A case study of electrostatic accidents in the process of oil-gas storage and transportation

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Abstract. Ninety nine electrostatic accidents were reviewed, based on information collected from published literature. All the accidents over the last 30 years occurred during the process of oil-gas storage and transportation. Statistical analysis of these accidents was performed based on the type of complex conditions where accidents occurred, type of tanks and contents, and type of accidents. It is shown that about 85% of the accidents occurred in tank farms, gas stations or petroleum refineries, and 96% of the accidents included fire or explosion. The fishbone diagram was used to summarize the effects and the causes of the effects. The results show that three major reasons were responsible for accidents, including improper operation during loading and unloading oil, poor grounding and static electricity on human bodies, which accounted for 29%, 24% and 13% of the accidents, respectively. Safety actions are suggested to help operating engineers to handle similar situations in the future.

1. Introduction
Oil and gas are flammable and explosive, respectively. A small accident occurred in the process of oil-gas storage and transportation may lead to million-dollar property loss and a few days of production interruption, and a large accident can result in lawsuits, stock devaluation, or company bankruptcy. There are many causes for the accident, an important one of which is involved in static electricity. In order to prevent electrostatic accidents and to mitigate their consequences, many strict engineering guidelines and standards for the control of static electricity in industry have been published by trade organizations and engineering societies [1]. Though most companies have followed those standards and guidelines, electrostatic accidents still occurred in oil and gas industry. Therefore, it is of great significance to learn from the history for the future safe operation of oil-gas storage and transportation.

The purpose of this paper is to categorize the causes that lead to 99 electrostatic accidents occurred in the process of oil-gas storage and transportation in last 30 years, and to reduce potential hazards associated with static electricity. The fishbone diagram [2] is used to summarize the effects and the causes that create or contribute to those electrostatic accidents.

2. Overall statistics
The 99 electrostatic accidents were reviewed on the information collected from published paper-based
literature [3-11] and web reports in this paper, which occurred in the process of oil-gas storage and transportation over last 30 years. As indicated in table 1, accidents occurred more frequently at gas stations with 45 cases (45.4%). The second most frequently involved place was tank farms (28 cases, 28.3%). About 27.3% of accidents happened in petroleum refineries (11.1%), petrochemical plants (6.1%), oil fields (1.0%), and other types of industrial facilities (8.1%) such as gas plants, pipelines. The atmospheric external floating roof tank was the most frequent type and the inner floating roof storage tank was the second most frequent type as could be seen in table 2. Both types were used extensively for the storage of crude oil and oil products such as gasoline, diesel, fuel oil, etc. Table 3 showed that fire was the most frequent type of loss with 51 cases, and explosion was the second most frequent type of loss with 44 cases. In other words, fire and explosion together accounted for 96% of total cases.

Table 1. Type of complex where accidents occurred.

| Year     | Refinery | Tank farm | Chemical plant | Oil field | Gas station | Misc | Total |
|----------|----------|-----------|----------------|----------|-------------|------|-------|
| 1980-1989| 7        | 15        | 1              | 1        | 9           | 1    | 34    |
| 1990-1999| 3        | 2         | 2              | 0        | 14          | 4    | 25    |
| 2000-2009| 1        | 7         | 2              | 0        | 21          | 3    | 34    |
| 2010-2012| 0        | 4         | 1              | 0        | 1           | 0    | 6     |
| Total    | 11       | 28        | 6              | 1        | 45          | 8    | 99    |

Table 2. Type of tanks and contents.

| Content          | External floating top | Cone top | Sphere | Cone roof internal floating top | Refrigerated tank | Submerged tank | Fiber glass | Subtotal |
|------------------|------------------------|----------|--------|---------------------------------|-------------------|----------------|-------------|----------|
| Crude oil        | 4                      | 1        | 0      | 11                              | 0                 | 5              | 2           | 23       |
| Oil products     | 10                     | 3        | 0      | 4                               | 0                 | 4              | 1           | 22       |
| Gasoline         | 13                     | 0        | 0      | 3                               | 0                 | 0              | 0           | 16       |
| LGP              | 0                      | 0        | 7      | 0                               | 1                 | 0              | 0           | 8        |
| Subtotal         | 27                     | 4        | 7      | 18                              | 1                 | 9              | 3           | 69       |

Table 3. Type of accidents.

| Year     | Fire | Explosion | Spill | Misc | Total |
|----------|------|-----------|-------|------|-------|
| 1980-1989| 18   | 14        | 1     | 1    | 34    |
| 1990-1999| 14   | 10        | 1     | 0    | 25    |
| 2000-2009| 16   | 17        | 1     | 0    | 34    |
| 2010-2012| 3    | 3         | 0     | 0    | 6     |
| Total    | 51   | 44        | 3     | 1    | 99    |

3. Causes of accidents

As indicated in table 4, improper operation during loading and unloading oil was the most frequent cause of accidents, and poor grounding and static electricity on human bodies were the second and the third most frequent causes. The rest was the materials of oil and gas containers, different mix of oils, storage tank fault, etc. To illustrate causes and effects, a fishbone diagram is shown in figure 1.
Table 4. Cause of electrostatic accidents.

| Year          | 1980-1989 | 1990-1999 | 2000-2009 | 2010-2012 | Total |
|---------------|-----------|-----------|-----------|-----------|-------|
| Improper operation during loading and unloading oil | 7         | 6         | 16        | 0         | 29    |
| Poor grounding                                       | 6         | 8         | 10        | 0         | 24    |
| Static electricity on human body                     | 5         | 2         | 5         | 1         | 13    |
| Materials of oil and gas containers                  | 5         | 5         | 2         | 0         | 12    |
| Different mix of oils                                | 3         | 3         | 3         | 1         | 10    |
| Storage tank fault                                  | 3         | 1         | 2         | 0         | 6     |
| Misc                                                   | 3         | 1         | 1         | 0         | 5     |
| Total                                                  | 32        | 26        | 39        | 2         | 99    |

3.1. Improper operation during loading and unloading oil

29 electrostatic accidents were caused by improper operation during loading and unloading oil. Among the 29 cases, loading and unloading oil by spitting is responsible for 15 accidents. In general, loading and unloading oil by spitting will make the liquid that ejects from the nozzle split into many small droplets. When the droplets are in contact with air, an electronic rearrangement occurs to minimize the energy at the interface. Since this process is generally not reversible, charge separation occurs when contact is lost between the surfaces. If the interface is disrupted at a rate faster than equilibrium conditions, additional charge separation will occur. Moreover, the position of the pipeline export will also affect the generation and accumulation of electrostatic charge when oil flows into the tanks or other containers. For example, on July 22, 1996 in a petroleum chemical plant, a fire happened and spread to other areas when a worker begun loading with putting the crane tube into the tank with good static grounding. Surv ey data showed that the vertical height from the mouth of crane tube to the bottom of tank was 1.19 m. Huge amounts of electrostatic charge was built up by the impact and splash during the oil falling, and then discharge detonated the oil vapor.

Too fast flow rate of oil is the second frequent cause in this category. Electrostatic hazards arise during oil and gas transporting when charge separation occurs and leads to an accumulation of one
sign of charge within some defined boundary, such as inside a pipeline. When oil flow velocity is too fast, there also can be significant charge accumulation, even to the point where incendive discharge can occur. In 1982, Venezuela in the northern part of Latin America, the Caribbean coast, a group of tanks blew up to an oil fire while unloading crude oil to storage tanks. The fire lasted for 4 days. There were 145 workers died and more than 500 people injured in this incident. The investigation proved that this accident was caused by the discharge of static spark resulted from too fast flow rate of oil. In consideration of that, the faster liquid flow velocity is, the easier static electricity produces, the oil flow must keep within the speed limit. For example, if the pipe is less than 150 mm in diameter, the flow velocity of gasoline, kerosene and other light oil should be restricted below 3 to 4 ms⁻¹, and that of the heavy oil should be restricted below 7ms⁻¹.

3.2. Poor grounding
There are two major causes of poor grounding related electrostatic accidents. The first one is no installation of static grounding wire, and the second is damage or open of grounding wire. Among 24 poor grounding accidents, some storage tanks are directly ignited by the discharge of static electricity. An explosion to a tank car containing gasoline on October 2, 2000 in Hubei resulted in 4 casualties and property damages of 3 million dollars. Investigations showed that this gas station was in violation of the norms of anti-static operation, and not installed static grounding device as required. In 1997 a accident happened during cargo oil transferring operations in Yangtze River, a tanker and three barges destroyed by fire, and nearly ten thousand tons of crude oil spilled. The cause of accident was that the rope of sampler did not conduct electricity, so the static charges gathered on the rope.

3.3. Static electricity on human body
The clothing of the staff is the most frequent cause in this category. Among the 13 cases, no use of anti-static clothing is responsible for 10 accidents. An accident in 1987 at a cave oil depot, in Liaoning of China, was caused by the ignition of static electricity on human bodys during instrument maintenance. 8 workers were killed, and 12 workers were injured in this explosion. In 2002, an explosion occurred while a worker wearing synthetic clothes was refueling a car in a gas station. The electrostatic discharge generated by human bodys is one of the important reasons for static ignition hazards, so operating personnel must wear anti-static clothing and must touch grounding body to remove static electricity when stepping into a potentially dangerous place with regard to explosions.

3.4. Materials of oil and gas containers
The cause of 12 out of 99 electrostatic accidents was the inappropriate materials of oil and gas containers. Loading oil with plastic barrel is the most frequent cause in this category. In 1999 an accident, a fire broke out at a gas station when a refueling worker was filling a plastic bucket with gasoline. A Jeep car, two computer tankers and many other auxiliary facilities burned down in the accident.

3.5. Different mix of oils
Transitional loading of oil and mixture of oil-gas and air are responsible for 40% and 30% of this category, respectively. Impurities settlement and oil-water mixture are in total responsible for the remaining 30%. When the oil contains water or different oil or gas with air, the amount of static electricity generated will increase [12]. The experiment proved that if water content in oil is 5%, it can make the electrostatic effects increase 10-50 times. In 1987, when the diesel fuel was filled into an empty gasoline tanker in an oil loading station, the tanker burst into flames. The accident survey indicated that the fire was caused by static electricity during the tanker transitional loading.

4. Conclusion
The information of 99 electrostatic accidents occurred in the process of oil-gas storage and transportation in last 30 years was reviewed. Based on this statistical data, this paper has expressed the
causes and the contributing failures that led to these accidents with a fishbone diagram. Static electricity is a real and important cause of fires and explosions associated with oil and gas operations. Therefore, electrostatic hazards must be given proper consideration and effectively guarded against in the storage and transportation process of oil and gas. Thus, most of those electrostatic accidents could be avoided if good engineering in operation was practiced and safety management program was implemented effectively.

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