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ORIGINAL ARTICLE

The Credit of Fire and Explosion Index for Risk Assessment of Iso-Max Unit in an Oil Refinery

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ABSTRACT

The risks of fire and explosion in oil and gas industry need to be managed. The objectives of the present study were to assess the risk of fire and explosion in Iso-max unit of Tehran Oil Refinery using Dow's fire and explosion index and to study the influences of the controlling methods. The latest version of DOW fire and explosion index guideline was applied to calculate the fire and explosion index at process subunits of Iso-max. The important process subunits in Iso-max unit were identified based on important affecting parameters such as process pressure, temperature and material value. In next step, the important parameters affecting the fire and explosion index were identified and estimated. The fire and explosion index was calculated for each subunit. Mean time, the controlling methods for each case was identified and its influences were studied. The results revealed that, 6 subunits out of 8 studied subunits had a sever fire and explosion risk. One subunit had a heavy risk and one had an intermediate risk of fire and explosion. The separating container at high pressure was the most critical subunit of Iso-max, holding an F&E Index of 220. The reactor feeding furnace was the least dangerous subunit with an F&E Index of 122. The study showed that the application of controlling methods could reduce the F&E Index extensively.

Keywords: *Iso-max, Index, Fire, Explosion, Risk*

INTRODUCTION

Inherently safe plant infers a plant with no hazards on an absolute basis, with "Zero Risk". It might be impossible to design and operate such an inherently safe plant. Therefore, hazards and risks are needed to be strategically and systematically managed [1, 2].

Inherently safer approaches to plant design and general theory on how it can be built into the design process has been presented since 1960s [3]. Inherently safety index has been applied for identifying hazards and generated alternative designs as well [2].

The most general and traditional safety approach has focused on layer of operation (LOP) where additional safety devices and features are added to the process. The LOP method has been successful in analyzing safety systems. However, in this approach, the hazard with in the process remains. It also increases the complexity of the process and hence the capital and operating cost [2]. In oil and gas industries, 15 to 30% of the capital cost goes to safety issues and pollution prevention [4].

Other efforts toward safety studies tend to focus on hazard identification and control. In addition to the traditional analysis methods such as Check List, Safety Review Relative Ranking and What If analysis, more

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advanced hazard and risk analysis methods such as Failure Modes and Effects Analysis (FMEA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Cause-Consequence Analysis (CCA), preliminary Hazard Analysis (prHA), Human Reliability Analysis (HRA), and Hazard and Operability (HAZOP) study have been developed [5-8].

For chemical process loss prevention and risk management several hazard indices have been developed. Safety weighted hazard index (SWeHI) was developed as a tool to define fire, explosion, and toxic release hazards [9]. Environmental Risk Management Screening Tools (ERMSTs) was developed by Four Elements Inc for ranking environmental hazards including air, ground water, and surface water pollution [10]. Mond Index is a tool to define fire, explosion, and toxic release hazard [10].

Hazardous waste index (HWI) is used as a tool for flammability, reactivity, toxicity, and corrosivity hazards of waste materials [9]. Transportation Risk Screening Model (ADLTRSs) is a tool for determining risk to people and environment posed by chemical transportation operations [9].

Heikkila (1999) developed Inherent safety index at Helsinki University of Technology. This method classifies safety factors into two categories: chemical and process inherent safety. The chemical inherent safety includes the choice of material used in the whole process by looking at its heat of reaction, flammability, explosiveness, toxicity, corrosivity, and incompatibility of chemicals. The process inherent safety covers the process equipment and its conditions such as inventory, pressure, temperature, type of process equipment, and structure of the process [11].

Overall inherent safety index was developed by Edward and Lawrence (1993) to measure the inherent safety potential for different routes of reaction to obtain the same product [12].

Fuzzy logic-based inherent safety index (FLISI) was developed by Gentile (2004) [13]. The major problem in applying inherent safety is the safety which is mostly based on the qualitative principles and cannot easily be evaluated and analyzed. FLISI was an attempt to use hierarchical fuzzy logic to measure inherent safety and provide conceptual framework for inherent safety analysis. Fuzzy logic is very helpful for combining qualitative information (expert judgment) and quantitative data (numerical modeling) by using fuzzy IF–THEN rules.

Fire and Explosion Index (F & EI) was invented by Dow's chemical exposure hazards and American Institute of Chemical Engineers (AIChE) in 1967 as a tool to determine relative ranking of fire, explosion, and chemical exposure hazards. It has been revised six times since then. Its' last revision (e. g. 7^{th} edition) was published in 1994 [14]. A computer program was developed to automate F & EI calculation and perform sensitivity analysis using Microsoft's Visual Basic by Etowa and et al in 2002 [15]. However, their program was not intended to determine business interruption and loss control credit factors, to conduct process unit risk analyses.

Index methodologies are found to be robust and are not able to cover all safety parameters [16]. The application of Dow fire and explosion index (F & EI), and safety weighted hazard index (SWeHI) as a predictive tool for loss prevention and risk management in oil and gas industry cab be considered a new merit for them. One of the attempts in present study is to apply F & EI to predict the safety status of an old oil refinery.

Dow Fire and Explosion Index (F & EI) is the most widely used fire index. This index gives a relative value to the risk of individual process unit losses due to fire and explosions and to communicate these risks to management in terms of easily understood i. e. potential of financial losses due to lost production and damage to plant facilities. This index estimates the hazards of a single process unit based on chemical properties and inventories, and then uses plant construction cost or replacement cost to estimate the potential risk in dollar terms.

Since it's invention, Dow F & EI has been adjusted based on both internal and external data as well as qualitative and quantitative analysis. The aim of this tool is to communicate the risk to management in such a way, that management may take appropriate actions to reduce risk. The purpose is not to rate a given facility as safe or unsafe, but to give a relative ranking of hazards and risks with in an organization [17].

Dow F& EI is a relatively simple technique which includes a complete methodology to calculate the total risk of the process. It does not require highly qualified expertise and its' calculation is not time consuming. Dow F & EI is the only index which considers all safety parameters and it is able to select the most critical parts of the process. It is able to calculate the value of damages and other losses using the day outage, property damage, replacement value and value of lost production. These characteristics signify Dow F & EI among other fire and explosion risk indices.

The objectives of the present study were to assess the risk of fire and explosion in Iso-max unit of Tehran Oil Refinery using Dow's fire and explosion index and to study the influences of the controlling methods.

MATERIALS AND METHODS

The last version of F & EI published in 1994 was applied for the present study. The general procedure for using the F & EI Guide is shown in Fig 1, and involves the following steps: Material Factor (MF) which represents the measure of the potential energy released by material under study is obtained first. MF is obtained from data bases, material safety data sheet (MSDS), or manual calculation. This is achieved by using flammability, N_F, and reactivity value, V_R. The sum of potentialities that contributes to loss probability and its magnitude is then estimated. This is called general

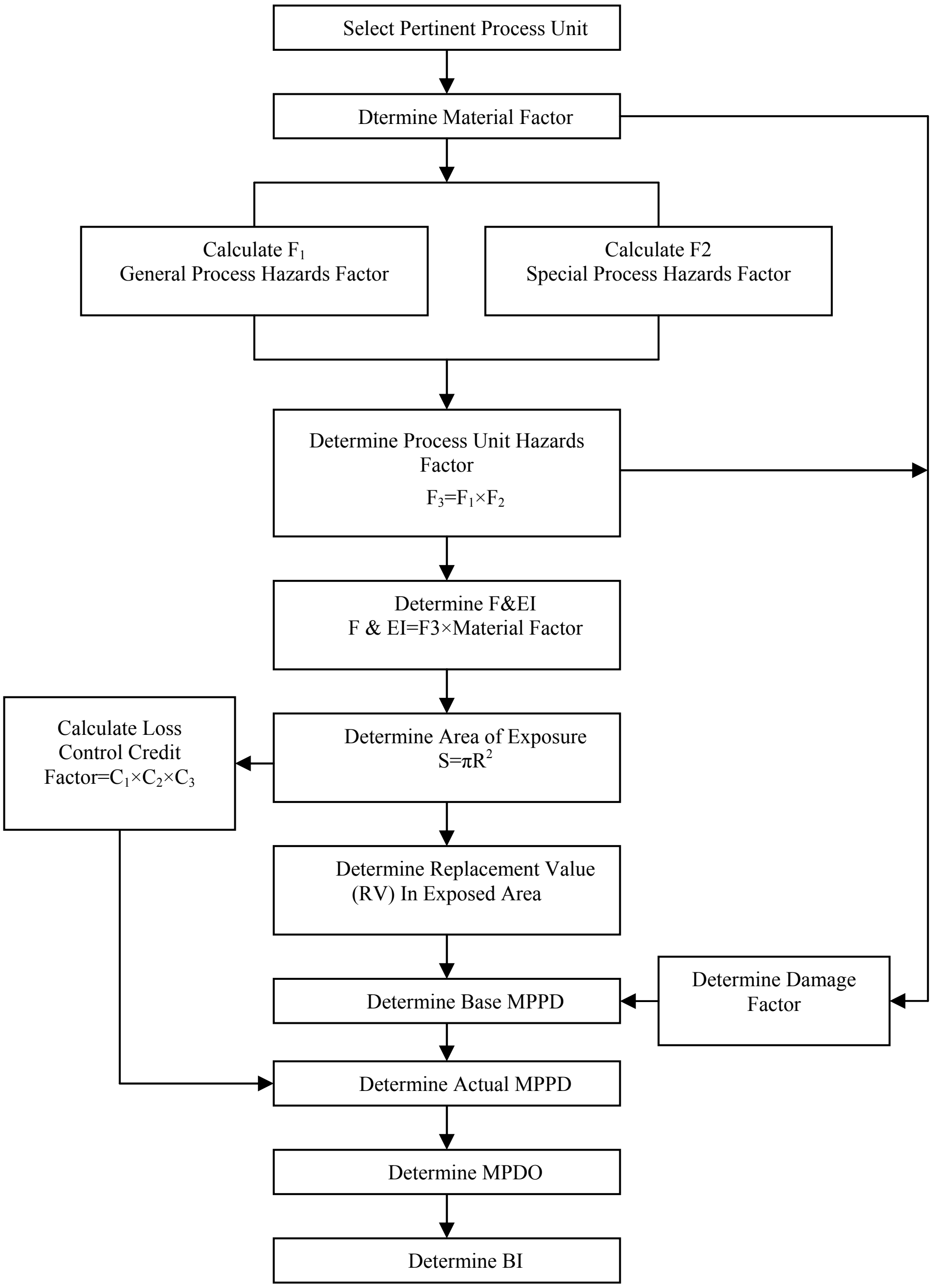

Fig 1. F&EI Procedure [18]

process hazard factor, F_1. In this step, special process hazard factor, F2 is also determined. This factor is the sum of factors that can increase the probability and historically contributes to major fire and explosion incidents.

General process hazards cover six items although it may not be necessary to apply all of them. These items include exothermic chemical reactions, endothermic processes, material handling and transfer, enclosed or indoor process units, access and damage, as well as spill control.

Special process hazards cover twelve items. These items include operation in or near flammable range, hot oil heat exchange system, leakage-joints and packing, sub-atmospheric pressure, quantity of flammable /unstable material, dust explosion, relief pressure, toxic material, low temperature, corrosion and erosion, use of fired equipment, and rotating equipment. Each item is represented in terms of "potentials" and "credit factors".

The Fire and Explosion Index is then calculated using equation 1 and 2 [18].

Table 1. Hazard assessment using F & EI [19]

F&EI	Degree of Hazard
1-60	Light
61-96	Moderate
97-127	Intermediate
128-158	Heavy
159-up	Severe

$$F_3 = F_1 \times F_2 \qquad (1)$$

$$F\ \&\ EI = MF \times F_3 \qquad (2)$$

In the next step, business interruption (BI) is calculated. BI is estimated based on Fire and Explosion Index calculated. F & EI will determine the radius and the area of the exposure using equation 3. Any equipment and facility with in this area will be exposed to hazard.

$$R = 0.256 \times F\ \&\ EI \qquad (3)$$

The damage factor which represents the overall effect of the fire and blast damage is then estimated. This is the damage to the unit equipment produced by fire, blast, release of fuel or reactivity energy.

By having original equipment cost and value of production per month (VPM) as an input, the actual minimum probable property damage (Actual MPPD) can be determined and then BI is calculated from equation (4) [18].

$$BI(\$US) = \frac{MPDO}{30} \times VPM \times 0.7 \qquad (4)$$

The degree of hazard in the plant can be assessed using Table 1 [19].

A calculation spreadsheet in excel was developed for the study. Its validity was tested using step by step validation of the calculation process comparing the results with hand calculated results. Total validation of the calculation sheet was implemented comparing the results with benchmark data. Tests for total validation were run prior to the final calculation.

Studied Case: The case of the present study is an oil refinery established in 1969. Iso-max unit consisting of Reactor and Distillation sections is one of the main units in this refinery. The flow diagram of the Iso-max unit is shown in Fig 2. In Reactor, iso-feed is broken down through hydro-cracking process in high temperature and pressure using hydrogen in a catalytic bed. In Distillation section, the reaction production from Distillation tower is separated and stabilized in stabilizing towers. Light flammable hydro-carbons handling in very high operating pressures of up to 2500 psi and high temperatures of up to 800°F with exothermic reactions inside the reactors may categorize Iso-max unit as a high risk process.

Fire and Explosion Index was determined for eight sub-sections including, Reactor Feeding Oven, Catalytic Reactor, High Pressure Separator, Low Pressure Separator, Distillation Feeding Container, Distillation Oven, Distillation Tower, and Diesel Sputter Tower in their existing status. F& EI was also predicted for after the application of proposed control measures in these sub-sections.

RESULTS

The predicted F& EI for 8 sub-units showed that the maximum, minimum and mean values of F & EI were 220, 122 and 180.8±37.9 respectively. With the application of proposed control measures they will be reduced to 135, 60.0 and 97.6±24.1 respectively (Fig 3). The statistical paired *t*-test showed that the application of the proposed control measures will significantly (p<0.001) reduce F & EI mean value.

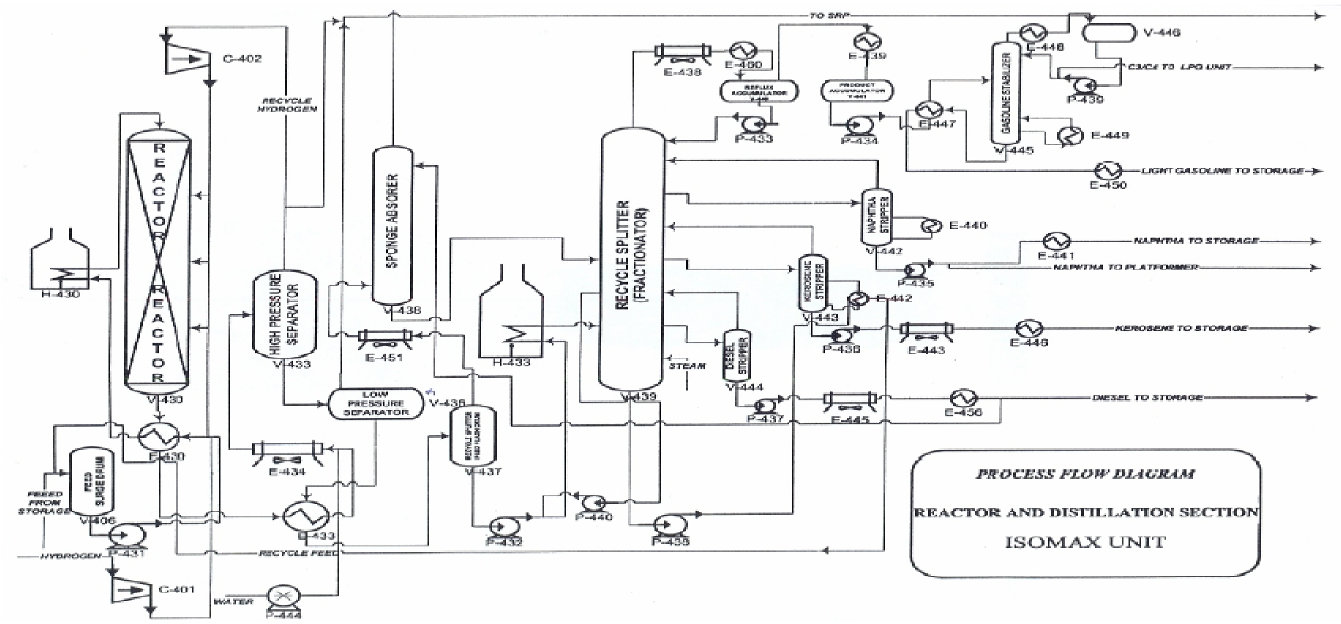

Fig 2. Iso-max unit process flow diagram [20]

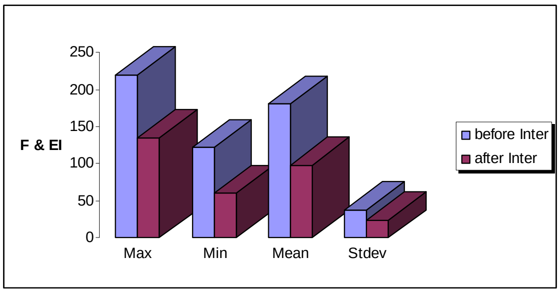

Fig 3. F & EI in Iso-max unit before and after proposed interventions

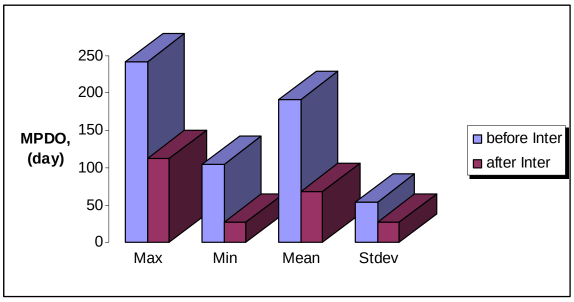

Fig 4. MPDO (day) in Iso-max unit before and after proposed interventions

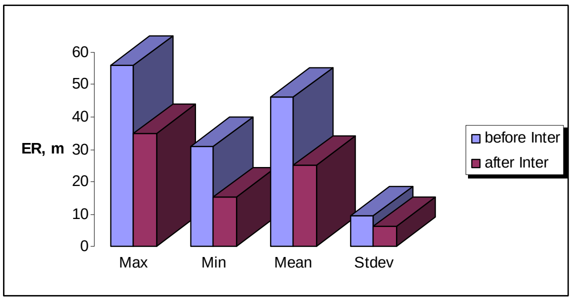

Fig 5. Exposure Radius before and after proposed interventions

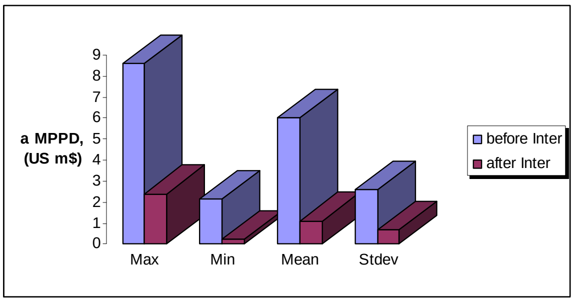

Fig 6. Actual MPPD (million US$) before and after proposed intervention

According to the results, the High Pressure Separator with maximum Fire and Explosion Index of 220 is the most critical sub-unit.

At the present condition, 6 sub-units have severe risks, while the Diesel Sputter Tower and Reactor Feeding Oven experience heavy and intermediate risks respectively (Table 2). The implementation of the proposed control measures will reduce the risk categories significantly (Table 2).

In case of a fire and explosion, at the Lower Pressure Separator, the plant will experience the highest outage (MPDO=242 days), while an explosion at the Reactor Feeding Oven will shut the plant for at least

105 days. After the implementation of the proposed control steps the plant is expected to experience the highest and lowest outages of 112 and 28 days with a fire and explosion at the Catalytic Reactor and Diesel Sputter Tower respectively (Fig 4).

The mean value of Maximum Probable Day Outage (MPDO) is 191±54.0 days with existing situation. It is expected to be reduced to 67.9±26.7 days if the proposed control measures are applied (Fig 4). Statistical paired *t*-test showed that there is a significant difference (p<0.001) between MPDO mean values at existing condition and after the proposed control measures applied. The application of proposed control measures is expected to reduce the mean values of MPDO by 64.5%.

The Iso-max unit will experience the maximum Exposure Radius (ER) of 56 m and the minimum ER of 31 m with a fire and explosion at the High Pressure Separator and Reactor Feeding Oven respectively (Fig 5). The plant is expected to experience the highest ER of 35 m and the lowest ER of 15.2 m with a fire and explosion at the Catalytic Reactor and Diesel Sputter Tower respectively, with the implementation of the control measures (Fig 5).

The results also showed that the mean Exposure Radius value of 8 studied sub-sections were 46.3±9.70 m. The applications of the proposed control measures are expected to reduce it to 25.0±6.30 m (Fig 5) which is significantly different (p<0.001) from its present value.

According to the results, in case of a fire and

Table 2. Risk categories of Iso-max unit before and after proposed intervention

Process unit	Before intervention		After intervention	
	F&EI	Risk Category	F&EI	Risk Category
Reactor feeding oven	122	Intermediate	76	Moderate
Catalytic reactor	162	Severe	135	Heavy
High pressure separator	220	Severe	121	Intermediate
Low pressure separator	217	Severe	91	Moderate
Distillation feeding container	195	Severe	90	Moderate
Distillation oven	181	Severe	110	Intermediate
Distillation tower	214	Severe	98	Intermediate
Diesel sputter tower	135	Heavy	60	Light

Table 3. Business Interruption cost due to fire and explosion in Iso-max (million US$)

BI	Before intervention	After intervention
Max	847	392
Min	367.5	98
Mean	668.5	237.6
Stdev	189.0	93.3
No	8	8

explosion, the Highest, Lowest and mean value of actual MPPD in 8 studied sub-units were 8.61, 2.15 and 6.00±2.60 US million dollars respectively. With the application of proposed control measures they were expected to be cut down to 2.40, 0.23 and 1.10±0.70 US million dollars respectively (Fig 6). The statistical paired *t*-test showed a significant difference ($p<0.001$) between actual MPPD mean values at existing situation and after interventions.

A fire and explosion in Low Pressure Separator, may lead to the highest Business Interruption cost of up to 847 US million dollars in Iso-max unit. The BI cost is expected to be cut significantly ($p<0.001$) down by 53.7% (Table 3) with the proposed control measures applied. After the implementation of the proposed control measures, a fire and explosion in the Catalytic Reactor will lead to the highest BI cost of 392 US million dollars (Table 3).

DISCUSSION

Jensen and Jorgensen (2007) obtained an almost similar F & EI of 238 for Methyl Iso-Cyanat container in Bopal incident [17]. High operating pressure is the main specification of the High Pressure Separator in present study while the high Material Factor of Methyl Iso-cyanat was the main reason for a higher F & EI in Jensen and Jorgensen study.

High volume of liquids which are pumped from three reactors to the High Pressure Separator, high amount of heat released, liquidity of the material, improper drainage system, process temperatures higher than the liquids boiling point, the application of hot fluid in heat exchangers, high corrosive and the leakage potential from sight glasses are the main reasons of high Fire and Explosion Index in High Pressure Separator subunit.

Different studies including Etowa and et al. (2002), Suardin (2005) and Suardin et al. (2007) [2, 14, 15] showed that reducing the amount of material used in the process leads to a lower F & EI which well agrees with the results of the present study. The application of proposed control measures is expected to reduce the mean values of F & EI by almost 46.0%. The implementation of a drainage system as the most effective and applicable control measure is expected to reduce the mean value of F & EI by 29.3%.

Gupta (1997) suggested a modification of 25 to 50% over estimate in Dow Index parameters for developing countries due to the international nature of large projects which involve multinational funding, as well as licensing of technology, design, fabrication, erection, commissioning and/or training by foreign companies. With Gupta's suggestion considered for the modification of BI, the mean value of BI is expected to be modified by 42.8% [21].

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REFERENCES

1. Crowl DA. *Inherently safer chemical processes: A life cycle approach*, New York, AIChE, 1996.
2. Suardina J, Mannana S and El-Halwagi M. The integration of Dow's fire and explosion index (F & EI) into process design and optimization to achieve inherently safer design. *Loss Prevention in the Process Industries* 2007; 20(1): 79-90.
3. Mansfield D, Cassidy K. Inherently safer approach and how this can be built into the design process. *Institution of Chemical Engineers Symposium Series* 1994; 134: 285-299.
4. Palaniappan C, Srinivasan R, Tan R. Selection of inherently safer process routes: a case study. *Chemical Engineering and Processing* 1997; 43: 647–653.
5. Wang Y. *Development of computer–aided fault tree synthesis methodology for quantitative risk analysis in the chemical process industry.* PhD thesis, A&M university college station, TX, 2004.
6. Hyatt N. *Guidelines for Process Hazard Analysis, Hazard Identification & Risk Analysis*, 3rd edition, Ontario, Canada, Dyadem press, 2003.
7. Siavapiraksam SP, Surianarayanan M, Swaminathan G. Hazard assessment for the safe storage, manufacturing and handling of flash compositions. *Journal of Loss Prevention in the Process Industries* 2009; 22: 254-256.
8. jafari, MJ, Gharari N, Sheikhi HR. The reliability of a tunnel boring machine. *IJOH* 2009; 1: 19-24.
9. Khan FI, Sadiq R, Amyotte PR. Evaluation of Available Indices for Inherently Safer Design Options. *Process Safety Progress* 2003; 22(2): 83-97.
10. Hendershot D. Process minimization, making plants safety. *Chemical Engineering progress*. Jan 2000: 35-40.
11. Heillila AM. *Inherent safety in process plant design: an index based approach*. PhD thesis, Technical Research Center of Finland, VTT, Espoo; Finland, 1999.
12. Edward DW, Lawrence D. *Assessing the inherent safety of chemical process routes: Is there a relation between plant cost and inherent safety?* Trans IChem, PT. B (Process Safety and Environmental Protection), 71B, 252, 1993
13. Gentile M. *Development of a hierarchical fuzzy model for the evaluation of inherent safety*. PhD thesis, College Station, Texas A & M University, 2004.
14. Suardin J. The integration of Dow's Fire and Explosion Index into Process Design and Optimization to achieve an Inherently Safer Design. MSc thesis, Texas A&M University. Aug 2005.
15. Etowa CB, Amyotte PR, Pegg MJ, Khan FI. Quantification of Inherent Safety Aspect of the Dow Index. *Loss Prevention in the Process Industries* 2002; 15(6): 477-487.
16. Khan FI, Amyotte PR. How to make inherent safety practice a reality. *The Canadian Journal of Chemical Engineering* 2003; 81: 1-16.
17. Jensen N, Jorgensen SB. Taking credit for loss control measures in the plant with the likely loss Fire and Explosion Index (LL-F & EI). *Trans IChem E, part B Process Safety and Environmental Protection* 2007; Vol 85(B1): 51-58.

18. AIChE. *Dow's Fire and Explosion Index Hazard Classification Guide*. 7th ed. New York. AICHE. 1994: 1-64.

19. AICHE. *Dow's Chemical Exposure Index Guide*, 1st ed, New York. 1994

20. Ramezani A. *Iso-max Unit No:1*, Manual Operation –Tehran refinery:1990.

21. Gupta JP. The application of Dow's fire and explosion index hazard classification guide to process plants in the developing countries. *Journal of Loss Prevention. Process Industry* 1997; 10 (1): 7-15.