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Analysis of Accidents in Chemical Process Industries in the period 1998-2015

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Abstract: The present research work is briefly providing some of major accidents in chemical process industries which occurred for the period 1998-2015. For this study, 70 major process accidents have been considered from 30 countries across the world. The criteria considered for the analysis of process accidents are the frequency of accidents occurred, the number of people killed and the number of people injured in developed and developing countries. Moreover, the primary and chemical causes of accidents are identified in this study. It is observed that, the number of accidents occurred in the chemical process industries are more in developed countries than in developing countries. The number of people deaths isless and number of injuries is more in developed countries. But number of deaths is considerably more in developing countries than developed countries. It is revealed that, most of the accidents concerned with hydrocarbons and toxic chemicals are 55% and 30% respectively. Furthermore, around 63% and 25% of accidents are concerned with explosions and fire due to flammability and explosive nature of hydrocarbons. The present study understands the mechanism of the process accidents and is useful to develop the prevention and mitigation strategies for controlling the process accidents.

Keywords: Chemical disaster, process accident, chemical process industry (CPI), environmental pollution, developed countries, developing countries.

1. Introduction

World countries have been experienced to worst-case chemical disasters in the past history and draw lessons learnt from them. An increase in the number of accidents in the process industries and the concomitant damage potential is a cause of concern in many countries. In order to control the alarming risk posed by these industries, the United States government has asked each manufacturing facility to carry out a worst-case disaster study and to develop alternatives to control the high risk[1].The Bhopal disaster resulting from a combination of inherently unsafe designs and poorly managed operations is a well-known case study[2].

The chemical process industry is a highly complex system with diverse equipment, control schemes and operating procedures. When process failures occur, some may be recovered from, while others escalate into minor or major accidents and losses[3]. The major hazards with the chemical process industry are explosion, fire and toxic release. In a very large number of situations, explosions in chemical process industries are either caused by fire, or lead to a fire. According to the United Nations Environment Programme (UNEP)database, a major industrial accident was defined by the criteriaof 25 deaths or more; or125 injured or more; or10000 evacuated or more; or10000 people or more deprived of water[4].However, most of the process industries are generally reluctant in revealing the causes of accidents and number of people killed or injured. Due to the

political, economic and social conditions, several accidents information is not reported in the international database and media[5,6,7,8].

1.1. Need for a study

The review understands the mechanism of the process accidents and essential to know about past accidents and learn lessons from them. It is useful to develop the prevention and mitigation strategies for controlling the process failures particularly dealing with highly flammable chemicals such as hydrocarbons and toxic chemicals in the process industries.

1.2. Research questions

a) Assessing the frequency or rate of process accidents?
b) Assessing the rate of deaths and rate of injuries?
c) What are the top ten countries with highest number of deaths and injuries?
d) Identifying the number of deaths and injuries in developed countries?
e) Identifying the number of deaths and injuries in developing countries?
f) Identifying the primary causes of process accidents?
g) Identifying the chemical causes of process accidents?

1.3. Related literature

Faisal I. Khan and S.A. Abbasi (1999) analysed the major accidents in process industries for the period 1926-1997.*Efthimia K. Mihailidouet al*. (2012) recorded and analysed319 major industrial accidents according to UNEP specified criteriafor the period 1917-2011.

2. Brief Accidents History

2.1. Process accidents in international scenario

The chemical industry which includes basic chemicals and their intermediates, petrochemicals, fertilizers, paints, pesticides, bulk-drugs and pharmaceuticals is one of the most diversified industrial sectors covering more than 70,000 commercial products[9]. Emergencies may arise from industrial manufacturing, storage or process, transport or other incidents involving hazardous substances, including waste[10, 11]. The most notable industries where disasters frequently happen are the petro-chemical and energy industries. Table 1; provide some of the notorious industrial disasters that have shaken the world and their essence still persists[12].

2.2. Accidents information databases

The accidents information is provided by the many online databases such as ARIA[13], FACTS[14], INRS[15], MARS[16], ZEMA[17], Ility[18], CCPS[19], NTSB[20], JST[21], COSO[22], and OSHA[23] etc.Table 2; provide the major process industrial accidents in an international scenario for the period 1998-2015[4, 24, 25].Numerous major chemical accidents happened over the last several years. Most of these accidents involved fatalities, and have some significant impact on people in nearby residential communities. All involved worker injuries and substantial on-site property damage. Some of the most important accidents are provided in Table 1 and 2.

Table 1. Top ten notorious industrial accident disasters for the period 1900 to 2011

S.No	Date	Country	Incident	People killed
1	7-Aug-1956	Colombia	Explosion	2,700
2	3-Dec-1984	India	Gas Leak	2,500
3	26-Apr-1942	China P Rep	Other	1,549
4	10-Mar-1906	France	Explosion	1,099
5	17-Oct-1998	Nigeria	Explosion	1,082
6	17-Aug-1989	Iraq	Explosion	700
7	4-Jun-1989	Soviet Union	Explosion	607
8	21-Sep-1921	Germany	Explosion	600
9	16-Apr-1947	United States	Explosion	561
10	25-Feb-1984	Brazil	Explosion	508

**Source: http://www.emdat.be/*

Table 2. Major process industrial accidents- international scenario in the period 1998–2015

S.No	Year	Location	Country	Chemical	Incident	Deaths	Injuries
1	1998	Jess ,Niger Delta	Nigeria	Gasoline	Explosion	1000	0
2	1998	Berre l' Etang	France	Hydrocarbons	Fire	0	0
3	1998	RasGharib	Egypt	Oil	Fire	0	0
4	1998	St.John	Canada	Hydrocarbons	Explosion	1	0
5	1998	Langford	Australia	Hydrocarbons	Explosion	2	8
6	1999	Taylor	Canada	Hydrocarbons	Explosion	0	15
7	1999	Bombay high	India	Gas	Fire	0	0
8	1999	Sri Racha	Thailand	Hydrocarbons	Explosion	8	13
9	1999	Thessaloniki	Greece	Hydrocarbons	Fire	0	0
10	1999	Wuppertal	Germany	Potassium Hydroxide	Explosion	0	50
11	1999	Richmond	USA	Hydrocarbons	Explosion	0	0
12	2000	Salamanca	Mexico	Melatthion	Explosion	0	0
13	2000	Enscheda	Netherland	N/A	Explosion	18	946
14	2000	Adeje,Warri	Nigeria	Oil	Explosion	250	0
15	2000	Pasadena	USA	Hydrocarbons	Explosion	1	69
16	2000	Mina Al-Ahmadi	Kuwait	Hydrocarbons	Explosion	5	50
17	2001	Humber River	UK	Gas	Explosion	0	185
18	2001	Tulsa	USA	Arsenic	Toxic release	0	138
19	2001	Taiwan	Taiwan	Gas	Explosion	1	112
20	2001	St.James	USA	Styrene	Fire	0	0
21	2001	Lemont	USA	Hydrocarbons	Fire	0	0
22	2001	Lake Charles	USA	Hydrocarbons	Fire	0	3
23	2001	Wood River	USA	Hydrocarbons	Fire	0	0
24	2001	Birkenhead	UK	Hydrocarbons	Fire	0	2
25	2001	Carson city	USA	Hydrocarbons	Fire	0	0
26	2001	Aruba	Aruba	Oil	Fire	0	0
27	2001	Campos Basin	Brazil	Gas	Explosion	10	0
28	2001	Toulouse	France	Ammonium nitrate	Explosion	30	3000
29	2003	Ukmerge	Lithuania	Polystyrene foam	Blast	2	12
30	2003	Les Franqueses	Spain	Toxic gas	Massive fire	0	0
31	2003	Madrid	Spain	Oil	Fire	0	0
32	2003	Enscheda	Netherland	N/A	Fire	0	0
33	2003	Tornio	Finland	N/A	Explosion and Fire	3	0
34	2004	Ghislenghien	Belgium	Natural gas	Explosion	24	132
35	2004	Dalton	USA	Triallylcyanurate	Toxic release	0	154
36	2004	Skikda	Algeria	LNG	Explosion	23	74
37	2004	Glasgow	UK	N/A	Explosion	9	40
38	2004	St.Petersburg	Russia	Bromomethane	Explosion and Fire	0	30
39	2005	Jilin	China	Benzene	Toxic release	8	60
40	2005	Hertfordshire	UK	Oil	Explosion	0	43
41	2005	Texas	USA	Hydrocarbons	Explosion	15	170
42	2006	Lagos city	Nigeria	Oil	Explosion	260	60

43	2006	Bellingham	UK	Ammonia gas	Explosion	0	0
44	2006	Harbin	China	Solvent reagent	Explosion and Fire	0	2
45	2006	Harbin	China	Benzyl leakage	Explosion	0	0
46	2007	Changzhou	China	N/A	Explosion	5	80
47	2007	Ramat	Israel	Organic phosphate	Blast	0	7
48	2008	Arak	Iran	Detergents	Explosion	30	38
49	2008	Icheon	South Korea	Gas	Fire	40	10
50	2008	Guangxi Zhuang	China	Polyvinyl acetate	Fire	20	60
51	2008	Varanus I land	Australia	Gas	Explosion	0	0
52	2008	Booneville	Arkansas	Ammonia gas	Explosion and Fire	0	0
53	2008	St. Petersburg	Russia	Ammonia gas	Blast and Rupture	1	17
54	2009	Jaipur	India	Oil	Fire	12	150
55	2010	Harbin	China	Explosives	Explosion	20	153
56	2010	Gulf of Mexico	USA	Oil	Explosion	11	0
57	2010	New Cumberland	USA	N/A	Explosion	3	1
58	2011	Fukushima	Japan	Radioactive gas	Explosion	0	0
59	2011	Shandong Baoyan	China	N/A	Blast	3	0
60	2012	Jiaxing	China	N/A	Blast	3	0
61	2012	Irkutsk	Russia	N/A	Explosion	0	0
62	2012	Gumi	South Korea	Hydro-fluoride acid release	Explosion	5	8
63	2012	Guiyang	China	Flammable liquids spillage	Explosion	21	0
64	2013	West Texas	USA	N/A	Explosion	15	200
65	2013	Louisiana	USA	Hydrocarbons	Blast	2	76
66	2013	Antwerp	Belgium	Steam pipe	Blast	2	0
67	2013	Qingdao, Beijing	China	Oil pipe line	Blast	62	135
68	2014	Charleston , West Virginia	USA	Hydrocarbons	Chemical spillage	0	0
69	2014	Kunshan, Jiangsu	China	Metallic(Aluminum and Iron) dust	Dust explosion	146	114
70	2015	Ulsan	South Korea	Polyvinyl chloride	Explosion	6	0
Total						**2077**	**6417**

2.3. Impact of chemical accidents

Chemical units include a wide range of hazards arising from the process itself, properties of the chemicals and their handling, such as fire, explosion and exposure to toxic substances. However, there is a still real potential of major industrial accident with catastrophic impact[26].In addition to loss of life, the major consequences of chemical disasters include impact on livestock, flora/fauna, the environment (air, soil, and water) and losses to industry[27]. A small accident occurring at the local level may be a prior warning signal for impending and the disaster. Chemical disaster, through low in frequency, has the potential to cause significant immediate or long term damage[9].Frequency and severity of chemical disasters has increased in last few years

due to rapid development of chemical industries of a wider range[28]. Major impacts of chemical disasters on biotic and abiotic environment are illustrated in Figure 2.

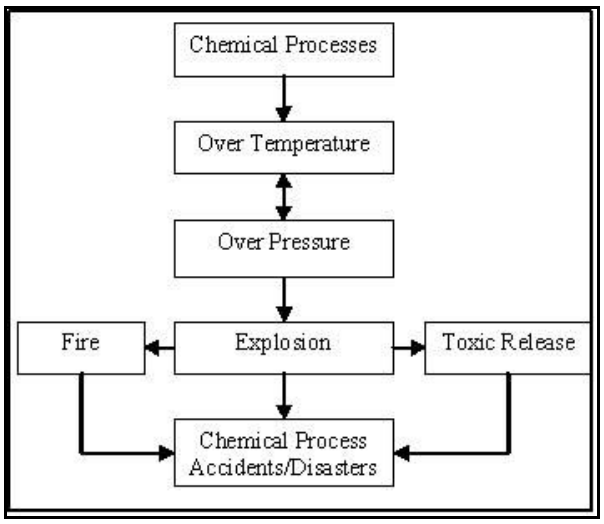

Figure1. Root causes of chemical process industrial accidents

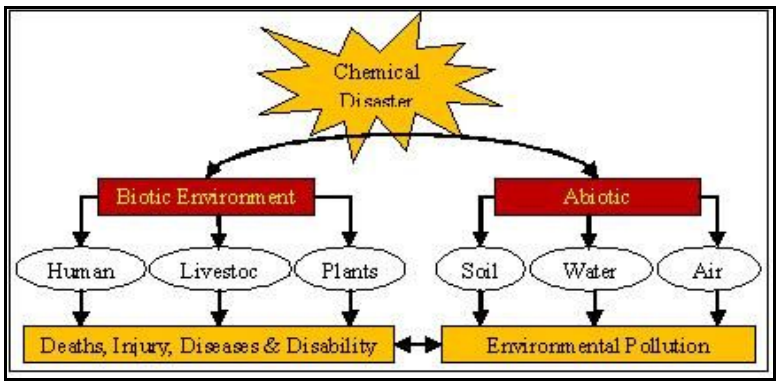

Figure 2. Impacts of chemical disasters

3. Accidents Analysis

3.1. Previous accidents analysis

The growth of chemical industries has been leading to an increase in the risk of occurrence of accidents associated with hazardous chemicals. Chemical accidents result in fire, explosion and toxic release. Most of the accidental analysis revealed that, the process accidents occurred due to abnormal operating conditions such as over temperature and over pressure as shown in the Figure 1. Chemical productions operated in extreme conditions such as high pressure and high temperature require a detailed analysis of all potentially dangerous situations that can lead to a major industrial accident and cause a loss of life and property [26,27, 29]. Chemicals, in general, are the main source of fire, explosion, toxicity and corrosion hazards. About two third of impacts are initiated by explosion compared to fire [30]; however, toxicity is more influence on the number of affected people compared to fire and explosion [31].

A study of equipment based process accident has been carried out. The study reveals that about 78% of equipment failures in the chemical process industry (CPI) are technically oriented including design and human/technical interface errors. The accident analysis has been conducted based on the Japanese Failure Knowledge Database (FKD), identified 549 accidents from the different parts of the world. About 66% of accidents are related to the CPI [32]. Previous review studies related to process equipment caused accidents in CPI are mainly due to reactors, storage tanks, pressure vessels, boilers and pipe lines[33,34,35,36].Vapor cloud explosion (VCE) isthe main cause of the greater risk of damage in the process industries for the period 1926-1997[37].The pre-startup stage involves variety of jobs and prone to errors due to ill-defined work process. A large number of

accidents have been reported during petrochemical plant startups and 40% of plant accidents occurred during new process startups[38,39].However, human errors and understandings in the stage have not been given much of attention even it deserves[40]. The root causes of accidents for many chemical process industries are explosion, fire and discharge of toxic chemicals. These accidents are to be prevented through better design and appropriate operations[41, 42, 43].

3.2. Assessing frequency or rate of accidents

The number of foremost process accidents happened for the period 1998-2015 is shown in Table 3. Figure 3 shows the frequency or rate of accidents occurred across the world. A total number of 70 accidents are taken place from 1998 to 2015.The highest number of accidents raised in the year 1999, 2001, and 2008 are 6, 12, and 6 respectively. However, no accidents transpire in the year 2002. The frequency or average rate of accidents are observed 4 per year.Furthermore, the accidents are declining from the year 2012; probably, it may be due implementation of strict legislation, public awareness and safety regulations.

Table 3. Number of accidents, deaths and injuries in the period 1998-2015

S. No	Year	Number of Accidents	Number of Deaths	Number of Injury
1	1998	5	1003	8
2	1999	6	8	78
3	2000	5	274	1065
4	2001	12	41	3440
5	2002	0	0	0
6	2003	5	5	12
7	2004	5	56	430
8	2005	3	23	273
9	2006	4	260	62
10	2007	2	5	87
11	2008	6	91	125
12	2009	1	12	150
13	2010	3	34	154
14	2011	2	3	0
15	2012	4	29	8
16	2013	4	81	411
17	2014	2	146	114
18	2015	1	6	0
Total		**70**	**2077**	**6417**

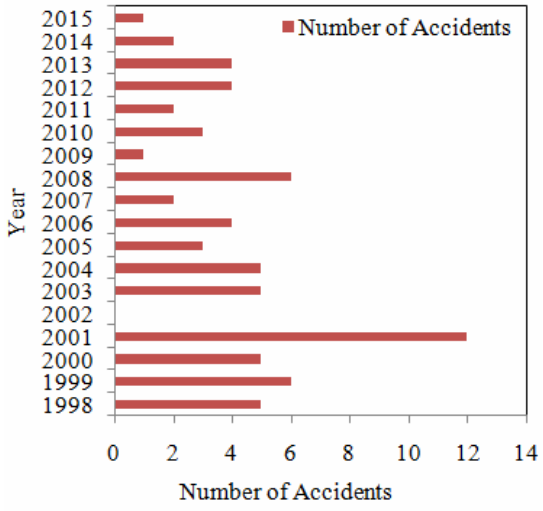

Figure 3. Rate of accidents per year

Figure 4 shows the number of major process accidents from 1998 to 2015 in developed and developing countries. The USA, China and UK having more number of process accidents are 15, 11, and 5 respectively. Hence, the proportional share of accidents is also high in these countries. From the Figure 4, it is observed that, the number of accidents is more in developed countries than in developing countries.

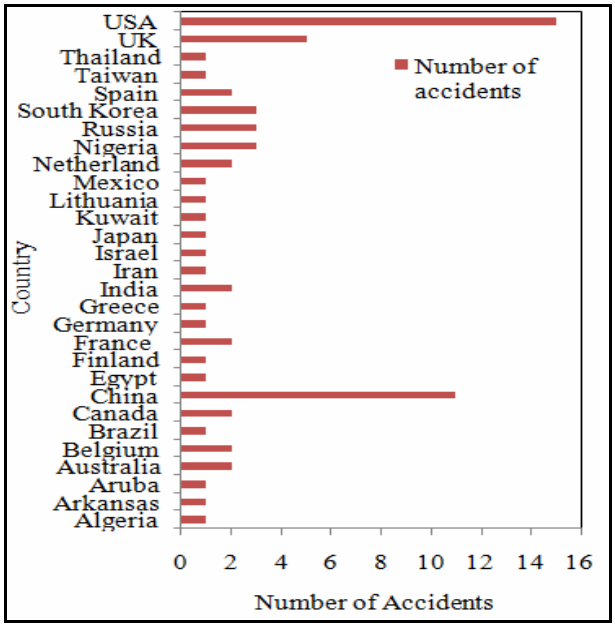

Figure 4. Number of accidents in developed and developing countries per year

3.3. Assessing rate of Deaths and Injuries

Figure 5 shows the rate of deaths and injuries taken place due to process accidents in each year from the period 1998-2015. The large number of deaths appeared in the years 1998, 2000, 2006 and 2014 are 1003,274,260 and 146 respectively. A large number of injuries are appeared in the years 2000, 2001, 2004 and 2013 are 1065, 3440, 430 and 411 respectively. The average rate of deaths and injuries are observed as 115 and 356 per year. It clearly indicates that the rate of injuries is three times to the rate of death rate for the period 1998-2015. However, neither deaths nor injuries are appeared in the year 2002; probably, this is due to the impact of accidents in the previous year's 1998, 2000 and 2001.

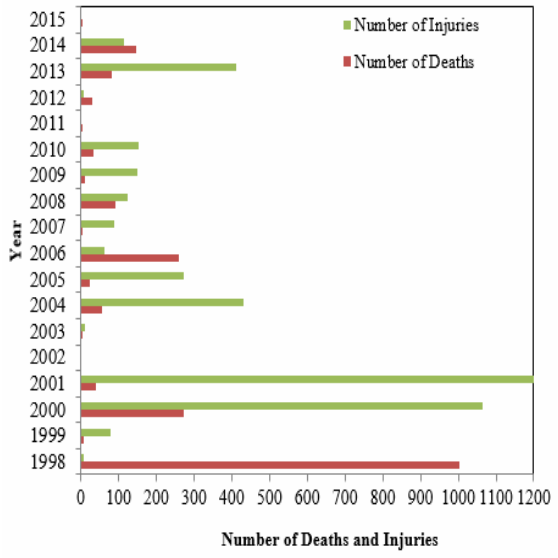

Figure 5. Rate of deaths and injuries per year in the period 1998-2015

The number of deaths and injuries happened due to process accidents in the developed and developing countries in each year from the period 1998-2015 is shown in Table 4 and Figure 6: A large number of deaths appeared in the Nigeria, China and Algeria are 1510, 288 and 74 respectively. The highest number of injuries is appeared in the France, Netherland, USA, China and UK are 3000,946,811,604 and 270 respectively. It implicates that, the countries follows poor maintenance in process safety and safety regulations in the events of process accidents. However, neither deaths nor injuries appeared in the Arkansas, Aruba, Egypt, Greece, Japan, Mexico and Spain.

Table 4. Number of deaths and injuries in developed and developing countries

S.No	Country	Number of accidents	Number of Deaths	Number of Injuries
1	Algeria	1	23	74
2	Arkansas	1	0	0
3	Aruba	1	0	0
4	Australia	2	2	8
5	Belgium	2	26	132
6	Brazil	1	10	0
7	Canada	2	1	15
8	China	11	288	604
9	Egypt	1	0	0
10	Finland	1	3	0
11	France	2	30	3000
12	Germany	1	0	50
13	Greece	1	0	0
14	India	2	12	150
15	Iran	1	30	38
16	Israel	1	0	7
17	Japan	1	0	0
18	Kuwait	1	5	50
19	Lithuania	1	2	12
20	Mexico	1	0	0
21	Netherland	2	18	946
22	Nigeria	3	1510	60
23	Russia	3	1	47
24	South Korea	3	51	18
25	Spain	2	0	0
26	Taiwan	1	1	112
27	Thailand	1	8	13
28	UK	5	9	270
29	USA	15	47	811
Total		**70**	**2077**	**6417**

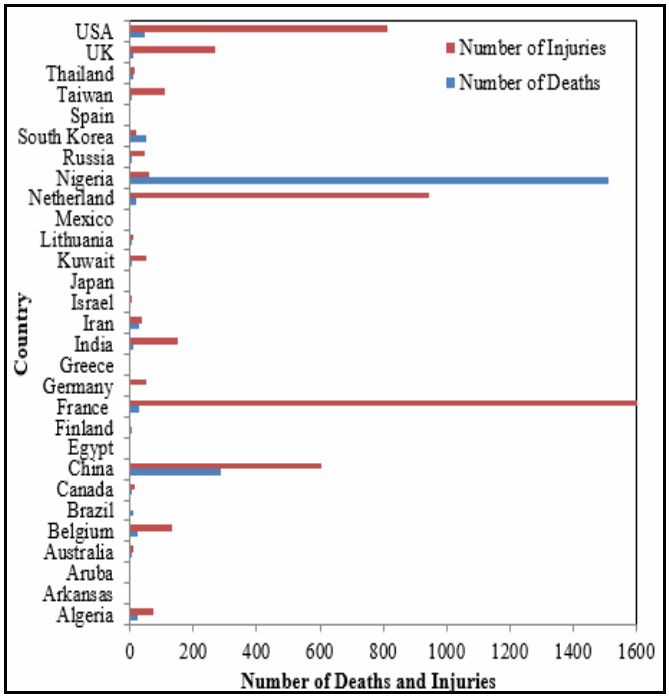

Figure 6. Number of deaths and injuries in developed and developing countries

3.4.Top ten countries with highest number of deaths and injuries

Figure 7 shows the top 10 countries with highest number of deaths in developed and developing countries. The deaths listed in the countries namely Nigeria, China, South Korea, USA, France, Iran, Belgium, Algeria, Netherland and India are 1510, 288, 51, 47, 30, 30, 26, 23, 18 and 12 respectively. Figure 8 shows the large number of injuries appeared in top 10 countries. The injuries in the countries namely France, Netherland, USA, China, UK, India, Belgium, Taiwan, Algeria and Nigeria are 3000, 946, 811, 604, 270, 150, 132, 112, 74 and 60 respectively. A largest number of people killed in Nigeria are 1510 with a huge sudden explosion of gasoline occurred in the recovery of gasoline process and second in the China are 258 followed by various process accidents. 3000 people are injured in France due to a huge explosion occurred in the manufacturing process of ammonium nitrate, which is a highly explosive in nature. A mysterious explosion occurred at the chemical factory in Netherland, around 1000 people are injured, but the causes of the explosion are not reported in the international database and media.

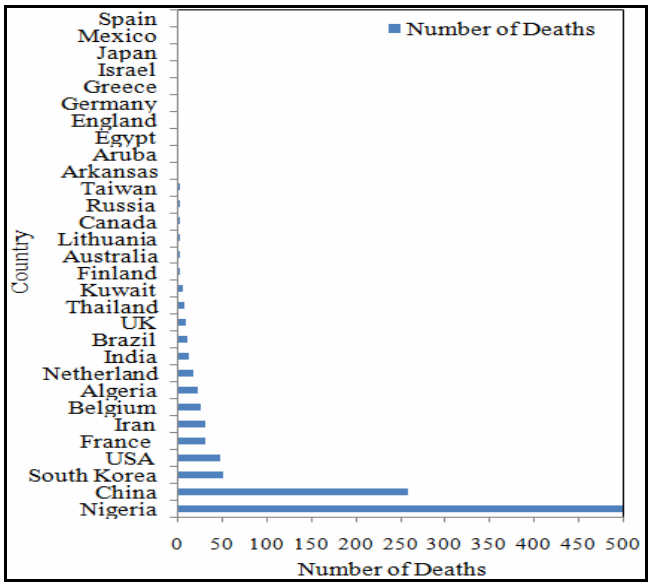

Figure 7. Top 10 countries with highest number of deaths in developed and developing countries

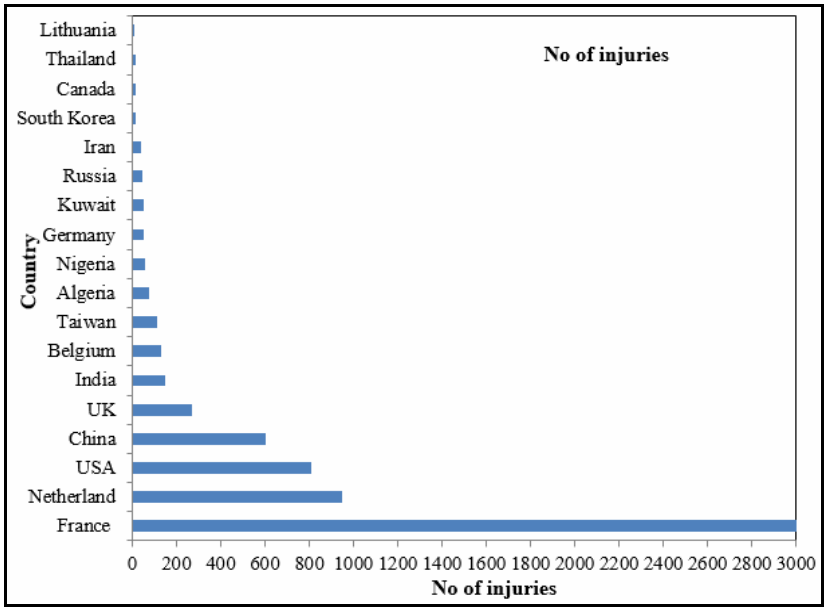

Figure 8. Top 10 countries with highest number of injuries in developed and developing countries

3.5. Identifying the number of deaths and injuries in developed countries

Table 5 shows the number of deaths and injuries happened due to process accidents in the developed countries are shown from the period 1998-2015. The highest numbers of deaths appeared in the South Korea, USA, France and Belgium are 51, 47, 30 and 26 respectively. The highest numbers of injuries appeared in the countries France, Netherland, USA and UK are 3000, 946, 811 and 270 respectively. The average deaths and injuries are observed as 5 and 130 per country in developed countries. It implicates that, these countries are under poor maintenance in process safety and safety regulations in the events of process accidents. However, neither deaths nor injuries are observed in the Greece, Japan and Spain. It reflects that, the developed countries follow robust safety process systems and safety guidelines particularly in the event of accidents.

Table 5. Number of deaths and injuries in developed countries for the period 1998-2015

S.No	Developed Countries	Number of Accidents	Number of Deaths	Number of Injuries
1	Australia	2	2	8
2	Belgium	2	26	132
3	Canada	2	1	15
4	Finland	1	3	0
5	France	2	30	3000
6	Germany	1	0	50
7	Greece	1	0	0
8	Israel	1	0	7
9	Japan	1	0	0
10	Netherland	2	18	946
11	South Korea	3	51	18
12	Spain	2	0	0
13	Taiwan	1	1	112
14	UK	5	9	270
15	USA	15	47	811
Total		**41**	**188**	**5369**

3.6. Identifying number of deaths and injuries in developing countries

The number of deaths and injuries happened due to process accidents in the developing countries for the period 1998-2015 is shown in Table 6. The highest number of deaths appeared in the countries China and Iran are 288 and 30 respectively. The highest number of injuries appeared in the countries China, India, Kuwait and Russia are 604, 150, 50, and 47 respectively. It is observed that, the countries China and Nigeria having more number of deaths and injuries than other developing countries. The average deaths and injuries are observed as 65 and 36 per country in developing countries. However, the numbers of deaths considerably less and numbers of injuries are more in developed countries than developing countries. It reflects that better process safety and robust enforcement of safety regulatory legislation need to follow in developed countries. Even so, number of deaths are considerably more in developing countries, because these countries are follows poor maintenance in process safety, safety regulations and lack of public awareness in the events of process accidents. Although, neither deaths nor injuries observed in the developing countries are Aruba, Egypt and Mexico.

Table 6. Number of deaths and injuries in developing countries in the period 1998-2015

S.No	Developing countries	Number of Accidents	Number of Deaths	Number of Injuries
1	Algeria	1	23	74
2	Arkansas	1	0	0
3	Aruba	1	0	0
4	Brazil	1	10	0
5	China	11	288	604
6	Egypt	1	0	0
7	India	2	12	150
8	Iran	1	30	38
9	Kuwait	1	5	50
10	Lithuania	1	2	12
11	Mexico	1	0	0
12	Nigeria	3	1510	60
13	Russia	3	1	47
14	Thailand	1	8	13
Total		**29**	**1889**	**1048**

4. Causes of Process Accidents

4.1. Identifying the primary causes of process accidents

The primary causes of process accidents in developing and developed countries are shown in Figure 9. The highest number of process accidents concerned with explosion in developed and developing countries are 23 and 20 respectively. Second highest number of accidents concerned with fire in developed and developing countries are 12 and 5 respectively. Additionally, less number of accidents concerned with other primary causes of toxic release, explosion associated with fire.

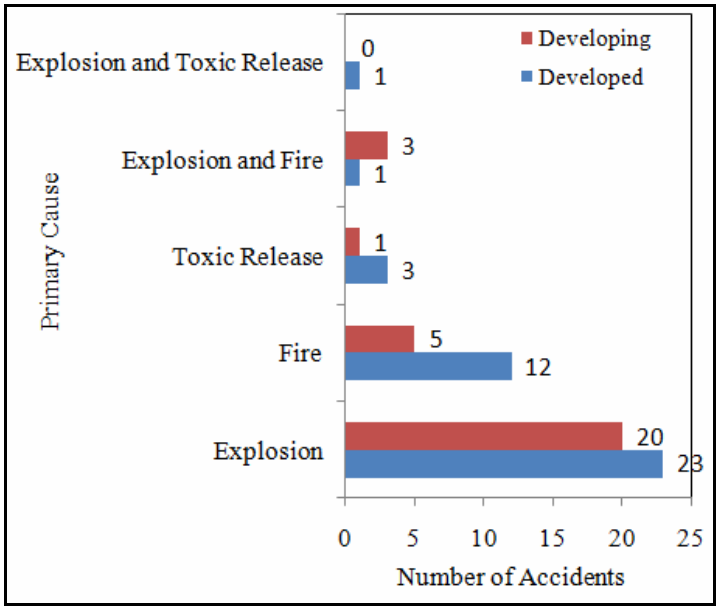

Figure 9. Primary causes of process accidents

From Figure 10, it is clearly indicated that, inthe developed and developing countries, most of the accidents are concerned with massive explosion and fire around 63% and 25% respectively.It is observed that, in developed countries, the process dynamics and control failed in controlling process that results in sudden explosion and fire.

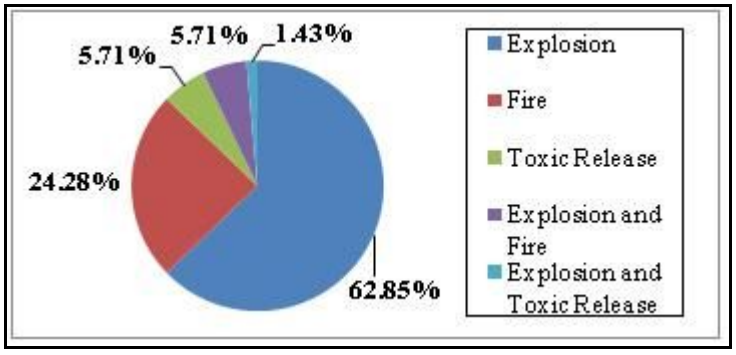

Figure 10. Primary causes of process accidents with % wise

4.2. Identifying the chemical causes the process accidents

Figure 11 shows the chemical causes of process accidents due to hydrocarbons, toxic chemicals and others in developed and developing countries. The most of process accidents are concerned with hydrocarbons (such as organic solvents, oils and natural gases, etc.) in developed and developing countries are 21 and 17 respectively. Furthermore, the process accidents are concerned with toxic chemical releases such as ammonium gas, radioactive gases, organic, inorganic acids and metallic dust (Arsenic, Iron, Aluminum etc.). Besides, a few number of accidents concerned with others such as steam pipe line blast and equipment related.

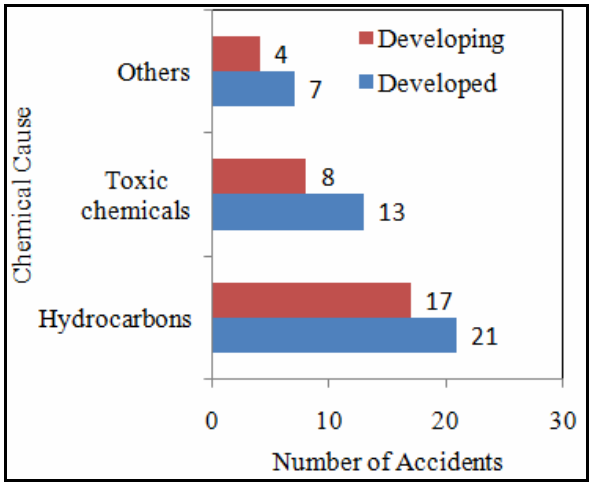

Figure 11. Major Chemicals causes of process accidents

From the Figure 12, it is revealed that, 55% and 30% of the accidents are concerned with hydrocarbons and toxic chemicals. Other accidents are related to the failure in the process equipment, steam lines and some of the chemical cause data is not available in the database.

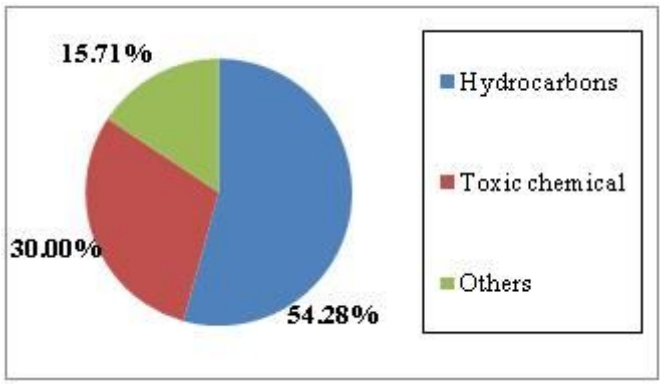

Figure 12. Major Chemicals causes of process accidents

5. Conclusion

According to the process accidental analysis for the period 1998-2015, the numbers of process accidents are more in developed countries than in developing countries.The number of deaths considerably less and number of injuries are more in developed countries than developing countries. Besides, numbers of deaths are considerably more in developing countries than developed ones. From the observations, it is revealed that the most of the accidents concerned with hydrocarbons and toxic chemicals are 55% and 30% respectively. Furthermore, around 63% and 25% of accidents are concerned with explosions and fire due to flammability and explosive nature of hydrocarbons.Therefore better process safety and robust enforcement of safety regulatory legislation need to be required in developed countries.The present investigation is useful to develop the prevention and mitigation strategies for controlling the process failures particularly dealing with highly flammable chemicals such as hydrocarbons and toxic chemicals in the process industries.

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