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Chemical Risk Assessment for Urea-Ammonia Production Plant

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Abstract

Nitrogen fertilizers are considered one of the most important chemical industries in the twenty-first century, due to their great use in agriculture. Increasing yields, this led to a great abundance of yield and contributed significantly to the abundance of global food. Most chemicals which are used in these factories are hazardous to health and may cause fire or explosion. The evaluation of the potential risks in these production units and the means of prevention and treatment are one of the most important axes discussed in this article. Improving safety aspects, including increasing culture and awareness, are one of the most important ways to prevent accidents.

Keywords: Nitrogen fertilizers • Urea • Ammonia • Natural gas • Hazard

Introduction

Urea fertilizer accounts for about 55% of total nitrogen production in the world. It is one of the most widely used nitrogen fertilizers. The current urea production capacity is around 208 million tons [1]. Urea fertilizer plant generally consists of ammonia and urea plants. In order to be sustainable, new factories adopt more integrated and compact unit operations, which require detailed in safety technology.

Several accidents have been reported at ammonia and urea plants in the past twenty years, and some major accidents have occurred in the past ten years. These accidents occurred in countries like India, Bangladesh and China as well as in United Kingdom and United States of America. On March 21, 2005, in a fertilizer plant in Pingyin County, Shandong Province, a urea synthesis reactor exploded (Figure 1). The explosion killed four peoples and 32seriously injured peoples, raising the direct economic losses to about 4.3 million dollars [2]. Other accidents include a fire and explosion caused by a mixture of hydrogen, nitrogen and ammonia at the Terra Nitrogen Plant, UK (Figure 2). On June 1st, 2006, due to pipeline failure; an ammonia container exploded at the Vatva Ammonia Plant, India, on April 12, 2010, due to high temperature, pressure build-up [3,4].

Methodology

In ammonia plant, most accidents are due to the release of ammonia. However, the possibility of explosion or fire related accidents where natural gas and hydrogen are present in high pressure units cannot be neglected. By looking at some of the physical properties of hydrogen gas, such as (flammability range and minimum ignition energy), the degree of danger of this gas can be visualized in terms of the wide range of flammability range (Figure 3) and the small need for energy required to ignite hydrogen as shown in Figure 4 [5]. Therefore, this data must be taken into consideration in hydrogen handling and all safety measures should be taken to prevent accidents.

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In urea manufacturing plant, most accidents are due to possibility of ammonia release as well as explosion due to formation of explosive gaseous mixture of oxygen and hydrogen in units like urea reactor, carbon dioxide gas purifier etc. Through corrosion, or runaway reaction [6-10]. Other factors involved are failure of pipes, improved valves, etc. [11-13].

Ammonia is manufactured in three basic process steps: High pressure catalytic reforming of natural gas, Purification of gases and Ammonia synthesis. The first two steps involve the production of hydrogen gas, the introduction of nitrogen in stoichiometric proportion and the removal of carbon dioxide, carbon monoxide and water, which are catalyst poisons. Ammonia synthesis involves the catalytic fixation of nitrogen at elevated temperature and pressure and the recovery of ammonia.

Figure 1. Urea synthesis reactor exploded in a fertilizer plant in Pingyin County.

Figure 2. Fire and explosion due to a mixture of hydrogen, nitrogen and ammonia at the Terra Nitrogen Plant, UK.

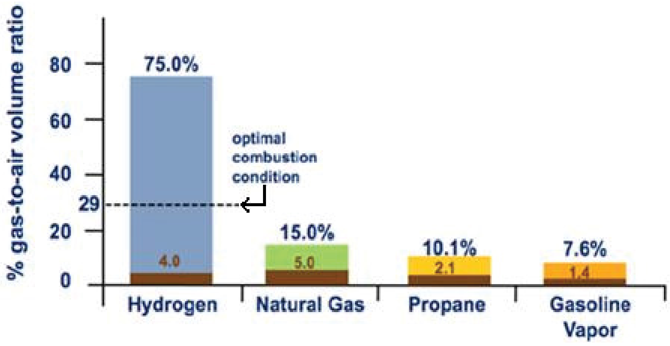

Figure 3. Flammability range of hydrogen.

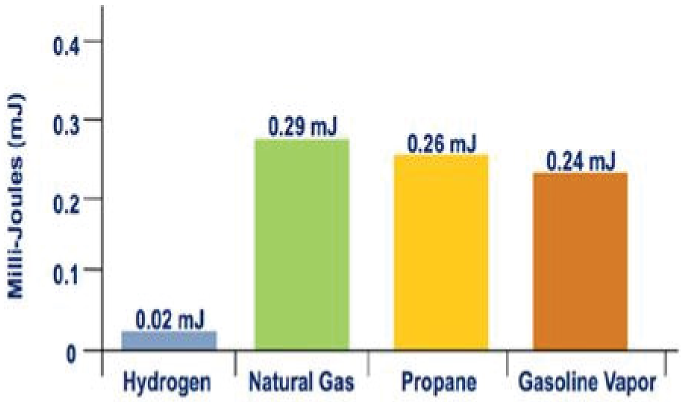

Figure 4. Energy required to ignite hydrogen.

Urea is produced from liquid ammonia and gaseous carbon dioxide at about 170-190°C and 13.5-14.5 MPa according to the following reactions:

$$2\ NH_3 + CO_2 == NH_2\ CO_2\ NH_4 \quad (1)$$

$$NH_2.CO.ONH_4 == NH_2.CO.NH_2 + H_2O \quad (2)$$

In the first reaction the carbon dioxide is converted into ammonium carbamate; the reaction is fast and exothermic. In the second reaction the ammonium carbamate decomposes to form urea and water. This second reaction is slow and endothermic. About 60% conversion of CO_2 into urea is obtained.

The reaction mixture then flows to a series of decomposers where the pressure is reduced and unconverted ammonium carbamate is decomposed by heat. The resulting ammonia and carbon dioxide, as well as the excess of ammonia originally charged, are ultimately recycled. The urea solution is concentrated by flash evaporation and pumped to the granulation section where solid granules are produced in a fluidized bed [14].

Results and Discussion

Major hazards

The ammonia industry is a type of industry which classified as a major hazard which consists of chemical leaks, fires and explosions. Fires are the most alarming danger compared to other major hazards [15]. The source of fires and explosions in ammonia industry are generally raw materials in the form of natural gas that is flammable and its process units use high temperatures and pressures. The stage of the ammonia plant process that most frequently fails is the reformer process unit, particularly the secondary reformer. Secondary reformer is one of the stages of the ammonia plant process with a flame temperature reaching 1200°C to convert methane (CH_4) to Hydrogen (H_2).

One of the causes of secondary reformer work failure is the failure of the catalyst function within the secondary reformer itself. This catalyst serves to accelerate chemical reactions that occur inside this reformer. The non-functioning catalyst may increase the secondary reformer temperature so that it has the potential to explode [16-20]. Hazard statements and precautionary statements for the main hazardous substances in the plant illustrated in Tables 1-4 for natural gas, hydrogen, ammonia and carbon dioxide respectively. The objectives of the Risk Assessment study are to identify all potential failure cases, which might affect the population and property in the vicinity of the facilities, and provide information necessary in developing strategies to prevent accidents and formulate the disaster management plan [21].

A major explosion ripped through an ammonia-urea plant in the Namrup-2 unit of the Brahmaputra Valley Fertilizer Corporation Limited (BVFCL). On January, 2020 (Figure 5) the blast destroyed several machines and caused extensive damage. However, no casualties have been reported. An official of the plant said, there is a blast in the factory but no workers have been injured. The plant might be shut down for an indefinite time for repairing. Researchers have multiple articles reviewing cases and accidents in various and varied sites [22,23].

Table 1. Hazard and precautionary statements for natural gas in the plant.

Hazard Statements	Precautionary Statements	GHS Label Elements	Ref.
Extremely flammable gas	Keep away from open flames, heat, sparks and hot surfaces.		[17]
May explode if heated	No smoking		
May cause damage to central nervous and respiratory systems	Do not breathe fume, gas, mist, vapors and spray.		
	Do not eat, drink or smoke when using this product.		

Table 2. Hazard and precautionary statements for ammonia in the plant.

Hazard Statements	Precautionary Statements	GHS Label Elements	Ref.
Extremely flammable gas.	Keep away from heat, hot surfaces, sparks, open flames and other ignition sources.		[18]
Contains gas under pressure.			
May explode if heated.			
May displace oxygen and cause rapid suffocation.	No smoking		
Burns with invisible flame.			
May form explosive mixtures with air			

Table 3. Hazard and precautionary statements for ammonia in the plant.

Hazard Statements	Precautionary Statements	GHS Label Elements	Ref.
May form explosive mixtures with air.	Close valve after each use and when empty.	 	[19]
Contains gas under pressure; may explode if heated.	Use equipment rated for cylinder pressure.		
May displace oxygen and cause rapid suffocation.	Do not open valve until connected to equipment prepared for use.		
Harmful if inhaled.	Use a back flow preventative device in the piping.	 	
Causes severe skin burns and eye damage.	Use only equipment of compatible materials of construction.		
Very toxic to aquatic life.	Always keep container in upright position.		
	Approach suspected leak area with caution.		

Table 4. Hazard and precautionary statements for carbon dioxide in the plant.

Hazard Statements	Precautionary Statements	GHS Label Elements	Ref.
Contains gas under pressure.	Close valve after each use and when empty.		[20]
May explode if heated.	Use equipment rated for cylinder pressure.		
May displace oxygen and cause rapid suffocation.	Do not open valve until connected to equipment prepared for use.		
May increase respiration and heart rate	Use a back flow preventative device in the piping.		
	Use only equipment of compatible materials of construction.		
	Always keep container in upright position.		

Figure 5. A major explosion ripped through an ammonia-urea factory in the Namrup-2 unit.

Conclusion

The ammonia-urea production plant is considered one of the important factories that benefit the increase in global food production. The materials used in these production units are considered hazardous due to toxicity and explosion. Globally several accidents have been reported at ammonia and urea plants in the past twenty years. The accidents were due to handling of dangerous materials in dangerous working conditions in terms of high temperatures and pressures. The main and important way to avoid accidents in this plant is to follow safety instructions and risk assessment procedures. Educating workers about the nature of risks will certainly help to put the factory in a safe working condition.

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