performance Modes, Performance Influencing Factors, Influence Factors and Performance Conditions [19]-[33]. This different terminology used was reviewed and a summary is introduced in the following.

A. Performance Shaping Factors

This terminology is used in techniques like THERP, SPAR-H, SLIM-MAUD, HRMS, JHEDI, ATHEANA, CAHR and in other models and taxonomies [19], [21], [22], [24]-[28], [30]. A PSF is an aspect of the human's individual characteristics, environment, organization, or task that specifically decrements or improves human performance, thus respectively increasing or decreasing the likelihood of human error [11].

B. Error Producing Conditions

This terminology is used in techniques like HEART [19], [20] and NARA [27]. It can be broadly considered as factors that negatively affect the reliability of human performance.

C. Common Performance Conditions

This terminology is used in CREAM and INCORRECT techniques [21], [24], [33]. Context information has very important role in defining possible error modes. It represents the work conditions under which the task is performed. Working conditions can be characterized using 9 factors called Common Performance Conditions [36].

D. Performance Influencing Factors

This terminology is used in INTENT technique [24], multifaceted taxonomy for description and analysis of events involving human malfunction [29], Taylor-Adams and Macwans [24] and Julius´ Procedure for the analysis of errors of commission [24], [32].

E. Factors

This terminology is used in Human Performance Data Base [27] with the same meaning of Influencing Factors.

F. Common Performance Modes

This terminology is used in Contextual Control Model [27]. This model of control mode transition consists of a number of factors, including the human operator's estimate of the outcome of the action (success or failure), the time remaining to accomplish the action (adequate or inadequate), and the number of simultaneous goals of the human operator at that time.

G. Influencing Factors

This terminology is used in Gerdes´s Model for Cognitive Behaviour and Cognitive Error Classification [31]. They are a set of relevant contextual factors with qualitative descriptors of level of influence.

A latent failure is the result of a decision or a measure taken much before the accident, although the consequences can be dormant for a long time. These failures usually have their origin at the level of the Manager to take decisions, Manager of the regulation or the administrators of the company, i.e., depend on people who are far removed in time and space of the resulting event. These failures can also be produced at any level of the system on the basis of the human condition, for example, low motivation or fatigue. In addition, the study of the factors of performance is not only useful to prevent errors and accidents, but also to improve the efficiency and the workload of the operators.

IV. Latent Failures in a Biodiesel Plant

The process to obtain biodiesel is simple, however it is a chemical process in which toxic and flammable substances such as methanol, sodium hidroxide, sulfuric acid, and others are used, or variables like temperature or pressure should be controlled to avoid any kind of incident. Therefore, operators should be very careful during all the process, especially during storage and handling not only of the raw material but also of the products and by-products. The facility can work several years without experiencing any problem but that no means that adopted work methods, designs or procedures are reliable and safety.

Reason [34], [35] developed the "Swiss cheese model" which involves various layers of defences. According to this model, incident or accident causation is characterised by the successive penetration of these defences by either active failures or latent conditions. Active failures are defined as *unsafe acts* committed by people in the form of slips, lapses, mistakes and violations. These have typically been the traditional focus of investigations of human error. Latent conditions, or latent failures, can arise from factors such as organisational culture, management decisions, the design of procedures, or deficiencies in training. They can translate into error provoking conditions or they can create weaknesses in the organisation's defences which may lie dormant within the system, until when combined with active failures, they contribute to the occurrence of an incident or accident. Latent conditions can be identifies and remedied before an adverse event occurs.

Literature report accidents where most human errors are related to the confidence of operators by the simplicity of the process; nevertheless the level of human reliability largely depends on the number of factors involved and that may constitute latent failures [5]. The main factors to take into account are: feasibility, context, ability and ambient.

V. Main Latent Failures Identified

Due to the simplicity of the process are possible find latent failures with ease. In small-scale production frequently the process is not automated and the intervention of human is more than the necessary. From the literature reviewed in this work and the data collection in Argentina, the main latent failures identified are related with procedures, storage, process tasks, safety precautions and processing equipment.

In the following each cause of latent failure identified is descripted joint to their associated problem and an accepted practice is proposed.

A. Procedures

Cause of Latent failure

Scarcity of written procedures or available procedures little detailed. It is required the presence of the most experienced operator who indicates steps to follow.

Associated problems

In case of absence of this operator (due to a personal problem, accident or death) details of the procedure to obtain biodiesel are not available.

Accepted practices

It is highly recommended to write detail procedures so all the temporary workers will have complete and standard information not only for training but also to follow proper safety and quality procedures during each step.

B. Storage

Cause of Latent failure

Lack of a place to store raw material (oil) and by-products of the process (glycerol, and water washing). Sometimes tanks are stored in the building process which is open to the air.

Associated problems

Reduced space to move when making processing tasks. A source of fuel in case of fire.

Accepted practices

It is desirable to have a place to store tanks separated from the process building.

C. Process tasks

Cause of Latent failure

Lack of a specific place to prepare the catalyst (sodium hydroxide).

Associated problems

Inhalation of low levels of sodium hydroxide as dusts or mists may cause irritation of the nose, throat, and respiratory airways.

Accepted practices

Buy liquid catalyst or one that does not need to be grinding it.

D. Safety precautions

Cause of Latent failure

Sometime operators know main risks of working with methanol and sodium hydroxide. However they do not have the Material Safety Data Sheet (MSDS) for these compounds.

Associated problems

In case of an accident, chemical information is not readily available for all workers or third parties involved.

Accepted practices

Dispose a place within the processing facility, where the Material Safety Data Sheets are kept readily accessible. This will allow workers and fire or emergency personnel to readily locate chemical safety information in case of an accident. Also, this is convenient to keep in mind the proper personal safety equipment required to manipulate chemical substances.

E. Processing equipment 1

Cause of Latent failure

Sometimes the addition of sodium hydroxide in methanol is carried out manually through an opening in the top of the methanol tank.

Associated problems

This design can result in increased fire risk, increased worker methanol exposure, and reduced fuel quality due to evaporation of methanol from the mixing tank.

Accepted practices

A closed system, wherein oil, chemicals, and end products can be safely transferred using pumps, tubing, and valves is ideal. Use of devices with sparking electric motors, near open containers of methanol also presents a fire risk and must be avoided.

F. Processing equipment 2

Cause of Latent failure

Sometimes pressure relief of the reactor must be done manually by opening a plug in its upper part.

Associated problems

Even experienced operators can forget to relief pressure when necessary in the process and overpressure may occur.

Accepted practices

It is recommended to automate this step in the process.

G. Processing equipment 3

Cause of Latent failure

Sometimes the opening and closing of valves that determine the direction of flow of different fluids of the process is made by hand and do not have a step-by-step guide for the state of valves.

Associated problems

Even experienced operators can make mistakes, and opening (or failing to open) certain valves during processing stages may result in spills or accidental release of dangerous chemicals into the workspace.

Accepted practices

Develop a well-thought out process diagram, including step-by-step guidelines for the state of valves and switches during different stages of production. This diagram should be posted on or near fuel-making equipment, to serve as a reference for all trained operators.

H. Processing equipment 4

Cause of Latent failure

In the step of adding sodium methoxide to the reactor, it is important that all operate properly.

Associated problems

Spills or releases can take place.

Accepted practices

It is recommended that each task performed should be registered and checked frequently by all the operators who work in the process avoiding possible mistakes or duplication of tasks.

I. Washing fuel 1

Cause of Latent failure

Inappropriate design of the plant and/or inadequate equipment to make washing fuel.

Associated problems

Operators can suffer burns when moving the hot water bucket. When opening the upper inlet of the reactor methanol vapours can be released.

Accepted practices

It is recommended to check the design of the plant and study the possibility to incorporate necessary equipment to do the water heating.

J. Washing fuel 2

Cause of Latent failure

Methanol is not recovered from the biodiesel fuel prior to do the washing.

Associated problems

The waste water from the first wash will contain significant methanol. The use of this water can increment fire risk due to flammable methanol vapours and can be dangerous to the operator’s health.

Accepted practices

Waste water from the first wash should be handled with care and it is recommended not to use it for other purposes.

K. Labeling stored fluids

Cause of Latent failure

Labelling stored fluids is missing.

Associated problems

It can occur a misuse of the stored substance. In case of accident, emergency- service personnel or operators do not know what they are dealing with.

Accepted practices

To be sure labelling all storage containers to avoid accidental misuse and to identify easily each stored substance.

L. By- product handling and disposal

Cause of Latent failure

Inappropriate extract of by-product glycerol.

Associated problems

Crude glycerol by-product is contaminated with methanol (approximately 25% by volume) and as such may be considered hazardous waste. Methanol will not evaporate from stored glycerol at ambient temperatures sufficiently to consider the glycerol uncontaminated. As consequence, improper handling can cause health problems to operators or create a source of ignition.

Accepted practices

It should be handled as if it were methanol: wearing gloves and goggles and avoiding any concentrated vapors. It is highly recommended to recover methanol from glycerol via distillation, prior to disposal or further use. This practice reduces environmental pollution and allows producers to reuse methanol, reducing in this way costs and improving energy balance.

VI. SUMMARY OF REVIEW AND CONCLUSIONS

Old works show that most human error is related to the confidence of the operators by the simplicity of the process. Like other chemical process a number of factors involved may constitute latent failures and it is highly recommended:

- write detailed procedures;
- have a place to store tanks separated from the process building;
- buy liquid catalyst or one that does not need to be grinding it.
- dispose a place within the processing facility, where the Material Safety Data Sheets can keep readily accessible;
- having a closed system, wherein oil, chemicals, and end products can be safely transferred using pumps, tubing and valves;
- use devices with sparking electric motors, near open containers of methanol presents a fire risk and must be avoided;
- develop a well-thought out process diagram, including step-by-step guidelines for the state of valves and switches during different stages of production;
- each task performed should be registered and checked frequently by all the operators who work in the process avoiding possible mistakes or duplication of tasks;
- check the design of the plant and study the possibility to incorporate necessary equipment to do the water heating;
- waste water from the first wash should be handled with care and it is recommended not to use it for other purposes;
- label all storage containers to avoid accidental misuse and to identify easily each stored substance;
- recover methanol from glycerol via distillation, prior to disposal or further use. This practice reduces environmental pollution and allows producers to reuse methanol, reducing in this way costs and improving energy balance.

REFERENCES

[1] P. Franklin, "Introduction to Human Reliability Engineering", tutorial notes at the 2012 Annual Reliability and Maintainability Symposium, Reno, NV, USA.

[2] J. Henderson and D. Embrey, "Quantifying human reliability in risk assessments", *in El Technical, Safety¸*Petroleum Review, 2012.

[3] J. Reason, *Human Error.* Cambridge University Press, 1990, pp. 173–216.

[4] J. D. Moré, "Análisis de la Confiabilidad Humana en una refinería de petróleo. Uso de metodología borrosa.", Cuadernos del CIMBAJE Nº 12, pp. 71-84, Nov, 2009.

[5] S. S. Rivera and J. E. Núñez Mc Leod "Recommendations Generated about Human Reliability Analysis on Biodiesel Plants" in *Proc. of the World Congress on Engineering*, London, UK, 2012, vol. I, pp. 558–593.

[6] S. S. Rivera and J. E. Núñez Mc Leod, "Human Error in Biofuel Plants", in Proc. of the World Congress on Engineering, Vol II, July 2-4, 2008, London, U.K.

[7] E. Salzano, A. Basco, M. Di Serio and E. Santacesaria, "The risk of biodiesel production by trans-esterification of oils", Processes and Technologies for a Sustainable Energy, Ischia, June 27-30, 2010.

[8] E. Salzano, M. Di serio and E. Santacesaria, "Emerging safety issues for biodiesel production plant*", Chemical Engineering Transactions*, p. 19 in *Proc. Of CISAP4 – 4rd International Conference on Safety & Environment in Process Industry*, Firenze, Italy, 2010, p. 19.

[9] NRC, "Technical Basis and Implementation Guidelines for A Technique for Human Event Analysis (ATHEANA)", Nureg-1624, Rev. 1, USA, 2000.

[10] S. Gitahi Kariuke and K. Löwe, "Increasing human reliability in the chemical process industry using human factor techniques", *Process Safety and Environmental Protection, 84(*B3), pp. 200-207, May 2006

[11] H. S. Blackman, D. I. Gertman and R. L. Boring, "Human Error Quantification using Performance Shaping Factors in the SPAR-H Method", *52nd Annual Meeting of the Human Factors and Ergonomics Society,* September 2008.

[12] IAEA-TECDOC-1048, "Collection and classification of human reliability data for use in probabilistic safety data for use in probabilistic safety assessments", *IAEA Final report of a co-ordinated research programme*, 1995-1998.

[13] C. Johnson, "Why human error modeling has field to help systems development", Elsevier, Interacting with Computers, 11, pp. 517-524, 1999.

[14] W. L. Mostia, (2002, 09,11), "*Human error in instrumentation systems"*, Control, Available: http://www. controlglobal.com/ articles/2006/140.html?page=full

[15] T. Dalijonp, J. Castro, K. Löwe and H. J. Löher, "*Reducing Human Error by Improvement of Design and Organization"*, Trans IChemE, Part B, May 2006, Process Safety *and Environmental Protection, 84(B3), pp. 191-199.*

[16] A. G. Foord and W. G. Gulland, "*Can Technology eliminate Human Error?"*, Tans IChemE Part B, May 2006, Process Safety *and Environmental Protection, 84(B3), pp.171 – 173.*

[17] C. R. Nelms, "*The Latent Causes of Industrial Failure….How to Identify Them and What to DO About Them"*, Available: http://www.maintenanceworld.com/articles/nelmsc/thelatent.pdf

[18] M. Madonna, G. Martella, L. Monica, E. Pichini Maini and L. Tomassini, *"The Human Factor in Risk Assessment: Methodological comparison between Human Reliability Analysis Techniques"*, Prevention Today, 2009, vol. 5, no. 1/2, pp. 67-83.

[19] B. Kirwan. "*The validation of three Human Reliability Quantification techniques - THERP, HEART and JHEDI:Part 1 - technique descriptions and validation issues"*, Industrial Ergonomics Group, School of Manufacturing & Mechanical Engineering, University of Birmingham, Edgbaston B15 2TT, UK, 1996, Available: http://www.ncbi.nlm.nih.gov/ pubmed/15677076

[20] L. Chadwick and EF. Fallon, "*Human Reliability Assessment of a critical nursing task in radiotherapy treatment process"*, Aoolied Ergonomics, 2012, vol. 43 no.1, pp. 89-97

[21] Research Report RR679, Health and Safety Executive, "*Review of human reliability assessment methods",* 2009.

[22] E. A. Rosa, P.C. Humphreys, C.M Spettel and D.E. Embrey, *"Application of SLIM-MAUD: A test of an interactive computer-based method for organizing expert assessment of human performance and reliability"*, NUREG/CR-4016, BNL-NUREG-51828, Vol. 1, 1985.

[23] K.M. Groth, *"A data-informed model of performance shaping factor for use in human reliability analysis"*, 2009, Available: http://drum.lib.umd.edu/bitstream/1903/9975/1/Groth_umd_0117E_10944.pdf

[24] I. M. Fam, A. Kianfar and M. Faridan, "*Application of Tripod-Beta Approach and Map-Overlaying Technique to analyze occupational fatal accidents in Chemical Industry in Iran"*, International Journal of Occupational Hygiene, 2010, Vol. 2, no. 1, pp.30-36.

[25] J. Forester,A. Kolaczkowski, D. Bley and E. Lois. "*ATHEANA User's Guide*", Final Report, NUREG-1880, U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research Washington, DC 20555-0001, 2007.

[26] B. Kirwan, "*The development of a nuclear chemical plant human reliability management approach:HRMS and JHEDI"*, Reliability Engineering & System Safety, Vol. 56, issue 2, 1997, pp. 107-133.

[27] B. Subotic, "Framework for the analysis of controller recovery from equipment failures in air traffic control", MSc.BSc. thesis, London Centre for Transport Studies Department of Civil and Environmental Engineering Imperial College London, United K, 2007.

[28] O. Sträter, "Considerations on the elements of quantifying human reliability", *Reliability Engineering & System Safety*, 2004, vol. 83, no. 2, p.p. 255-264.

[29] J. Rasmussen et al. "Classification System for Reporting Events Involving Human Malfunctions". Riso-M-2240 Riso National Laboratory, March 1981.

[30] Research Report RR543, White Queen Safety Strategies & Environmental Resources Management, "Development of a working model of how human factors, safety management systems and wider organizational issues fit together", 2007.

[31] V. Gerdes, "Identification and Analysis of Cognitive Errors. Aplication to Control Room Operators", PhD thesis, Mechanical Maritime and Materilas Engineering, 1997.
[32] J. Julius, E. Jorgenson, G.W. Perry and A.M. Mosleh, " *A procedure fir the analysis of errors of commission in a probabilistic safety assessment of a nuclear power plant at full power"*, Reliability Engineering and System Safety, vol.50, pp. 189-201.
[33] T. Kontogiannis, "*A framework for the analysis of cognitive reliability in complex systems: a recovery centred approach",* Reliability Engineering and System Safety, vol. 58, pp. 233-248.
[34] J. Reason, *"Human error: models and management"*. BMJ, vol. 320, 2000, pp. 768-770.
[35] J. Reason, "*Human error"*, Western Journal of Medicine, vol. 172, no. 6, 2000, pp. 393-396.
[36] K. Schemeleva, C. Nguyen, S. Du Rieux and C. Caux, "*Human error probabilities computation for manufacturing system simulation using CREAM"*, 9th International Conference of Modeling, Optimization and Simulation – MOSIM´12, 2012, Bordeaux – France.