RISK ASSESSMENT OF GÖRDES NICKEL-COBALT PROCESS PLANT

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RISK ASSESSMENT OF GÖRDES NICKEL-COBALT PROCESS PLANT

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

RISK ASSESSMENT OF GÖRDES NICKEL-COBALT PROCESS PLANT

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High pressure acid leach (HPAL) is commonly utilized hydrometallurgical process for low grade laterites for the extraction of nickel and cobalt. The plant malfunctions bring about catastrophic accidents that prove the irreversible effects on human life, society, environment and economy. Identification of hazards is one of most important study for the risk assessment. Thus, investigating and reducing the probability of hazards and risks and inhibition of such accidents is very crucial for community and firms. In this study, the risk assessment of the Gördes Nickel–Cobalt process plant was performed. The plant is a huge construction and has complex working mechanism intrinsically can result in serious work accidents.

This study was aimed at investigating the possible hazards and risks to construct risk assessment to contribute to develop risk assessment plans and risk management strategies for the plant operations and mine site. Firstly, system's working principle was searched. Determination of possible hazards at units, estimation probability and severity of results caused by hazards and decision making of acceptable risk levels, elimination of risk or planning actions for decreasing the risk in terms of suitable safeguards and recommendations based on engineering judgement and previous data was done. In addition, accident data of five years (2014-2018) was investigated in order to determine the critical nodes of process plant, jobs, working hours *etc.*

As a result of the present study, the most risky area is HPAL that employees had accident mostly at HPAL area by 10.65 percent due to the unacceptable level of risk inherent in its operation. Unacceptable level of risk in the process plant can be decreased by level, flow, pressure, temperature monitoring, control valve, secondary containment, interlock system, spare pump, level alarm *etc.* Accident statistics shows that the almost all accidents can be prevented by proper training, development of safety culture and administrative arrangement.

This study can contribute to the integration of the occupational health and safety management system with quality, environmental, financial management systems, and sustainability of the whole system. This process plant has been unique for Turkey, thereby risk assessment's analysis may be a reference for similar plants to be constructed in future. In addition, accident analysis of the process plant can help to focus on risky working areas and conditions, thus the accident prevention techniques and appropriate trainings can be developed in terms of the results of the analyses.

Keywords: High Pressure Acid Leaching, Risk Assessment, Hazard Identification, Risk Management

ÖZ

GÖRDES NİKEL KOBALT PROSES TESİSİNDE YAPILAN RİSK DEĞERLENDİRMESİ

Torun Bilgiç, Elif
Yüksek Lisans, Maden Mühendisliği
Tez Danışmanı: Prof. Dr. Nuray Demirel

Eylül 2019, 140 sayfa

Yüksek basınçlı asit liçi (YBAL) proses tesisi çoğunlukla düşük tenörlü laterit cevherler için kullanılan bir yöntemdir. Bu proses tesisi, doğası gereği karışık bir çalışma sistemine sahip olduğu için ciddi iş kazalarına sebep olabilir. Proseste yaşanan bazı arızalar, insan hayatı, toplum, çevre ve ekonomi üzerinde geri döndürülemez, yıkıcı etkilere yol açmaktadır. Tehlike tanımlaması, risk değerlendirme çalışması için ön önemli adımlardan biridir. Bu nedenle, tehlike ve risklerin araştırılıp, oluşma ihtimalini azaltmak ve bu tip ciddi kazaları önlemek firma ve toplum için çok önemlidir. Bu yüksek lisans tez çalışmasında Gördes Nikel-Kobalt cevher hazırlama tesisinin risk değerlendirmesi yapılmıştır.

Bu çalışma, proses tesisindeki potansiyel tehlike ve risklerin araştırılması ve sonucunda risk değerlendirme yapılmasını amaçlamaktadır. Bu risk değerlendirmesi, tesisin risk değerlendirme planları ve risk yönetim stratejilerini geliştirmeye katkı sağlayacaktır. Öncelikle, sistemin çalışma prensibi üzerine araştırma yapılacak, ünitelerde oluşabilecek tehlikelerin belirlenmesi, tehlikelerden kaynaklanan sonuçların mühendislik hükümlerine ve önceki çalışmalara dayanarak olasılık ve şiddetinin tahmin edilmesi ve riskin kabul edilebilirliğine karar verilmesi, riski

ortadan kaldırmak ya da azaltmak için önlem ve tavsiyeleri planlamak için çalışma yapılmıştır. Ayrıca, 2014-2018 yılları arasında gerçekleşen kazalarda üretim bölgesi, meslek ve çalışma saatleri gibi parametreler incelenerek dikkat edilmesi gereken konular saptanmıştır.

Bu çalışmanın sonucunda, YBAL bölgesinin doğası gereği en riskli bölge olduğu ve tesisteki kabul edilemez derecedeki risklerin, seviye, akış, basınç, sıcaklık takip sistemi, kontrol vanası, tali güvenlik bariyeri, kilitleme sistemi, yedek pompa, seviye alarmı gibi önlemlerle azaltılabileceği sonucu çıkmıştır. Kaza istatistiklerine göre, neredeyse tüm kazaların eğitim, iş güvenliği kültürünün geliştirilmesi ve idari düzenlemeler ile önlenebileceği ortaya çıkmıştır.

Bu çalışma, işçi sağlığı ve iş güvenliği yönetim sisteminin çevresel ve finansal olarak bütünleşmesi ve tüm sistemin sürdürülebilir hale gelmesine katkı sağlayabilir. Bu çalışma alanı, Türkiye'de tek olduğundan ileride kurulması planlanan benzer tesisler için emsal teşkil edebilir. Ayrıca, tesisteki iş kazalarının incelenmesi riskli bölge ve durumların üzerine yoğunlaşılarak; uygun kaza önleme teknikleri ve eğitimlerle iş kazalarının önlenmesini sağlayacaktır.

Anahtar Kelimeler: Yüksek Basınç ve Sıcaklıkta Asit Liçi, Risk Değerlendirmesi, Tehlike Tanımlaması, Risk Yönetimi

To My Family, My Husband and My Daughter

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CHAPTER 1

INTRODUCTION

1.1. Background

Nickel (Ni) is a crucial metal in modern infrastructure and technology with widespread usages in stainless steel, alloys, electroplating, and rechargeable batteries. It occurs mainly in two types: sulphide or laterite. Sulphide ores are generally came into existence from volcanic or hydrothermal processes and generally contain Copper (Cu) and/or Cobalt (Co), and often precious metals such as, Gold (Au) or Platinum (Pt), Palladium (Pd), and Rhodium (Rh) (Naldrett, 2002). Laterite ores are derived from near the surface after extensive weathering of ultramafic rocks and occur abundantly in tropical climates around the equator, the arid regions of the central Western Australia or humid areas of the Eastern Europe (Elias, 2002).

Nickel prices are continuing a medium-term growth. Since 2016, the price of nickel arrived a 13-year low, nickel prices have increased by 61 percent that the average price was $13,392.5/tonnes in 2018. Experts foresee a very slow increase of $9,987/tonnes by 2022 (Knoema Corporation, 2018). The official price of nickel was $17,495/tonnes in 06 September 2019 according to London Metal Exchange (LME) (London Metal Exchange, 2019).

Both nickel sulphide and nickel laterite ore deposits are available in six countries: Australia, New Caledonia, Russia, Cuba, Canada, and Brazil have 84% of the known world reserves. However, the world's largest nickel deposit is placed at Goro in New Caledonia owned by Vale-Inco with a production amount of 54,000 tonnes/year as nickel oxide (Dalvi *et al.*, 2004). In addition, the resources of nickel in manganese nodules are forecasted between 2 and 14 billion tonnes (Alcock, 1988).

Nickel extraction methods of lateritic ores are classified into two groups: pyrometallurgical processes and hydrometallurgical processes. The pyrometallurgical processes are generally working with operation sequence of drying, calcining/reduction, and electric furnace smelting. The two main hydrometallurgical processes that are used at the present time are caron process and high pressure acid leaching process.

The caron process could be convenient for limonitic ores or a hybrid of limonite and saprolite. The ore is dried and nickel is selectively reduced to metallic nickel at approximately 700 °C. The metallic are gained by leaching in an ammoniacal solution. When the quantity of saprolite goes up, the performance of nickel and cobalt recovery falls away because nickel and cobalt are absorbed in silicate matrix and it is hard to solve at this temperature (Dalvi *et al.*, 2004).

High pressure acid leaching (HPAL) is commonly preferred hydrometallurgical process for low grade laterites. HPAL process is performed in autoclaves at the pressure of 35 - 55 atm and at the temperature of 240 – 255 ºC under stable conditions with sulphuric acid about an hour to produce a nickel rich refining intermediate (Georgiou and Papangelakis, 1998).

The HPAL includes many hazardous processes and stressors due to the high temperature and pressure conditions inherent in its operation. Any accident in the HPAL plant will be catastrophic on human life, environment, and equipment. For this reason, risk assessment and management are very crucial for efficient determination of workplace hazards.

1.2. Statement of the Problem

Process plant malfunctions have resulted in catastrophic accidents that prove the irreversible effects on human life, environment, society, and economy. Therefore; investigating and reducing the probability of hazards and risks and inhibition of such accidents is very crucial for community and firm (Lees, 2004).

High pressure acid leaching process plant is a huge construction and has complex working mechanism intrinsically can result in serious work accidents. In addition, technological changes bring about new hazards and risk types. Investigation of previous accidents in the process plants indicated that the cause of many accidents occurred because hazards had not examined in detail. Hazard identification is the initial step for the risk assessment. Early identification of hazards is one of the most important study of the risk analysis. Only hazards which are defined can be overcame by convenient safeguards.

The research questions of this study are:

- How can the hazards be defined for more hazardous units?
- Where are the risky areas of the HPAL plant?
- What can be the safeguards to prevent the potential hazards?

1.3. Objectives and Scope of the Study

The fundamental objective of this study is to perform risk assessment to contribute to develop risk assessment plans and risk management strategies for the high pressure acid leach (HPAL) process plant operations and mine site. To achieve this purpose, a literature survey is carried out with the standards, guidelines, and other documents related to the health and safety topic.

The other objective of this research study is hazard identification and analysis of hazards. After the hazard identification, consequences of the hazards, risk ranking, potential safeguards, and recommendations of the problems are listed in risk assessment tables.

In this study, general approaches, regulations, and standards were considered for a successful occupational health and safety management system establishment and requirement about hazard identification, then risk ranking and safeguards and recommendations. Thus, the reasons of work accidents and plant malfunctions that affect human life, environment, and economic condition can be investigated with the help of this study at this complex working mechanism.

The scope of this research study is HPAL process plant that located in Gördes town within the boundaries of Manisa province. The units of this HPAL plant was investigated separately, than hazards and risks was determined to compose risk matrix of the plant.

1.4. Research Methodology

Identifying the hazards, preventing risks or reducing risks to admissible level will ensure the best economic solution to achieve a healthy workplace. A risk assessment includes examining the process in every aspect to eliminate or decrease the hazards, observing the exposure of the worker to the hazard, and estimating the health effects resulting from exposure.

The methodology includes 5 steps:

- Study area definition
- Data collection and analysis
- Preliminary hazard identification (process hazard analysis)
- Risk computation, ranking, and evaluation
- Risk management strategies

Figure 1.1 illustrates the flowchart of the research methodology followed in this thesis study.

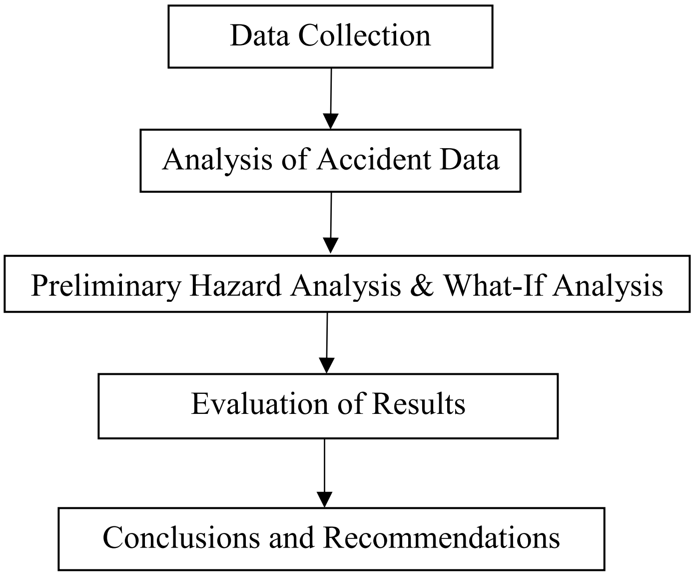

Figure 1.1. The flowchart of the thesis study

The parameters specifying the importance of hazard (1-3) and risk (1-9) are:

1. Inventory and properties of hazardous materials

2. Type of operation; process conditions

3. Complexity of operations

4. Design and operation relative to standards and codes

5. Layout of equipment

6. Plant layout

7. Preventative and protective measures

8. Plant site

9. Effectiveness of plant management (Witt and Ramzan, 2010)

The origin of hazard may be hazardous material or energy. Hazard potential relies on:

- Material properties,
- Physical conditions of process,
- Magnitude of material,
- Release mechanism (Cameron, 2010).

In this study, 4x4 risk matrix was decided to be used because it is mainly used to define the size of a risk and whether or not the risk is controlled adequately. A risk matrix consists of two parts, severity and probability. The compound of severity and probability was assigned a value on the risk matrix (CGE Risk Management Solutions, 2017). In 4x4 risk matrix, the severity of a consequence is appointed a ranking from 1 (lowest) to 4 (highest). The likelihood of a consequence is assigned a ranking between 1 (improbable) and 4 (frequent).

1.5. Outline of the Thesis

The research study begins with introduction part and continue with literature review in Chapter 2. Study area and process working mechanism is explained in Chapter 3. Analysis of accident data within 5-years period (2014-2018) are done with respect to the departments, working areas, jobs, ages, educational status, working year of injured personnel, injured organ, degree of accidents, injury types. In addition, working hour, shift, day, month of the occurrence time of accidents, accident frequency rate, accident weight rate and the accident and also the cause of accident (unsafe situation or behavior) are analyzed and results and discussions part of the analysis are explained in Chapter 4. Risk assessment of high pressure acid leach plant of 11 process circuit are performed with the method of what-if analysis and results and discussions part of the analysis are expressed in Chapter 5. Finally, conclusions and recommendations parts are presented in Chapter 6.

1.6. Contribution of the Study

This study can contribute to the integration of the occupational health and safety management system with quality, environmental, financial management systems, and sustainability of the whole system. This HPAL process plant has been unique for Turkey, thereby risk assessment's analysis may be a reference for similar plants to be constructed in future.

In addition, accident analysis of the process plant can help the definition of risky working areas, working hours, and also employees' properties that can be resulted in accident. Thus, the accident prevention techniques and appropriate trainings can be developed in terms of the results of the analyses.

CHAPTER 2

LITERATURE REVIEW

2.1. Background Information about Nickel

Nickel (Ni) was first found out in 1751 in the Swedish town of Cronstedt and after the XIX. century it is used in the production of copper – nickel alloy coins (U.S. Geological Survey, 2017a). A small amount of Ni mining and smelting occurred throughout Europe, particularly in southern Norway which had about 40 small Ni mines active by 1870. These sulphide ores typically contained around 1 to 2% Ni (Barlow, 1907).

Nickel has become the most used metal after iron by the developing industry has started in 1865 by working in New Caledonia's nickel deposits. Nickel influences both the structure and the mechanical properties of stainless steel substantially. Therefore, nickel became crucial part of the U.S. stainless steel industry. As the development of steel industry continue, the necessity of nickel will grow up.

Alcock (1988) stated that nickel is the 6^{th} widest element by weight among the other elements that together found not only in the Earth's crust but in the whole Earth. However, Boldt and Queneau (1967) claimed that nickel is not founded resourcefully in the Earth's crust hence it ranks 24^{th} element among the 90-odd elements in the Earth's crust which includes 0.008% nickel. The interior sections of our globe are significantly richer in nickel due to various nickel intensity than is the crust and below a depth of about 2900 km the Earth's core comprises natural iron-nickel alloys as in metallic meteorites containing from about 5% to over 50% nickel.

2.2. Use Areas of Nickel

Nickel is a crucial metal for the industry. It is used in stainless steel, alloys, electroplating and rechargeable batteries that all of which enhance our economic situation. Nickel is a commonly used element in many products such as, in industrial, military, marine, aerospace, and architectural applications. Nickel is also used in daily used products namely, coins, magnets, and rechargeable batteries. The magnetic properties and the electrical conductivity of nickel is convenient for using in computer hard drives and other electronics applications. Another usage area of nickel is the medical sector in production of medical tools and stents. The utilization area of nickel for different sectors are stated in Figure 2.1. It is seen that the major amount of nickel is consumed to produce stainless steel. In making many industrial and commercial products such as, stainless steel, coins, rechargeable batteries, magnets, special alloys, jewelry, surgical wire, electrical guitar strings *etc*. nickel is utilized for a long time.

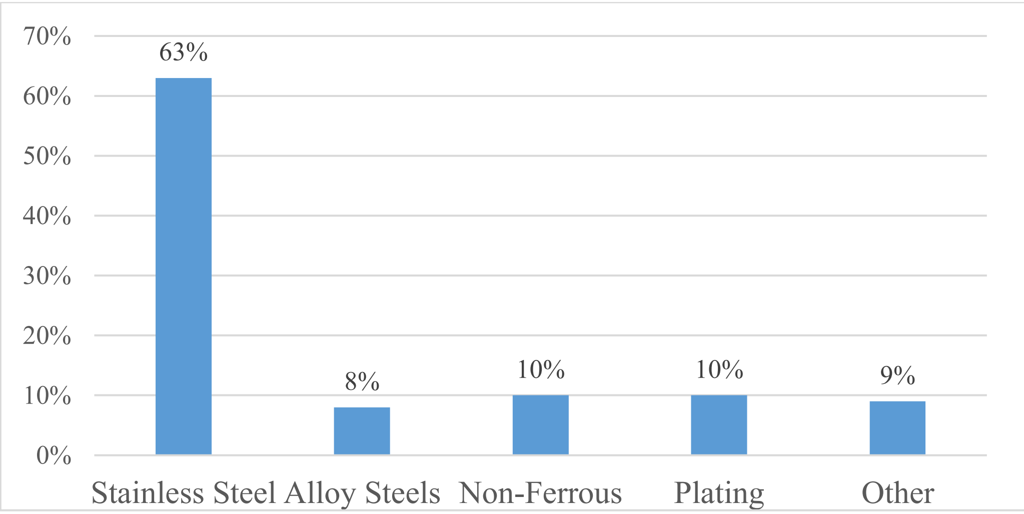

Figure 2.1. Worldwide applications of nickel by sector (Pariser, 2014)

The first and end uses of nickel for different sectors are indicated in Figures 2.2 and 2.3 respectively. First use means newly produced nickel while end use means recycled scrap because of the nickel's recyclable property.

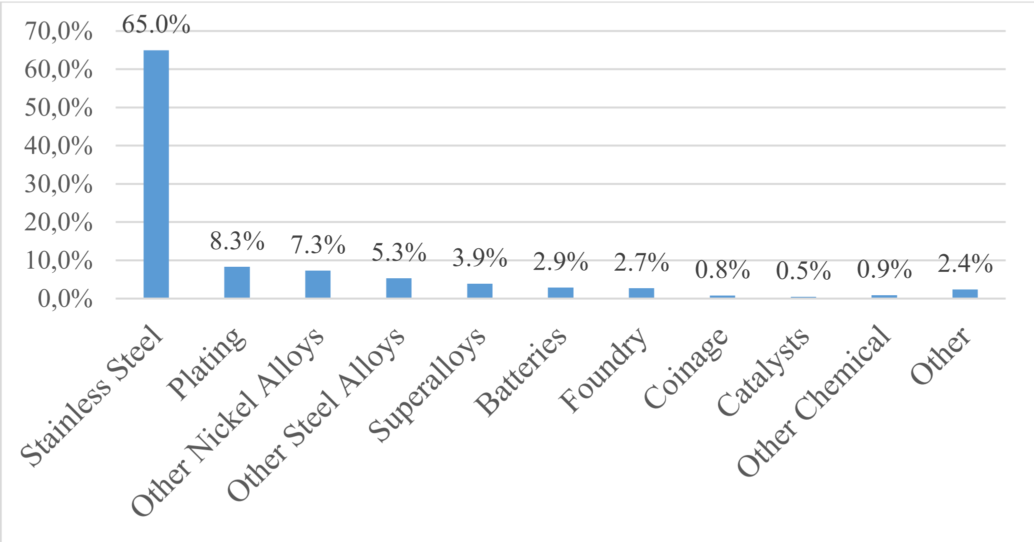

Figure 2.2. Estimated first use of nickel (Roskill, 2014)

The most important use of new nickel is the production of stainless steels. Other sectors of first use include other alloyed steels, high nickel alloys, castings, electro-plating, catalysts, chemicals, and batteries (INSG, 2018).

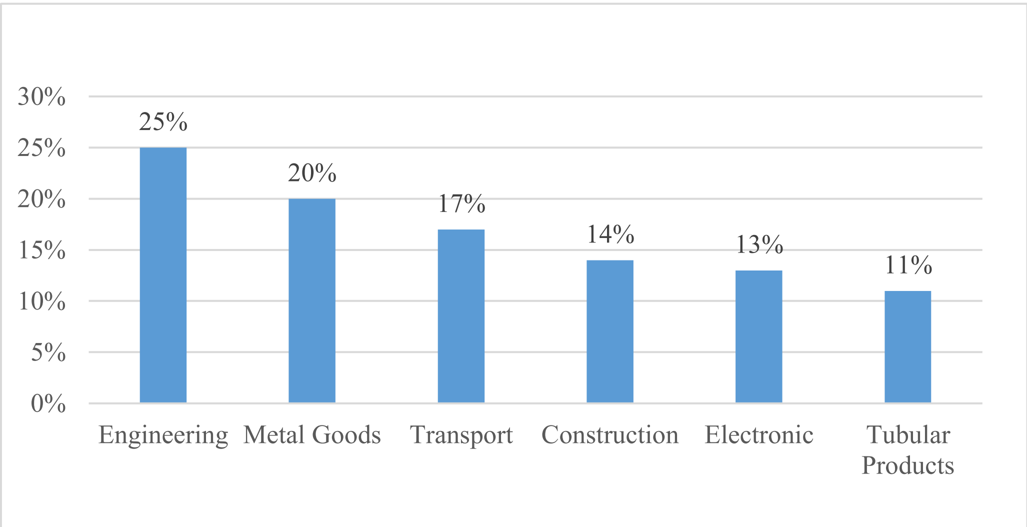

Figure 2.3. Worldwide end-use applications of nickel, 2012 (Pariser, 2014)

End use depend on nickel, usually comprises nickel including alloy that considerably transforms either the production process or the end product. As it is seen in the Figure 2.3, different private and public sectors utilize nickel for various applications.

2.3. Nickel Supply and Consumption

The need of nickel supply will increasingly continue owing to the regular demand on stainless steel industry and lithium-ion batteries. Past trends of nickel in metal market are indicated in Figure 2.4 and the nickel prices for the last 35 years are shown in Figure 2.5.

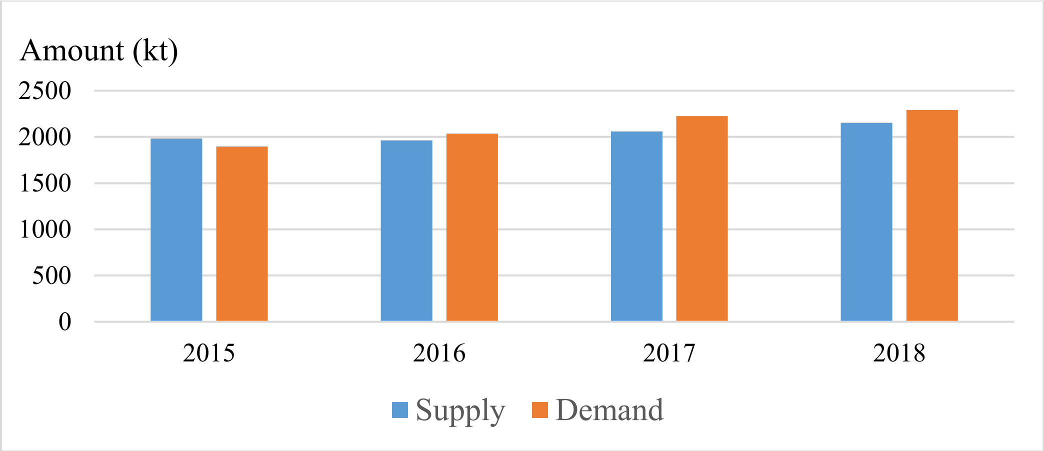

Figure 2.4. Nickel supply vs. consumption

Although, the demand increased on a regular basis between the years 2015 and 2018, the supply decreased due to big stainless steel destocking, the nickel price reached the lowest price in 2016.

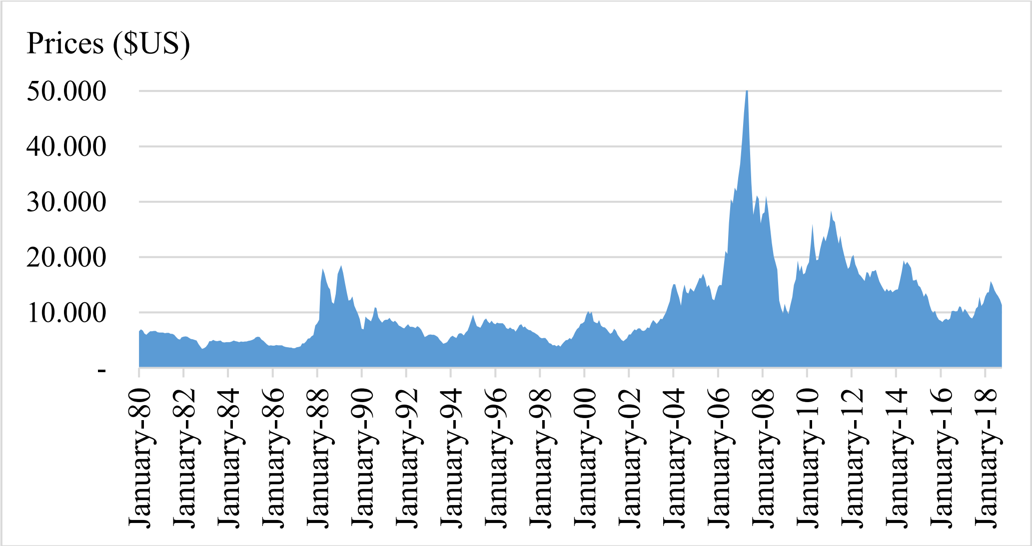

Figure 2.5. Nickel prices for the last 35 years (LME, 2018)

According to the Figure 2.5, by the early 1980s the nickel price was in fall due to small gap in supply and demand. In 2007, the nickel price had peaked because of big difference between supply and demand. The world nickel production had increased on a regular basis in the past decade.

2.4. Nickel World Reserves

In the world, about 60% of the reserve is in laterites and 40% is in sulphide deposits. Exploration teams has tended to work in more challenging locations like east-central Africa and the Subarctic due to decrease in exploration of new sulphide deposits in the long-term. Discovery of awaruite deposits in Canada may facilitate projected shortages of nickel concentrate (U.S. Geological Survey, 2017b). World nickel reserves are illustrated in Table 2.1.

Table 2.1. *World nickel reserves as contained nickel (U.S. Geological Survey, 2017)*

Country	Reserves (tonnes)
Australia	19,000,000
New Caledonia	12,000,000
Brazil	9,100,000
Russia	7,900,000
Cuba	5,500,000
Indonesia	4,500,000
South Africa	3,700,000
Philippines	3,100,000
China	3,000,000
Canada	2,900,000
Madagascar	1,600,000
United States of America	160,000
Other Countries	6,500,000
World Total (rounded)	81,000,000

Australia, New Caledonia, Russia, Cuba, Canada, and Brazil have 84% of the known world reserves in both nickel sulphide and nickel laterite. However, the world's largest nickel reserve is placed at Goro in New Caledonia owned by Vale-Inco with a production capacity of 54,000 tonnes of Ni/year as nickel oxide (Dalvi *et al.*, 2004). Moreover, the global resources of nickel in manganese nodules are forecasted between 2 and 14 billion tonnes of contained nickel (Alcock, 1988).

World nickel production is affected from the technical improvements and renewals in the nickel extraction applications. Since 1950, stainless steel production in the Western World has been increasing at an average rate of 6.0% per year. This situation has led to investigate new mine projects for more nickel production with the aim of satisfying this growing steel industry production. Statistical data acquired from the annual world nickel production illustrated in Table 2.2.

Table 2.2. *Nickel mine production by country (U.S. Geological Survey, 2019)*

Years	2013	2014	2015	2016	2017	2018
USA	-	3,600	26,500	24,100	23,000	19,000
Australia	234,000	220,000	234,000	204,000	190,000	170,000
Brazil	138,000	126,000	110,000	160,000	140,000	80,000
Canada	223,000	233,000	240,000	236,000	210,000	160,000
China	95,000	100,000	102,000	98,000	98,000	110,000
Cuba	66,000	66,000	57,000	51,600	51,000	53,000
Indonesia	440,000	240,000	170,000	199,000	400,000	560,000
Madagascar	29,200	37,800	49,000	49,000	45,000	39,000
New Caledonia	164,000	165000	190,000	207,000	210,000	210,000
Philippines	446,000	440,000	530,000	347,000	230,000	340,000
Russia	275,000	260,000	240,000	222,000	180,000	210,000
South Africa	51,200	54,700	53,000	49,000	49,000	44,000
Other Countries	377,000	410,000	410,000	150,000	150,000	180,000
World Total (rounded)	2,630,000	2,400,000	2,530,000	2,090,000	2,100,000	2,300,000

Russia, Indonesia, and Canada play an important role in global nickel production. Mine production in South Africa will increase with the help of technical facilities in the near future.

Nickel occurs mainly in two types: laterite or sulphide. Lateritic nickel ores are generally abundant near the surface of Earths' crust and at regions where the climate has some specific properties. These specific areas are generally tropical climates and are placed around the equator or dry regions of central Australia or parts of Eastern Europe with high humidity (Kerfoot, 2005).

Sulphide ores are typically came into existence from volcanic or hydrothermal processes and usually include copper (Cu) and/or cobalt, and sometimes other precious metals such as, gold or platinum and palladium (generally grouped as platinum group metals or PGMs). Historically, most nickel production has been derived from sulfide ores with laterite ores providing only a modest source (Mudd, 2009).

2.5. Nickel Production Methods

Nickel production methods are mainly classified into two groups as pyrometallurgical processes and hydrometallurgical processes. Main pyrometallurgical processes use conventional flowsheet involving drying, calcining/reduction, and electric furnace smelting. The major hydrometallurgical processes currently applied in practice are: caron process and HPAL process.

The lateritic deposits form 72% of the world's nickel sources, but only 42% of the primary nickel production gains from lateritic ores and the rest is obtained from the sulphide ores (Oxley and Barcza, 2013). Because conventional mineral processing techniques (e.g. flotation) cannot successfully be used for the concentration of lateritic nickel deposits, extractive metallurgical (e.g. hydrometallurgical) methods are applied to obtain nickel and cobalt from the deposit (Zubryckyj *et al.*, 1965; Queneau, 1970; Onodera *et al.*, 1987; Whittington and Muir, 2000; Muir and Johnson, 2006; Quast *et al.*, 2015; Farrokhpay and Filippov, 2016). Among these, the high pressure sulphuric acid leach process is one of the well accepted method to treat nickeliferous laterite ores (Carlson and Simons, 1960; Chou *et al.*, 1977; Kuxmann and Landau, 1981; da

Silva, 1992; Briceno and Osseo-Asare, 1995; Georgiou and Papangelakis, 1998; Rubisov *et al.*, 2000; Whittington and Muir, 2000; Whittington *et al.*, 2003; Whittington *et al.*, 2005; Loveday, 2008; Chalkley *et al.*, 2010; Guo *et al.*, 2011; Kaya and Topkaya, 2011; Liu *et al.*, 2012; Korkmaz, 2014; Önal and Topkaya, 2014).

Lateritic nickel ores are reacted with aqueous sulphuric acid solutions in autoclaves at temperatures of 230 - 270°C and at a pressure of 3.3-5.5 MPa for 60-180 minutes. Iron mainly creates insoluble solid oxides and sulphates, while nickel and cobalt dissolve and stay in the solution phase. Thus, selective separation of nickel and cobalt can be accomplished (Üçyıldız and Girgin, 2016).

The pyrometallurgical and hydrometallurgical routes chosen from those indicated in Figure 2.6 were flash smelting and acid pressure leaching, as flash smelting is the principal pyrometallurgical process while acid pressure leaching is becoming the most common hydrometallurgical route for laterite ores. In general, sulphide ores are relatively straight forward to process, smelt and refine to Ni, while laterite ores need very complex chemical and energy intensive processing (Mudd, 2010).

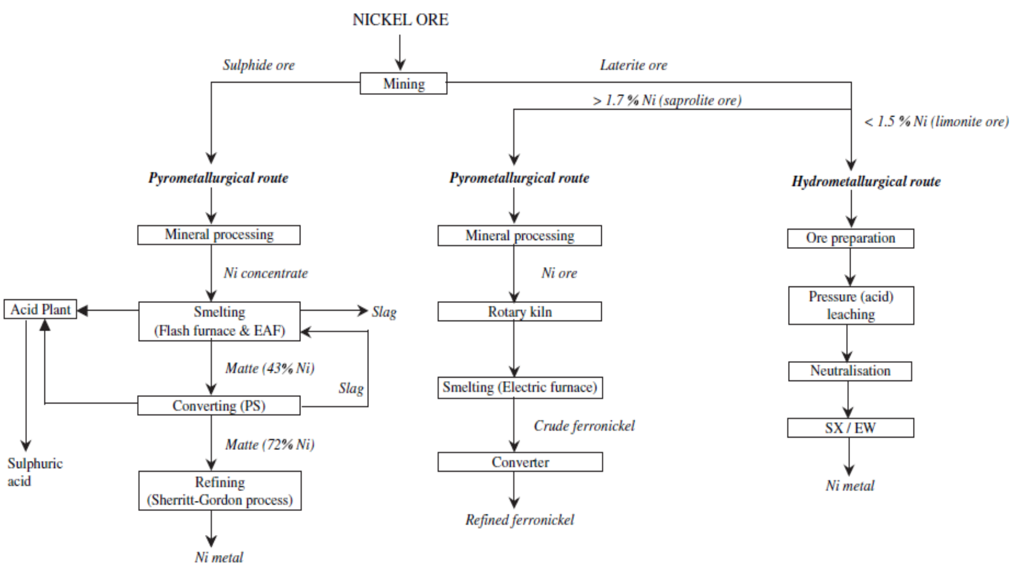

Figure 2.6. Main processing routes for nickel production (Norgate *et al.*, 2006)

2.6. Nickel Deposits and Reserves in Turkey

Both sulphide and lateritic type bedding is presented in Turkey. The major nickel laterite deposits are in Eskişehir-Mihalıççık-Yunusemre, Manisa-Turgutlu-Çaldağ, Manisa-Gördes, and Uşak-Banaz; and sulphide deposits in Bitlis-Pancarlı, Bursa-Orhaneli-Yapköy and Sivas-Divriği-Gümüş (State Planning of Organization, 2001).

Eskişehir-Mihalıççık-Yunusemre, Manisa-Gördes, and Manisa-Çaldağ nickel laterite deposits have sufficient economical significance for achieving the cut-off grade. Turkey nickel reserves are shown in Table 2.3 (Yeşil, 2010).

Nickel is present at 'normal – poor' group with regard to value of reserves of Turkey. However, evaluations of the value of a reserve is not objective and data about reserves is arguable most of the times (State Planning of Organization, 2006). Nickel derives from together with iron and in the form of sulphides, arsenides, and silicates in the environment. Turkey has a very strategic location to the existence of nickel in terms of the bedding type and geological conditions.

Table 2.3. *Turkey nickel reserves (Yeşil, 2010)*

Region	Proven Reserve (tonnes)	Probable Reserve (tonnes)	Possible Reserve (tonnes)
Manisa – Çaldağ	33,000,000	No data	No data
Manisa – Gördes	32,000,000	No data	No data
Eskişehir – Yunusemre, Mihalıççık	No data	86,625,000	No data
Uşak Banaz	No data	11,601,500	No data
Bursa – Yapköy	No data	82,000	No data
Bitlis – Pancarlı	No data	No data	15,500

Majority source of world nickel production has been sulphide deposits. However, decreasing amount in this type of deposits gives way to lateritic type deposits, which also include a great amount of cobalt reserves. One of the known nickel laterite deposits in the country is located at Türkmençardağı - Gördes region and HPAL process plant located at Türkmençardağı laterite deposit is examined in this study.

As it is mentioned before, the study area is of this thesis is the High Pressure Acid Leach (HPAL) plant located in Gördes town within the boundaries of Manisa province is performing with laterite nickel ore that is the unique plant in Turkey as work system. For this reason, previous chemical accidents and similar process plants in the world was mentioned in Chapter 2.9.

2.7. Information about Previous Accidents

The chemical process industry is a highly complex system due to 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 (Kujath *et al.,* 2010).

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 described by the criteria of 25 deaths or more or 125 injured or more or 10000 evacuated or more or 10000 people or more deprived of water. (Mihailidou, 2012).

The improvement of chemical industries has been leading to an increase in the risk of occurrence of accidents related with hazardous chemicals. Most of the accidental analysis ascertained that the process accidents occurred due to abnormal operating conditions such as, over temperature and over pressure as shown in Figure 2.7.

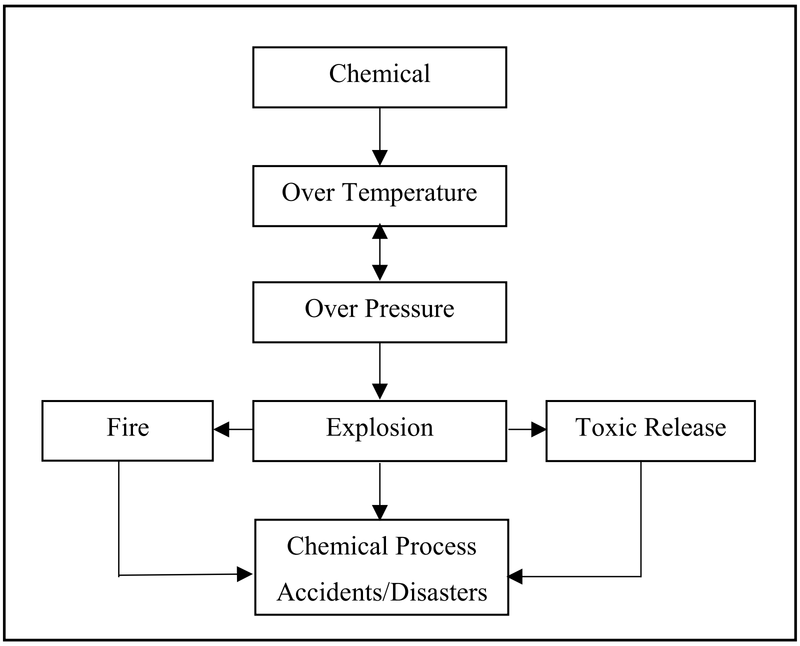

Figure 2.7. Root causes of chemical process industrial accidents (Yarrakula and Koteswara, 2016)

2.7.1. Impact of Chemical Accidents

Chemical processes involve a various hazards intrinsically such as fire, explosion and exposure to toxic substances. But, industrial accidents have also potential for catastrophic influence (Mannan and Lees, 2005). The primary effect of chemical disasters is not only human death but also negative effect on livestock, flora/fauna, environment, and equipment damage **(**Labovská *et al.,* 2014). A small-scale accident realizing at the local area may be predicted during the operation. However, chemical disasters has catastrophic effect that can lead to sudden or long-term loss (Bhawana, 2011). Severity and likelihood of chemical disasters has gone up in the recent time because of instant improvement of chemical industries (Government of India, 2009). The primary effects of chemical disasters on biotic and abiotic environment are shown in Figure 2.8.

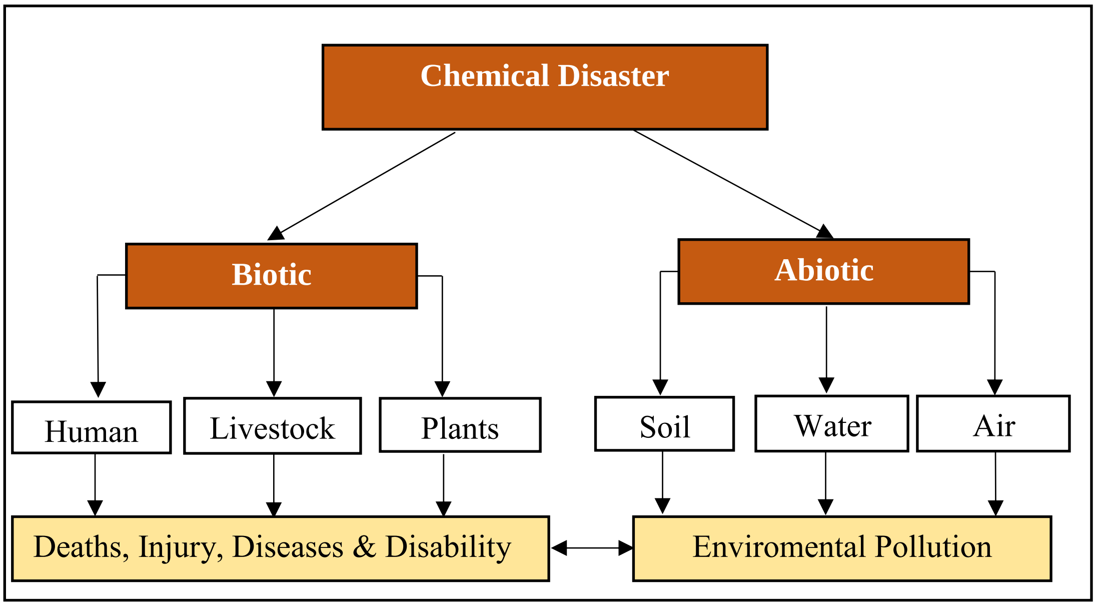

Figure 2.8. Impacts of chemical disasters (Yarrakula *et al.*, 2016)

According to Figure 2.8, the chemical disasters have destructive impact on human, livestock and plants in biotic environment while the chemical agents contamine the soil, water and air in abiotic environment. The effects of the chemical disaster on human can be death, injury, diseases and disability. The long-term effects of environmental pollution can be exposure to toxic chemicals by inhalation, ingestion, and skin contact.

2.7.2. Hazard Identification of Previous Accidents

Chemical process in extreme conditions necessitate a research study that all the hazards investigated before in order not to result in a major industrial accident and bring about human death or property damage (Mannan and Lees, 2005; Labovská *et al.*, 2014).

Chemical materials are the major factor for fire, explosion, toxicity and corrosion hazards. About 66% of accidents caused by explosion in comparison with the fire (Lees, 1996) but more people affect on toxicity with regard to fire and explosion (Belke, 2001).

A research about equipment basis accident demonstrates that about 78% of equipment failures in the chemical process industry occurs due to design or human mistakes. The accident analysis has been carried out based on the Japanese Failure Knowledge Database (FKD), defined 549 accidents from the various process site of the world. About 66% of accidents are associated with the chemical process industry (FKD, 2011). Previous accident analyses relevant with chemical process industry are majorly because of reactors, storage tanks, pressure vessels, boilers and pipe lines (Kidam *et al.*, 2015; Kidam and Hurme, 2012; Marsh and McLennan, 2011).

Vapor cloud explosion is the primary consideration for critical risks in the chemical process in years between 1926 and 1997 (Khan *et al.,* 1999). The pre-startup phase includes various occupational group and fatalities because of nebulated work process. According to the many accident report results of the petrochemical plants, 40% of plant accidents realized during new process startups **(**Nimmo, 1993; Yang *et al.*, 2010).

However, human errors have not been analyzed in detail in the phase (Shin, 2014). The main reasons of accidents for many chemical process industries are explosion, fire and discharge of toxic chemicals that can be inhibited by the help of proper process design and operations (Gunasekera and Alwis, 2008; Konstandinidou *et al.,* 2006; Nivolianitou *et al.,* 2006).

2.7.3. Determining the Main Reasons of Process Accidents

According to the process accidental analysis for the period 1998-2015, the main reasons of the accidents in developing and developed countries are indicated in Figure 2.9. The main reasons of the accidents with % wise are shown in Figure 2.10.

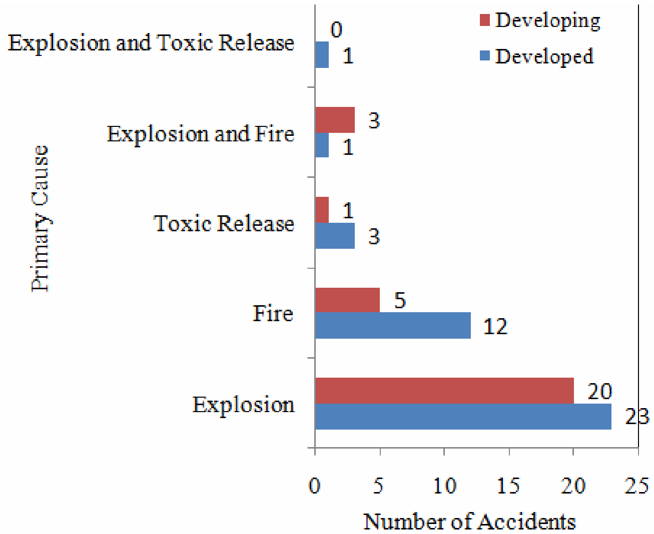

Figure 2.9. Primary causes of process accidents (Yarrakula *et al.*, 2016)

Most accidents occur due to explosion in developed and developing countries are 23 and 20 respectively. In the second rank, number of accidents related with fire in developed and developing countries are 12 and 5 respectively. Furthermore, fewer numbers of accidents are associated with other primary causes of toxic release, explosion associated with fire. As it is shown in the Figure 2.10, in the developed and developing countries, many accidents are related with massive explosion and fire due to flammability and explosive nature of hydrocarbons approximately 63% and 25% respectively.

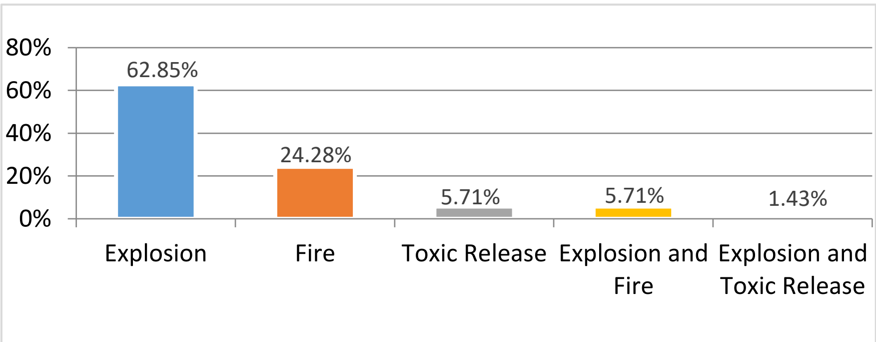

Figure 2.10. Primary causes of process accidents with % wise (Yarrakula *et al.*, 2016)

It is noticed that, in developed countries, interaction between process units and control errors in controlling units cause instantaneous explosion and fire. Thus, improvement of safety regulations and process design and decreasing the process control deficiencies concerning about highly flammable chemicals such as hydrocarbons and toxic chemicals in the process (Yarrakula *et al.*, 2016). The number of loss of life is substantially less and number of injuries are more in developed countries than developing countries. According to the researches, it is found out that many accidents associated with hydrocarbons and toxic chemicals are 55% and 30% respectively.

2.8. Investigation of Similar Process Plant Risk Assessments

Examination of similar projects is very important to recommend some studies to this study area for the long-term working plan. This part also includes useful information to provide to enchance the performed study.

Glandstone Pacific Nickel Project: Glandstone Pacific nickel project is located in Gladstone, Queensland. The refinery is investigated in 31 areas, 27 major hazards in 5x5 risk matrix. The risks are related with this process plant were analysed and determined mainly low risk level. However, solvent extraction, ammonia release and nickel and cobalt reduction areas have at medium risk. Ammonia, sulphur, slurry leakage can result in widespread impact on not only plant area but also warehouse, car pool, work shop and public housing. In addition, consequences modelling scenarios and their results are also formed with the consolidated weather data, leakage of sulphur dioxide/trioxide, and leakage of ammonia from bullet data (Hurree and Moffat, 2006).

The investigation of the short-term and long-term influences of a nickel refinery with regard to the human health is an essential issue. Therefore, the study was conducted by the Ontario Ministry of the Environment was explained below:

A nickel refinery had activated nearly 66 years up to 1984 in southern Ontario. The Ontario Ministry of the Environment analyzed approximately 2000 samples with the solid investigation method and carried out a human health risk assessment (HHRA) that was the first exhaustive multimedia risk assessment of a nickel-contaminated neighbourhood in North America for 7 metals: antimony, beryllium, cadmium, cobalt, copper, lead, nickel and arsenic was seen in the surface soils. According to the analyses, surface soil nickel grades reached the level of 17000 ppm. HHRA aimed to investigate total exposure from:

- Respiration of indoor and outdoor soil and dust,
- Fruit and vegetables,
- Drinking water and supermarket food,
- Skin touch with soil or dust,
- Breathing of ambient air in terms of the toxicity, exposure and potential receptors.

According to the HHRA results, the majority nickel form was nickel oxide that 80% of the total nickel on average and solid nickel intervention level of 8000 ppm based on noncancer endpoints, which was oriented to preserve toddler-aged children. Since, there were some uncertainties in dose response assessment, receptor characteristics and instability in the soil sampling data, the study had not achieve absolute accuracy in decision in the risk assessment (Birmingham and McLaughlin, 2007).

2.9. Confined Space Hazards and Risk Assessments

Confined spaces are tanks, vessels, pits, manholes, crawl spaces, silos, reservoirs, sewers, vats, degreasers, boilers, utility, pipelines and autoclaves (Suruda *et al.*, 1993). National Institute for Occupational Safety and Health (NIOSH) has given priority to confined space safety issues since 1986 and has studied about regulations and specific trainings. Occupational Health and Safety Administration (OSHA) indicated over 1.6 million U.S. employees work in special allowance needed areas that the regulation number (29 C.F.R., 1910.146,1993) must be applied but this regulation is applying for only a few occupational group (OSHA,1993).

The serious accidents in confined spaces are commonly occur from:

- Atmospheric hazards in the confined space (toxic gas, inert gas, oxygen deficiency, explosive mixtures *etc*.),
- Physical situations of the confined space (pressure, temperature),
- Inadequate ventilation of the confined space,
- Ineffective training of employees for entry and working procedure of the confined space,
- Inappropriate rescue plan,
- Deficiency of personal protective equipment (PPE) (Suruda *et al.*, 1993).

5 stages risk assessment method was applied for 10 confined spaces entries with 22 experts. The stages of the method are:

- Questionnaire to define confine spaces' working medium,
- Definition of the constituents of risks,
- Prediction of risks with concerted risk parameters and matrix,
- Classification of the risk type and level,
- Remarks on before and after risk reduction.

This method is useful for:

- Extensive risk identification by assessing all the risk parameters in a confined space,
- Determining the residual risks are acceptable or unacceptable,
- Classifying interventions and rescue circumstances by utilizing especial benchmark,
- Describing permit required confined spaces,
- Judgement of the external rescue is feasible or not **(**Vienney *et al.,* 2015).

2.10. Other Projects in the World

There are nine running HPAL projects in the world. The table of the HPAL projects in the world is shown in Table 2.4.

Table 2.4. *HPAL projects in the world (Global Mining Research, 2018)*

Operation	**Start**	**Design Production**	**Process**	**HPAL (MT/year)**	**Temp (°C)**	**Pressure (kPa)**	**Ni (%)**	**Acid (kg/t)**
Moa - Cuba	1959	37.000 tonnes/year Ni, 3.000 tonnes/year Co	Limonite	3.4	255	4.500	1.30	260
Murrin Murrin - Western Australia	1999	45.000 tonnes/year Ni, 3.000 tonnes/year Co	Smectite/ Blend	4.0	255	4.450	1.24	400
Coral Bay-Philippines	2005	24.000 tonnes/year Ni, 1.900 tonnes/year Co	Limonite	2.4	245	4.450	1.26	Not Available
Goro-New Caledonia	2010	60.000 tonnes/year Ni, 4.500 tonnes/year Co	Limonite/ Saprolite	4.0	270	5.600	1.50	355
Ambatovy-Africa	2012	60.000 tonnes/year Ni, 5.600 tonnes/year Co	Limonite	6.1	260	Not Available	1.13	Not Available
Ramu-Papua New Guinea	2012	33.000 tonnes/year Ni, 3.300 tonnes/year Co	Limonite / Saprolite	3.4	255	4.200	1.15	260
Taganito-Philippines	2013	36.000 tonnes/year Ni, 2.600 tonnes/year Co	Limonite	3.4	245	4.450	1.25	Not Available
Cawse - Western Australia	2014	9.000 tonnes/year Ni, 2.000 tonnes/year Co	Limonite	0.5	250	4.500	1.69	375
Gördes - Turkey	2014	10.000 tonnes/year Ni, 800 tonnes/year Co	Limonite	1.4	255	4.600	0.7	350

CHAPTER 3

HIGH PRESSURE ACID LEACHING NICKEL PROCESS PLANT IN GÖRDES

3.1. Study Area and Data

Study area is located in Western Turkey, within the boundaries of Manisa Province, between Akhisar and Gördes towns and around the Fundacık - Çiçekli – Kabakoz and Kalemoğlu villages. Mine site is 20 km away from Gördes town by an asphalt road and it is nearly 45 km from Akhisar town, 115 km from Manisa and 160 km from İzmir. The nearest state railway is about 40 km away. The site location map is shown in Figure 3.1 (Google Earth, 2019).

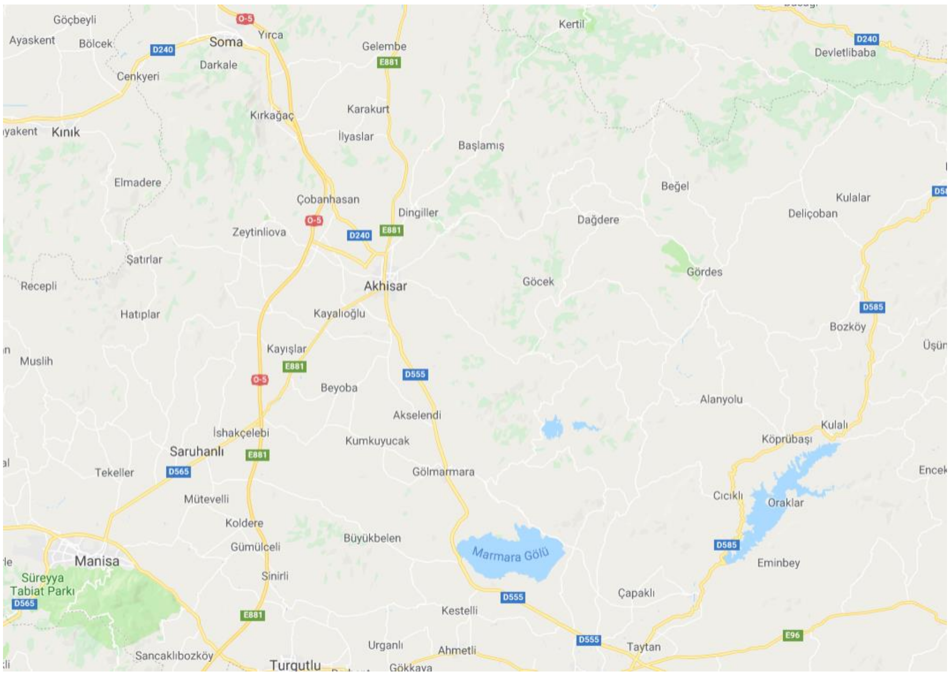

Figure 3.1. Site location map of study area (Google Earth, 2019)

A laboratory was established on mine site in 2007 to carry out chemical analyses on the samples provided from mine exploration team. The ore was exported in 2008.

Technological tests and the feasibility study were completed and environmental impact assessment (EIA) report for Gördes project was approved by the Ministry of Environment and Forestry in 2009. Based on recent studies and drilling, total mineable reserves for the property have been estimated 30 million tonnes with an average nickel content of 1% by weight.

Metallurgical testing to date has indicated an HPAL processing plant where a mixed hydroxide product nickel metal will be produced. Nominal capacity is initially targeted at 10,000 tonnes/year nickel and 700 tonnes/year cobalt with a potential expansion to double the capacity in a few years' time. Türkmençardağı hill mine includes the operating lease and it has been approved by Ministry of Environment and Urbanization.

Considerable exploration in the vicinity of Gördes has identified prospective nickel cobalt laterites in both limonite and nontronite deposits over an area of 500 square kilometers. Trenches and boreholes have been used to explore the deposits with sampled grades generally lower than 1% Ni but with some grades are higher than 2% Ni (Cobalt grades are approximately 0.1 % in the ore.). The laterite deposits are usually found at shallow depth and tend to occur on hilltops commonly covered by iron-silica caps. The presence of local limestone deposits is also an important asset to meet processing requirements.

According to the analyses, most of the trenches' sampled grades less than 1% Ni, the greater grades of Ni such as 1.23% -2.80% - 2.99% -10.24% are usually found at under the silica caps or deeper depth at laterite deposits.

As a result of General Directorate of Mineral Research and Exploration's (MTA) research, probable reserve have been estimated 68.5 million tonnes of Ni which has grade equal and greater than 1% in 5.3 square kilometers area. Higher Ni content are generally found at limonite and garnierite zone (Ağaçayak, 2008).

In the Gördes area, the firm has mined and exported more than 200,000 tonnes of ore for nickel extraction. These export quantities were monitored for both grade and tonnage, and although the measurements were not taken for reconciliation purposes they are useful to compare with predictions from drilling and geological models. The project life is estimated to be 15 to 20 years.

3.2. Regional Geology of the Plant Area

Up to date geological study relevant with the site and environments has been conducted by Konak *et al.* (1980). A generalized stratigraphic column of the region suggested by Konak *et al.* (1980) is shown in Figure 3.2.

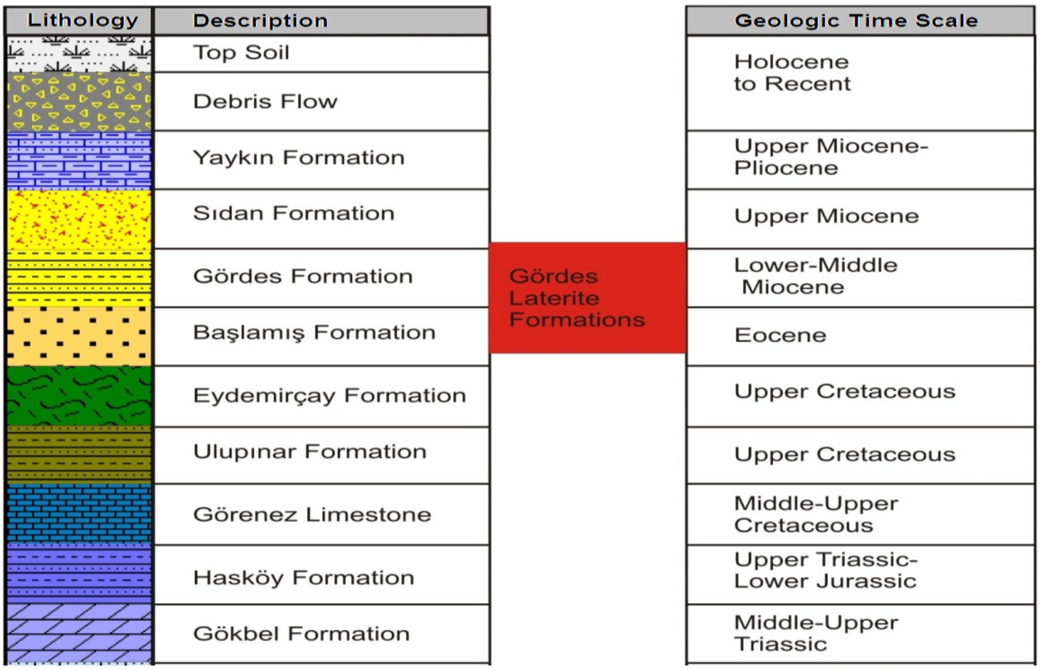

Figure 3.2. A Generalized stratigraphic column observed in the region (Konak *et al.*, 1980)

Various geological units starting with Paleozoic can be analyzed in the area. These units are summarized in Figure 3.2 according to principal geological times. Gördes laterite formations are in products of tropical weathering of ultramafic rocks as a sandstone and siltstone and lower-middle Miocene and Eocene time scale are illustrated in the figure. In the study area High Pressure Acid Leach (HPAL) process is applied. The details of the process was mentioned in the next subtitle.

3.3. Process Description of HPAL

In the HPAL process the ore is mined and crushed to obtain a fine material. These material blended with water. The slurry is preheated then is pumped into an autoclave with acid leaching. The slurry and acid mixture react within the autoclave. The leaching process time is nearly 60 minutes in the autoclave. The slurry is processed with three phase flash let-down system to be returned to the atmospheric conditions before leaving from the autoclave. Since the slurry is washed and separated at which point the nickel and cobalt can be regained from the liquid fraction.

Pressure leaching in autoclaves is used for the process of a range of ore types. All autoclave projects share some common design features but the technology is complex and highly ore specific in terms of metallurgy and operating conditions. The photo of the HPAL plant is given in Figure 3.3.

Figure 3.3. The photo of the HPAL plant

The facility consists of the following:

- Ore Processing Area
- Ore Preparation
- HPAL Area

  -Slurry Heating

  -Leaching

  -Flash Let-Down

  -Leach Vent Scrubber

  -CO_2 Scrubber and Heat Recovery

  -Agitator Seal System
- Recycle Leach Tank and Primary Neutralization
- Counter Current Decantation (CCD)
- Secondary Neutralization
- MHP 1 – Mixed Hydroxide Product
- MHP 2
- Manganese Removal
- Final Neutralization
- Sulfuric Acid (H_2SO_4)
- Lime and Limestone
- Flocculant
- Process Water and Cooling Water

The process of HPAL (High Pressure Acid Leach Plant) is composed of ten main process nodes that are listed above. The working mechanism of the system is explained in below. The flowchart of the HPAL plant is given Figure 3.4.

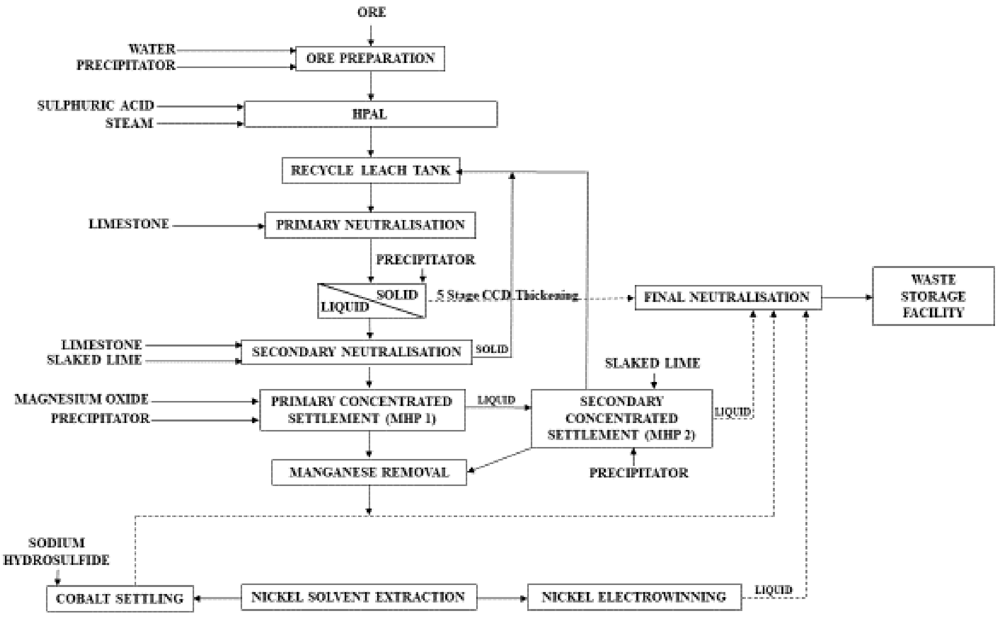

Figure 3.4. Flow chart of the High Pressure Acid Leach Plant

3.3.1. Ore Preparation

In ore preparation area, slurrying, separating the impurities, and sizing the run of mine operations are done. The area is included a drum scrubber, three squads of screen, one thickener, and the other associated support equipment. The ore is transferred to the drum scrubber feed chute trolley by a conveyor from ore stockpiles. The feed cute mixes the ore and water to provide the ore flow into the drum scrubber. The diagram of ore preparation area is shown in Figure 3.5 (SNC-Lavalin INC., 2011).

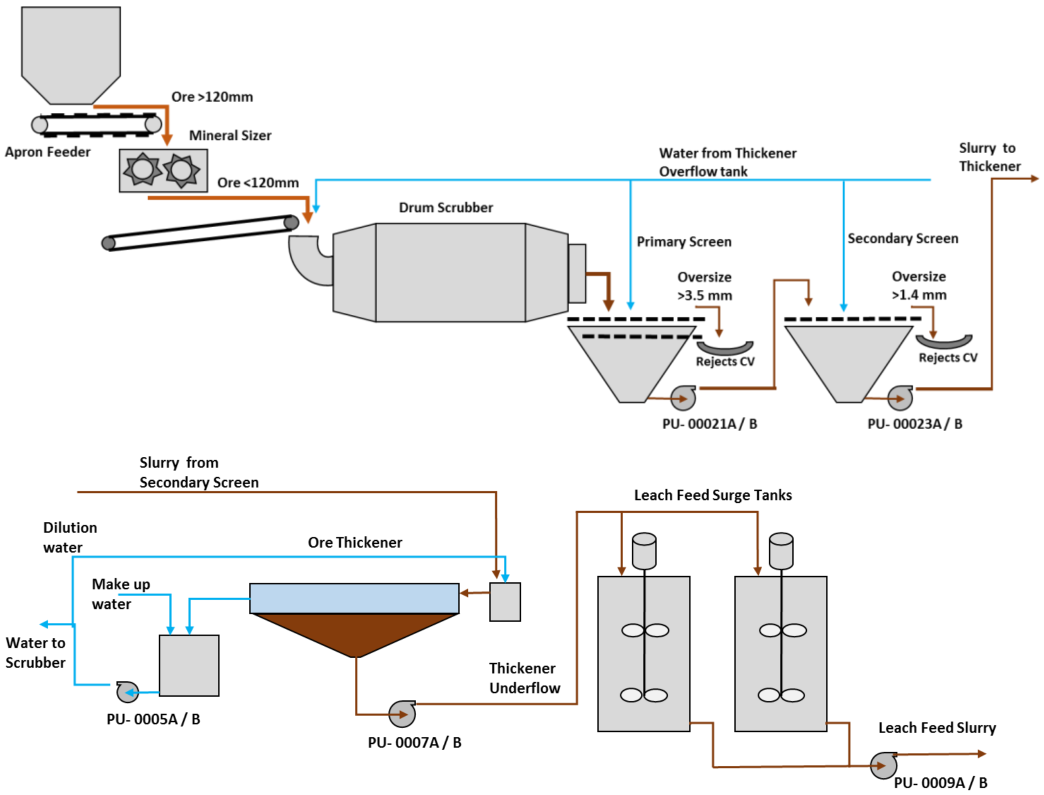

Figure 3.5. The diagram of ore preparation area (SNC-Lavalin INC., 2011)

The ore-water mix is turned upside-down in order to get rid of the part of agglomerated and relatively wetted ore in the drum scrubber with the help of the larger rocks in the ore. The de-agglomeration is a kind process that agglomerates can be broken without damaging the more fragile rocks in the ore. The output of the drum scrubber is slurry of fully wetted fine ore and rocks.

The drum scrubber discharge is rejected from larger rocks with a trommel to supply any material do not harm the screen for sizing below. Any large material is separated to the side of the drum scrubber.

The drum scrubber discharge screen is bifold, separates the rocks greater than 3.5 mm from the slurry than collects to the rejects stockpile. The undersize rocks are transferred to the medium screen. The rocks greater than 1.7 mm are separated and washed at this screen, then stored in the middling area.

The undersize slurry from the middling screen is transferred in the fines pump box and pumped to screen with 0.65 mm. The slurry passing from this screen is pumped to the ore thickener feed tank for processing. This agitated tank is the gathering point of all streams being fed to the ore thickener.

The ore thickener settles the solids at ideal thickness that can be pumped to direct contact heaters in the HPAL area. Flocculant is added to dilute slurry in the feed well of the thickener to achieve the high underflow density.

The thickened slurry from the ore thickener underflow is pumped to the leach feed surge tanks. This surge tanks provide to inhibit breakdowns in the ore flow to damage the continuity and plant's performance.

3.3.2. HPAL Area

The area of high pressure acid leach (HPAL) is composed of three parts namely, three progressive direct contact slurry heating, six compartments agitated autoclave, three progressive pressure let down and associated pumping and scrubbing equipment.

Fine thickened ore slurry is pumped to HPAL unit from the ore preparation area. Then, the slurry is heated by direct contact steam condensation and concentrate sulfuric acid is injected. Thus, the ore is leached in pressurized autoclave vessel to extract the nickel, cobalt, and contained metals from the laterite ore. After the leaching operation, slurry pressure is decreased to slightly above atmospheric pressure in recycle leach tank, generating steam to heat the incoming ore slurry concurrently.

Slurry Heating: Slurry coming from the ore leach surge tanks is pumped to the HPAL area and flowed into the top of the low pump (LP) heater. The slurry strikes to the half column baffles and flows down. Meanwhile, the steam dilutes because of giving heat to the slurry. Then, the dilute slurry is pumped by two sets of centrifugal variable frequency drive (VFD) pumps in series to the middle pump (MP) heater and strikes to a set of baffles touching with the steam from the MP flash vessel and continues to downflow. The discharge slurry from MP heater is transferred to a set of three centrifugal pumps (2 VFD pumps and 1 non-VFD pumps) in series to the high pump (HP) heater, then strikes to the baffles touching with the steam from the high pump (HP) flash vessel. The discharge slurry finally is pumped by the autoclave feed pumps into the leach autoclave.

Leaching: Pressure acid leaching is implemented at a temperature above 240°C to minimize the acid usage by the dissolution of iron compounds. At this temperature the dissolution rate of ferric sulphate become considerably lower and the dissolution rate is inversely correlated with the temperature rise. At a temperature above 240°C, the regained amount reaches maximum and cause more crystalline precipitate in the counter current decantation (CCD) operation downstream.

The first stage of the leaching is injection of high pressure steam to the first compartment of the autoclave with concentrated sulfuric acid and limited heated ore slurry. The steam and acid mixture gives the required heat to attain the operating temperature.

The autoclave consists of six agitated compartments that the leaching slurry flows into the each compartment walls to arrive the optimum reaction kinetics of a plug flow reactor. Leached slurry is transferred from the six compartments to the first stage of the high pump flash vessel.

Flash Let Down: Autoclave discharge slurry processes with a three phase flash let-down system. Controlled pressure relief occurs as the slurry discharge passes through the modulating ceramic-lined plug type control valve. As the hot, pressurized slurry flows into the choke valve, it releases energy and brings about pressure drop. Some water in the slurry becomes instant steam and the fluid in the valve accelerates due to initial pressure drop. The slurry and steam mixture is pump into the pool of slurry to spread its energy.

The steam that is generated inside each flash vessel is directed into associated slurry heater for heat recovery. Flashed slurry is transferred to successive vessels until a pressure slightly above atmosphere is achieved in the last vessel. The leached slurry is sent from the last flash vessel to the recycle leach tank.

Leach Vent Scrubber: Venturi gas scrubber includes a venturi unit, a flooded wet elbow, a variable throat, a cyclone separator, a gas exhaust, a secondary separator, and a clean gas exhaust stack. High temperature gases and steam are regularly vented from all three heaters and the autoclave to control pressure. These gases are gathered and piped to a high energy, high efficiency, and wet method venturi gas scrubber to get rid of fragmented material before being release to the atmosphere.

Pressure relief valves are used for overpressure protection on the high pump (HP) and medium pump (MP) flash vessels and the autoclave, relieving pressure directly to the relief evacuation vessel at atmospheric pressure.

CO_2 Scrubber and Heat Recovery: Vent gases includes recyclable energy and carbon dioxide in the primary neutralization tanks substantially. The gases are passed through a low pressure drop scrubber to intensify the steam with a low temperature water stream to regain this energy.

The energy inside the flash water achieved from the leach vent scrubber can be recovered by the heat is attained with demineralized water heater and transferred to the steam plant; therefore, diminishing the fuel needs and water requirements by cooling the scrubber liquor.

Agitator Seal System: A single high pressure seal system serves the leach autoclave agitators and is generally united as skid-mounted with autoclave agitator supplier and the autoclave agitator seal supplier. The objective of the first component of the seal system is to provide the cool high pressure seal fluid in the recirculation line supplying the six agitator seals on each autoclave vessel. This system is designed with safety and backup system to guarantee that the autoclave agitator seals operate safely above the operating pressure of the autoclave. This will inhibit depressurization of the autoclave and to prevent the process contents of the autoclave from entering the agitator seal system. The second component of the seal system ensures a flushing liquid to the lower section of the seal to hold the acidic ore slurry off from the sealing surface and is also used for manual flushing of pressure safety valve chemical seal necks.

3.3.3. Recycle Leach Tank and Primary Neutralization

The recycle leach and primary neutralization unit have 1 recycle leach tank and 3 primary neutralization tanks. The recycle leach tank supplies maximum temperature and acidity to re-dissolve recycled nickel and cobalt values. Leached nickel and cobalt values are precipitated as metal hydroxides in secondary neutralization and mixed hydroxide product (MHP2). These metal values are recycled back to the recycle leach in order not to lose to tailings. The tank has approximately one hour residence time for this re-dissolution.

The recycled streams contain other metal hydroxides that are precipitated and the gypsum crystals from the neutralization of the acid in solution by limestone slurry or slaked lime. The other metal hydroxides that are recycled are also re-dissolved in variable quantity. The aluminum's recycle has significant amount in the soluble aluminum circuit inventory and recycle flows.

In primary neutralization tank area, the crucial operation is the neutralization reaction of the limestone with acid with about one hour of residence time for each tank. The tanks work at slightly above atmospheric pressure, supplying sufficient pressure to send the carbon dioxide gases constituted from mixing acid and limestone to the CO_2 scrubber. The tank contains 66% by volume of recoverable energy of steam due to high temperature of the feed to the primary neutralization. Then, the leached slurry from primary neutralization is pumped to the counter current decantation (CCD) unit.

3.3.4. Counter Current Decantation (CCD)

The CCD unit includes five washing phases. Each phase has an agitated feed tank with a residence time about two minutes. CCD 2 overflow is transferred with pipe system to CCD 1 thickener directly, then the slurry pumped to the secondary neutralization area. All consecutive CCDs overflow is pumped to the previous CCDs feed tank as a wash solution. Process water, sulfuric acid, and tailings decant solution are included to CCD 6 for more settling.

Thickened CCD underflow is pumped forward to CCD feed tanks where it is mixed with CCD overflow. CCD 6 underlow is pumped to final neutralization. In this unit, the required is to reach the maximum solid ratio for all CCDs underflow. Because of this reason, flocculant is added to the feed wells of the CCDs. CCD 1 thickener acts as a prior storage for the secondary neutralization stage.

3.3.5. Secondary Neutralization

The secondary neutralization unit includes a premix tank, four neutralization tanks, a thickener, a thickener overflow tank, and relevant pumps. Pregnant leach solution (PLS) and the secondary neutralization thickener underflow are mixed to help seeding. The mixture is pumped into the secondary neutralization premix tank. This is an agitated tank with a retention time about five minutes. The slurry evacuated with an upcomer from the bottom of the tank feeds to the top of the first secondary neutralization tank. This upcomer system is applied for the other secondary neutralization tanks. The final tank feeds to the secondary neutralization thickener with the help of gravity.

The secondary neutralization tanks are all agitated tanks with residence times of one and a half hours each. Limestone slurry is fed to the first tank to raise the final pH and settle impurities of iron, aluminum, and chromium exactly while reducing nickel and cobalt residue. The most crucial issue for the secondary neutralization thickener is the clearness of the overflow. Potential solid existence will result in contaminating the MHP product in the next stage. The flocculant is included to the feed well of the thickener in order to ensure the clarity and thickened of the solids as much as possible. The thickener overflow is fed to the secondary neutralization overflow tank by the help of gravity and from there is transferred to the MHP premix tank.

3.3.6. Mixed Hydroxide Product (MHP 1) Precipitation

The MHP 1 precipitation unit comprises of a magnesia powder mixing circuit, a premix tank, and three precipitation tanks, a thickener, a thickener overflow tank, and related pumps. Secondary neutralization thickener overflow (pregnant solution) and MHP 1 thickener underflow slurry are mixed in the premix tank to help seeding. This is an agitated tank with a retention time about five minutes. The discharge of this tank is mixed with magnesia powder to raise the pH in order to provide to precipitate nickel and cobalt while minimizing manganese settlement.

The first MHP 1 precipitation tank has a bottom discharge that feeds with an upcomer into the second tank in the unit. This upcomer system is also applied to the final tank and from there the feed is pumped into the MHP 1 thickener. All the tanks are agitated with residence times of forty minutes each. The flocculant is included to the feed well of the thickener in order to ensure the clarity and thickened of the solids as much as possible. The thickener overflow is fed to the MHP 1 overflow tank by the help of gravity and there transferred to the MHP 2 premix tank.

3.3.7. Mixed Hydroxide Product (MHP 2) Precipitation

The MHP 2 precipitation unit comprises of a premix tank, two precipitation tanks, a thickener, a thickener overflow tank, and related pumps. MHP 1 overflow and MHP 2 thickener underflow slurry are mixed in the premix tank to help seeding. This tank is an agitated tank with a residence time of about five minutes. The discharge of the tank is fed to first MHP 2 precipitation tank with an upcomer system. This upcomer system is the same with the other MHP 2 precipitation tanks as well. These are agitated tanks have residence times of one hour each. The substances of the final tank are transferred to the MHP 2 thickener with the help of gravity.

Slaked lime is added to the first tank to increase the final pH and settle any remaining nickel and cobalt in solution. The flocculant is included to the feed well of the thickener in order to ensure the clarity and thickened of the solids as much as possible. A steady pace of the thickener underflow is fed back to the MHP 2 premix tank for the duty of seed. The remaining part is fed to the recycle leach tank to regain the nickel and cobalt. The thickener overflow is transferred with the influence of gravity to the MHP 2 overflow tank and then pumped to the manganese removal unit or limestone plant.

3.3.8. Manganese Removal

The manganese removal unit comprises of three precipitation tanks, a thickener, a thickener overflow, and relevant pumps. MHP 2 thickener overflow slurry and manganese removal thickener underflow are mixed in the first manganese removal tank to help seeding. This tank is an agitated tank with a residence time of about five minutes. The discharge of the tanks is fed to the top of subsequent tank with an upcomer system. The manganese removal tanks are agitated tanks have residence times of one hour each. The substances of the final tank are transferred to the manganese removal thickener with the help of gravity.

Slaked lime is added to the first tank to increase the final pH and settle any remaining manganese in solution. The flocculant is included to the feed well of the thickener in order to thicken of the solids as much as possible. A steady pace of the thickener underflow is fed back to the first manganese removal tank for the duty of seed. The remaining part is fed to the final neutralization. The thickener overflow is transferred by the help of gravity to the manganese removal tanks and then pumped to CCD 6 feed tank to serve as a wash solution.

3.3.9. Final Neutralization

Final neutralization unit has two agitated tanks with one hour residence time each. The CCD 6 underflow and manganese removal thickener underflow are transferred to the final neutralization tanks and then are pumped to the tailings pond. Waste storage surface water is fed to the plant to be reutilized. Slaked lime from a ring main is added to optimize the pH that can be pumped to tailings.

3.3.10. Sulphuric Acid

The acid is distributed to the CCD 6 feed tank and demineralized water plant, as required, by a centrifugal solution pump. High pressure acid leach plant is fed using high pressure acid pumps.

3.3.11. Lime and Limestone

Slaked lime and limestone slurry are supplied by the client. Limestone slurry is delivered to the limestone storage tank and is fed to its ring main from there. Slaked lime is delivered into the ring main and the recirculating portion returned to the client. The limestone slurry and slaked lime are mixed in the correct proportions and then sent to process tanks in the process plant with their respective ring mains.

3.3.12. Flocculant

Dry flocculant supplied in bulk bags is fed to three flocculant preparation plants. The bulk bag is placed on a bag breaker where the bag is emptied to a hopper. From the hopper the dry flocculant is metered to a jet – wet mixer that feeds a mixing tank. In the mixing tank the flocculant is diluted with water to the desired concentration for stock flocculant solution.

The mixing tank is emptied to a storage tank in batches using a progressive cavity pump. The storage tank allows flocculant to age and acts as a distribution tank. Stock flocculant is distributed to thickeners using progressive cavity pumps. For further dilutions process water or thickener overflow is used.

3.3.13. Water Resources

Water resources are the cooling water and process water. Process water is using as cooling water. Cooling water is returned to the process water pond. Filtered water is stored in a process water pond. Then, this is pumped to the process plant via two pumps (one operating, one spare). Flow indication is provided in all area branches.

CHAPTER 4

ANALYSIS OF ACCIDENT DATA

4.1. Analysis of Accident Data (2014-2018)

Accident data was gathered from yearly reports. Number of accidents in the related year, information about departments, working areas, jobs, ages, educational status, working year of injured personnel, injured organ, degree of accidents, injury types has been included in these reports. Working hour, shift, day, month of the occurrence time of accidents, accident frequency rate, accident weight rate and also the cause of accident (unsafe situation or behavior) are mentioned in the reports.

Number of accidents between years 2014 and 2018 is 37, 43, 50, 71, and 62 respectively. Analysis of totally 263 accidents was performed in terms of 16 various aspects of accidents within 5-years period. The information about near miss accidents, loss time injury, gender, marital status, and physiological situation of the injured personnel and other specific data for human health risk assessment and psychological survey is not available in the data sources. Accident data between years 2014 and 2018 was collected and the data was analysed according to the departments (Table 4.1, Figure 4.1), working areas (Table 4.2, Figure 4.2), jobs of injured personnel (Table 4.3, Figure 4.3), injury types (Table 4.4, Figure 4.4), degree of accidents (Table 4.5, Figure 4.5), experience of injured personnel (Table 4.6, Figure 4.6), injured organ (Table 4.7, Figure 4.7), age of injured personnel (Table 4.8, Figure 4.8), educational status of injured personnel (Table 4.9, Figure 4.9), unsafe situation and behavior (Table 4.10, Figure 4.10). Accident distribution graphs by working hours (Table 4.11, Figure 4.11), by shifts (Table 4.12, Figure 4.12), by days (Table 4.13, Figure 4.13), by months (Table 4.14, Figure 4.14), and yearly accident frequency rate (Table 4.15, Figure 4.15), accident severity rate (Table 4.16, Figure 4.16) were prepared.

Table 4.1. *Accident data about departments (2014-2018)*

Year	Mechanical Maintenance and Repair	Electrical Maintenance and Repair	Mining Production and Exploration	Logistic and Warehouse	Process	Administrative Affairs	Accounting Department	Laboratory	Environment Department	Occupational Health and Safety	Security	Purchasing Department	Civil Work Department	Other	Research- Development	Total
2014	8	5	7	3	7	2							1	4		37
2015	13	2	1	2	16	5			1	2	1					43
2016	10		4	2	25		2	3	1	1	2					50
2017	8	7	8	2	32	5	1				1	2		2	3	71
2018	21		3	2	22	2		3		1	1		4		3	62

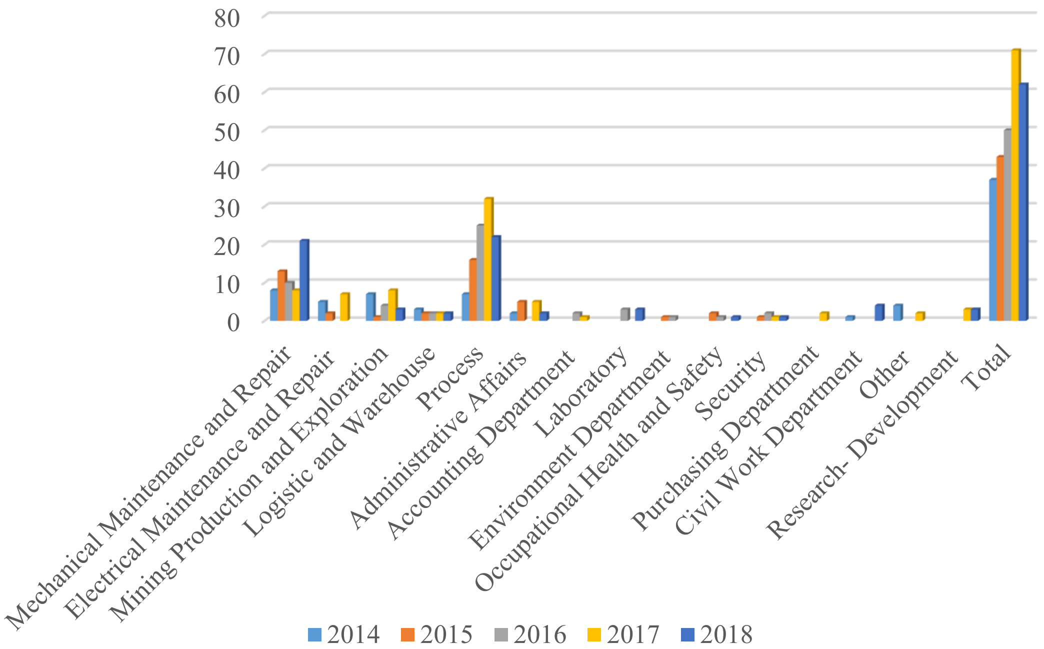

Figure 4.1. Accident distribution by departments (2014-2018)

Table 4.2. *Accident data about working areas (2014-2018)*

Year	HPAL	Waste Storage Facility	Acid Storage	Warehouse	Administrative Building Yard	Ore Preparation Area	Secondary Neutralisation	MHP 1 Circuit	MHP 2 Circuit	Final Neutralisation	Process Ponds	Transformation Stations	Mining Sites	Stockpile	Magnesium Oxide Warehouse	Crushing Screening Area	Agitators	Filter Press	Steam Plant	CCD Circuit	Office Kitchen	Mechanical Workshop	Coal Stock Area	Demineralisation Plant	Field Road	Lime Grinding Mill	Sulphuric Acid Delivery and Storage	Lime Preparation	Welding Shop	Laboratory	Carpenter's Shop	Flocculant	Other	Total
2014	3		3	3	1	2			1		1	1	1	1	1	3			1	4	1	2	5	1	1	1								37
2015	1		1	1	7	4			2		2	1	2		1				3	4		8		1		1		1			1	2		43
2016	11			4	3	2	1	1	1	1	2	2		1		1	1	2				1		1	1		4		3	2			5	50
2017	6	2			5	7				1				1	3	5		1	12			4		2	11		4		2	3			2	71
2018	7	5		2	2	2	1	2		2	3				4	2			4	3		4				3		3	3	3		1	6	62

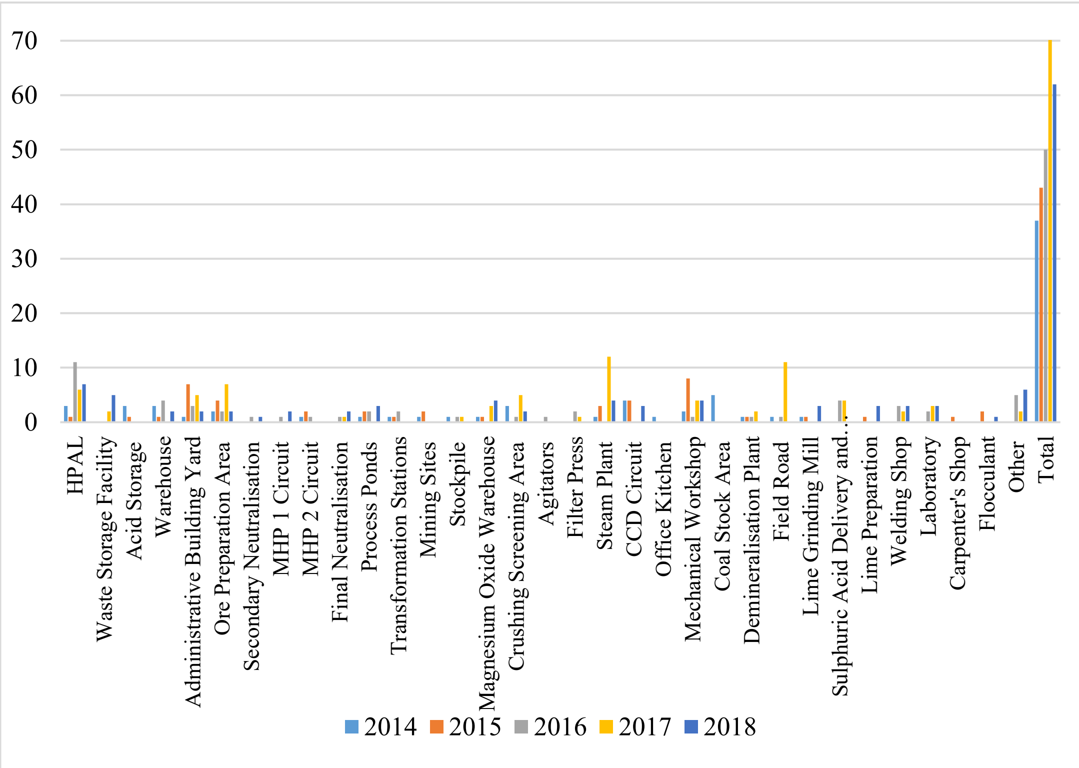

Figure 4.2. Accident distribution by working areas (2014-2018)

According to the departments, employees have accident mostly at process area by 38.78 percent, then at mechanical maintenance and repair department by 22.82 percent and mining production and exploration area by 8.75 percent respectively. Process area are more risky than the other departments because of its highly structured features.

According to the key components of process plant, employees have accident mostly at HPAL area by 10.65 percent, then at steam plant by 7.6 percent and at mechanical work shop by 7.2 percent respectively. HPAL area is most risky than the other working areas due to the high temperature and pressure conditions inherent in its operation. Injury type of burning is mainly associated with steam plant accidents, has the fifth rank as shown in Figure 4.4.

Table 4.3. *Accident data about jobs (2014-2018)*

Year	Security	Operator	Employee	Chemist	Manager	Engineer	Driver	Draftperson	Technican	Plant Operator	Foreman	Foreman Asistant	Visitor	Total
2014	1	5	17	0	0	1	3	1	4	3	1	0	1	37
2015	1	8	17	0	0	1	1	1	5	5	2	1	1	43
2016	1	2	16	0	3	5	1	1	5	11	2	1	2	50
2017	1	6	25	1	1	3	2	1	14	4	9	4	0	71
2018	1	3	18	0	1	1	2	0	12	12	7	5	0	62

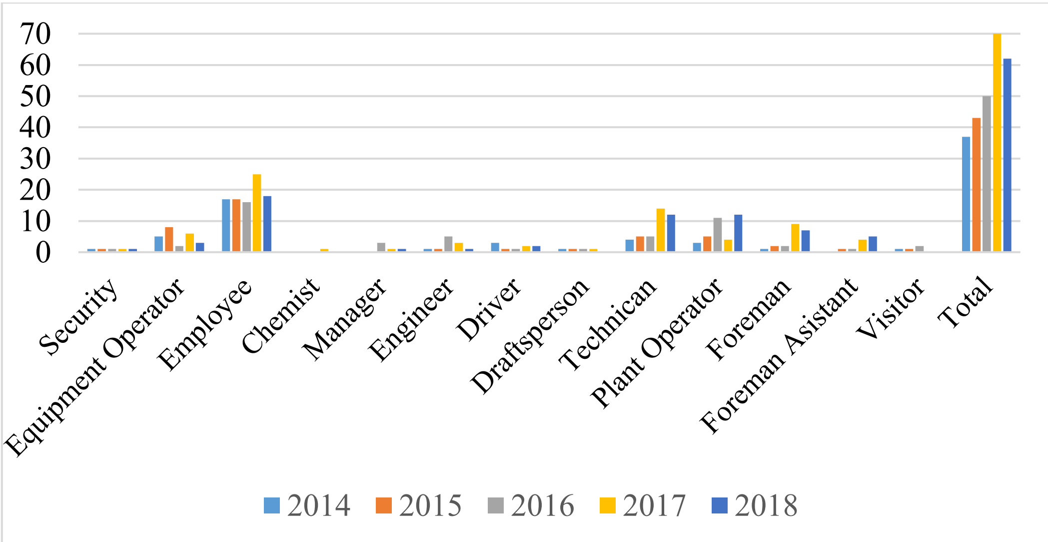

Figure 4.3. Accident distribution by jobs (2014-2018)

On the basis of occupational group that have accident, employees have the first place by 36.50 percent, technicians have the second place by 15.21 percent, and plant operators have the third place by 13.31 percent. Because employees and technicians are mostly working at production stages, they are prone to have an accident and employees are sure of himself/herself due to the opinion of nothing would happen to me. The visitors were also included to accident data as a minor injury type of fifth degree of accident.

Table 4.4. *Accident data about injury types (2014-2018)*

Year	Cutting	Squeezing	Falling	Hitting	Burning	Injury	Breaking	Eye Injury	Flying Object	Sprain	Total
2014	5	4	8	6	4	6	1	0	1	2	37
2015	4	4	12	16	2	1	2	1	0	1	43
2016	5	3	14	18	3	4	1	2	0	0	50
2017	8	14	20	15	2	5	0	2	3	2	71
2018	15	11	16	10	0	4	0	1	1	4	62

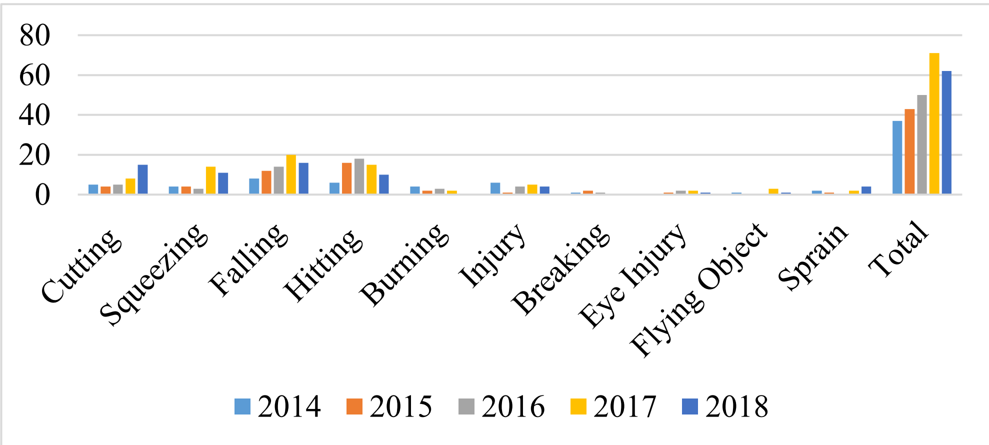

Figure 4.4. Accident distribution by injury types (2014-2018)

In the distribution of accident according to the causes of accident, falling has the most accident ratio that has by 37 percent, then hitting has by 24.71 percent and cutting has by 14.07 percent respectively. Falling is the first reason of other work accidents in the other sectors because workers could not give full attention or focus to work due to various reasons.

Table 4.5. *Accident data about degree of accident (2014-2018)*

Year	1. Degree	2. Degree	3. Degree	4. Degree	5. Degree	Total
2014	0	1	4	3	29	37
2015	0	0	4	3	36	43
2016	0	0	5	1	44	50
2017	0	1	1	1	68	71
2018	0	1	3	3	55	62

Accident data about degree of accident and accident distribution by degree of accident within 5-years period are shown in Table 4.5 and Figure 4.5 respectively.

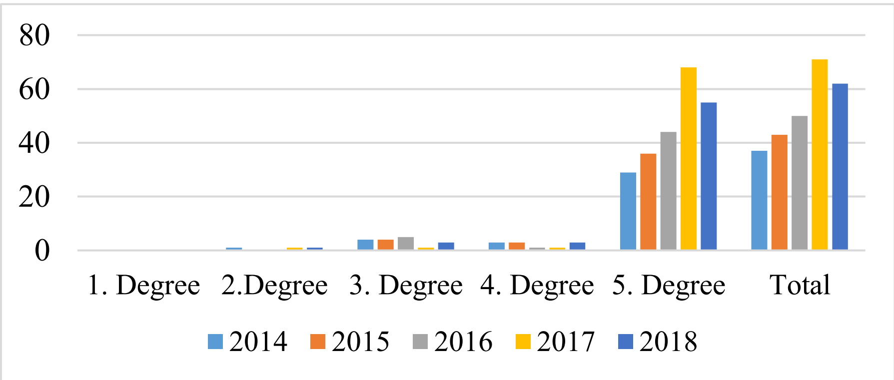

Figure 4.5. Accident distribution by degree of accident (2014-2018)

In the distribution of degree of accident, many accidents are belonging to the fifth degree, small amount of accidents have fourth, third and second degree. Since there is no catastrophic accident resulting in human death, occupational disease, disability or loss of organ in the process plant, 88.21 percent of accidents has fifth degree in five years.

Table 4.6. *Accident data about experience of injured personnel (2014-2018)*

Year	**0-1 year**	**1-3 year**	**3-5 year**	**5-7 year**	**7-10 year**	**10 year and above**	**Total**
2014	6	9	2	5	2	13	37
2015	5	5	4	6	8	15	43
2016	7	6	4	8	8	17	50
2017	10	9	6	11	12	23	71
2018	6	7	9	7	8	25	62

According to the accident distribution by injured personnel experience's, 10 years and above experienced employees have mostly an accident by 35.4 percent and 7-10 years experienced employees has by 14.45 percent, then 5-7 years experienced employees has by 14.07 percent respectively as shown in Figure 4.6.

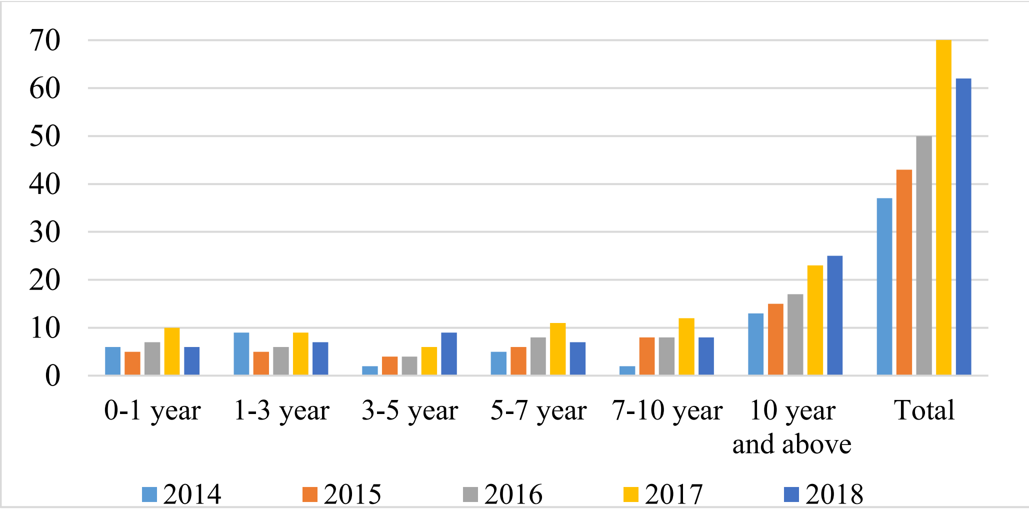

Figure 4.6. Accident distribution by experience of injured personnel (2014-2018)

This process plant has nearly 6 years experiences so the experienced employees have worked in other sectors before this workplace. For this reason, the study about the accident distribution by injured personnel experiences can be more reliable in the forthcoming years.

Table 4.7. *Accident data about injured organ (2014-2018)*

Year	**Finger**	**Hand**	**Arm**	**Head**	**Face**	**Foot**	**Toe**	**Leg**	**Chest**	**Waist**	**Back**	**Other**
2014	8	7	2	4	2	6	1	2	1	1	1	2
2015	12	6	4	5	4	7	0	3	0	2	0	0
2016	8	10	8	6	5	4	0	8	0	1	0	0
2017	10	12	2	11	11	6	2	8	3	2	0	4
2018	15	17	2	6	5	4	5	4	2	2	0	0

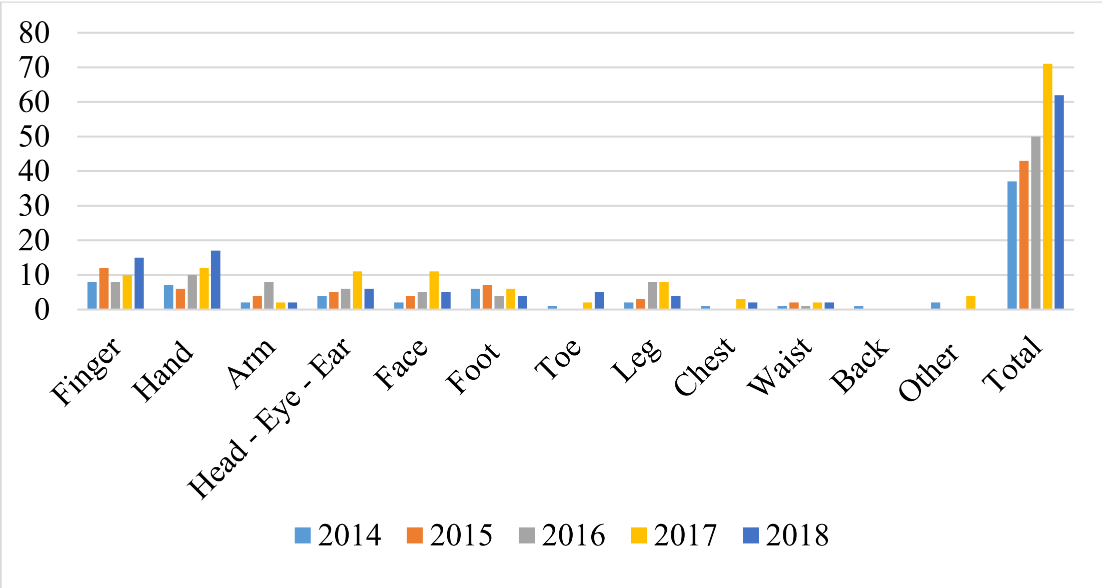

Figure 4.7. Accident distribution by injured organ (2014-2018)

On the basis of effected organ, hand injury has the highest percent by 19.77 and the second one is finger injury has by 16.35 percent and the third one is head-eye-ear injury has by 12.17 percent.

Since mechanical repair and maintenance has required in many stages for process breakdown, most of the hand and finger injury took place during these actions. Major eye irritation occurred owing to contacting with the chemical agents.

Table 4.8. *Accident data about age of injured personnel (2014-2018)*

Year	**20-25 year**	**26-30 year**	**31-35 year**	**36-40 year**	**41-45 year**	**46-50 year**	**50 year and above**	**Total**
2014	7	9	5	13	2	0	1	37
2015	5	9	10	7	7	2	3	43
2016	6	8	12	8	8	5	3	50
2017	10	12	7	15	12	9	6	71
2018	7	7	4	20	10	11	3	62

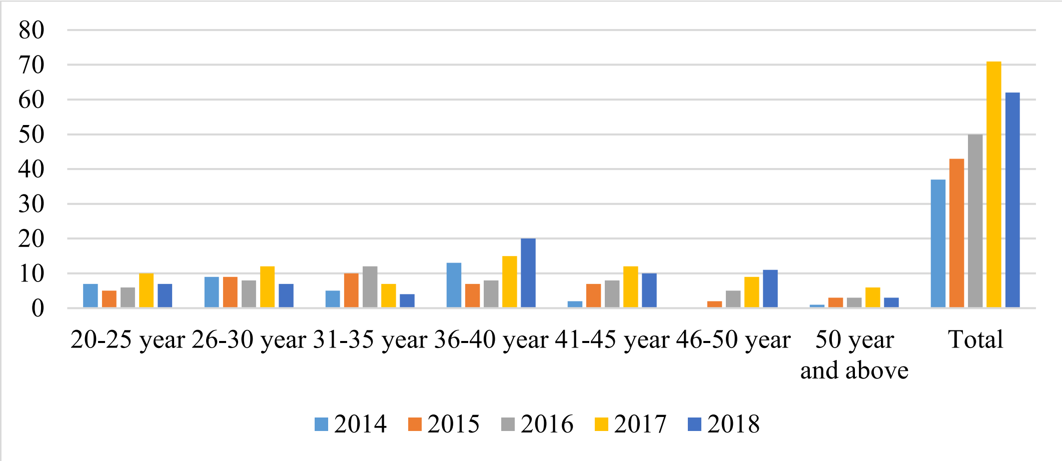

Figure 4.8. Accident distribution by age of injured personnel (2014-2018)

According to the accident distribution by injured personnel age's, between the ages 36-40 have mostly an accident by 23.96 percent, and between the ages 26-30 has by 17.11 percent, then between the ages 31-35 has by 14.45 percent respectively. The workers have old experience on agriculture and livestock breeding so the accident distribution by injured personnel age's can be more reliable in the forthcoming years with detail study.

Table 4.9. *Accident data about educational status of injured personnel (2014-2018)*

Year	**Elementary Education**	**High School**	**Vocational High School**	**Associate Degree**	**Bachelor's Degree**
2014	19	4	7	5	2
2015	20	5	10	2	6
2016	20	10	9	4	7
2017	28	10	15	12	6
2018	28	11	10	12	1

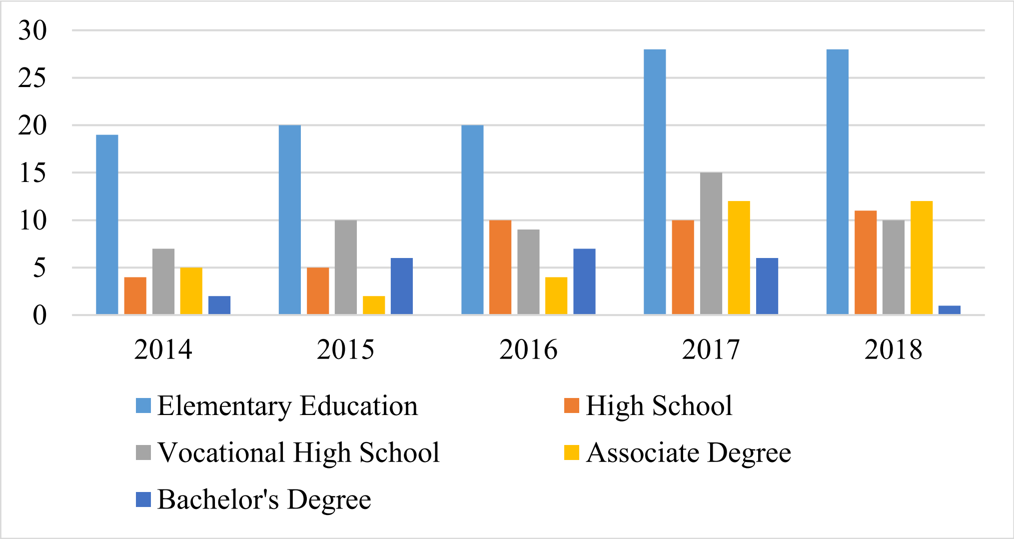

Figure 4.9. Accident distribution by educational status of injured personnel (2014-2018)

According to the accident distribution by injured personnel educational status, elementary school graduated has mostly an accident by 43.73 percent, vocational high school graduated has by 19.39 percent, high school graduated has by 15.21 percent respectively. Poorly educated people commonly have courage of ignorance that they do not play safe.

Table 4.10. *Accident data about unsafe situation and behavior (2014-2018)*

Year	Unsafe Situation	Unsafe Behavior	Total
2014	6	31	37
2015	8	35	43
2016	9	41	50
2017	13	58	71
2018	8	54	62

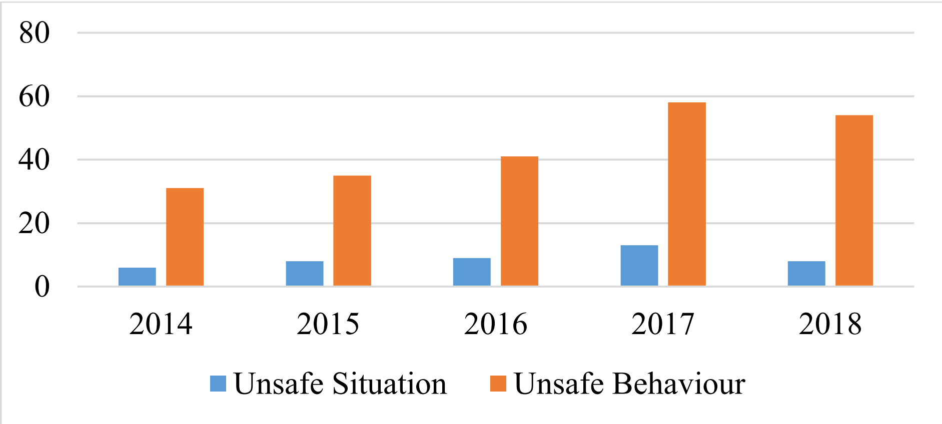

Figure 4.10. Accident distribution by unsafe situation and behavior (2014-2018)

According to the accident distribution by unsafe situation and behavior, the most accident has occurred due to unsafe behavior by 83.27 percent and unsafe situation has by 16.73 percent. The ratio between unsafe behavior and unsafe situation is coherent with the literature data for all workplaces. Thus, the accident ratio can be decreased with the help of qualified occupational health and safety training and creating safety area.

Table 4.11. *Accident data about working hours (2014-2018)*

Year	01 - 03	03 - 05	05 - 07	07 - 09	09 - 11	11 - 13	13 - 15	15 - 17	17 - 19	19 - 21	21 - 24	Total
2014	1	0	1	2	7	7	11	3	2	3	0	37
2015	1	2	0	5	7	5	9	6	2	4	2	43
2016	1	1	1	2	5	9	5	7	10	2	7	50
2017	0	1	3	9	9	5	9	15	10	5	5	71
2018	1	1	0	2	14	9	8	14	5	2	6	62

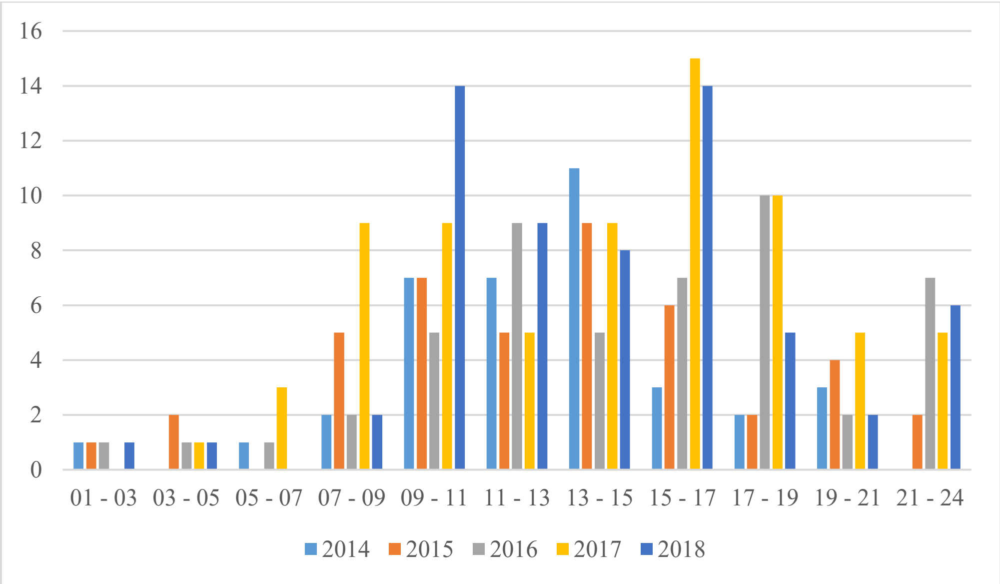

Figure 4.11. Accident distribution by working hours (2014-2018)

According to the accident distribution by hour graph, employees have mostly an accident at the time of 15:00-17:00 and a 17.11 percent, then at the time of 09:00-11:00 and 13:00-15:00 and a 15.97 percent respectively. Employees get tired and loose attention to work towards the end of working hours, so the accident ratio increases due to these physiological effects of employees.

Table 4.12. *Accident data about shifts (2014-2018)*

Year	**1.Shift (00:00-08:00)**	**2.Shift (08:00-16:00)**	**3.Shift (16:00-00:00)**	**Total**
2014	2	29	6	37
2015	3	29	11	43
2016	3	24	23	50
2017	4	39	28	71
2018	2	40	20	62

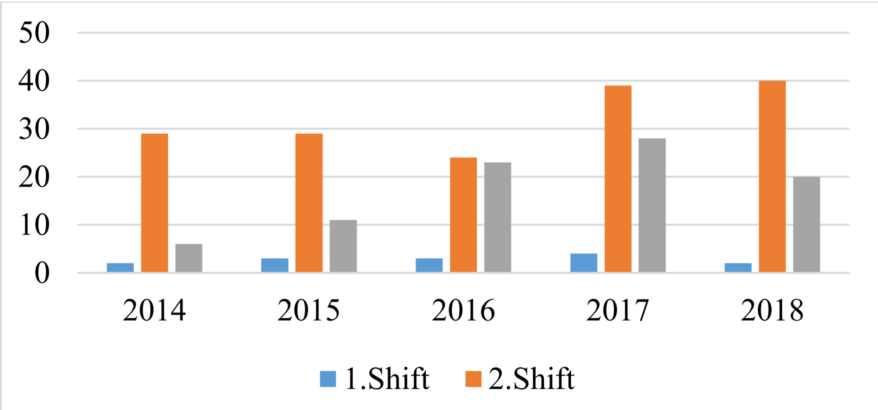

Figure 4.12. Accident distribution by shifts (2014-2018)

According to the accident by shift graph, the many accidents are belonging to the second shift has a 61.2 percent, then the third shift has a 33.5 percent and first shift has a 5.32 percent respectively. Since most accident occurred at a time of 15:00-17:00, it comes up to second shift.

Approximate number of employees in the first shift is 50, in the second shift is 70 and the third shift is 65. Nearly 350 employees work at 08:00- 18:00. Thus, most of the accident occurred at the time between 08:00 and 16:00.

Table 4.13. *Accident data about working days (2014-2018)*

Year	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
2014	2	2	7	13	8	3	2
2015	7	6	6	10	6	3	5
2016	8	9	7	7	2	5	12
2017	11	10	12	6	18	8	6
2018	4	5	17	12	10	8	6

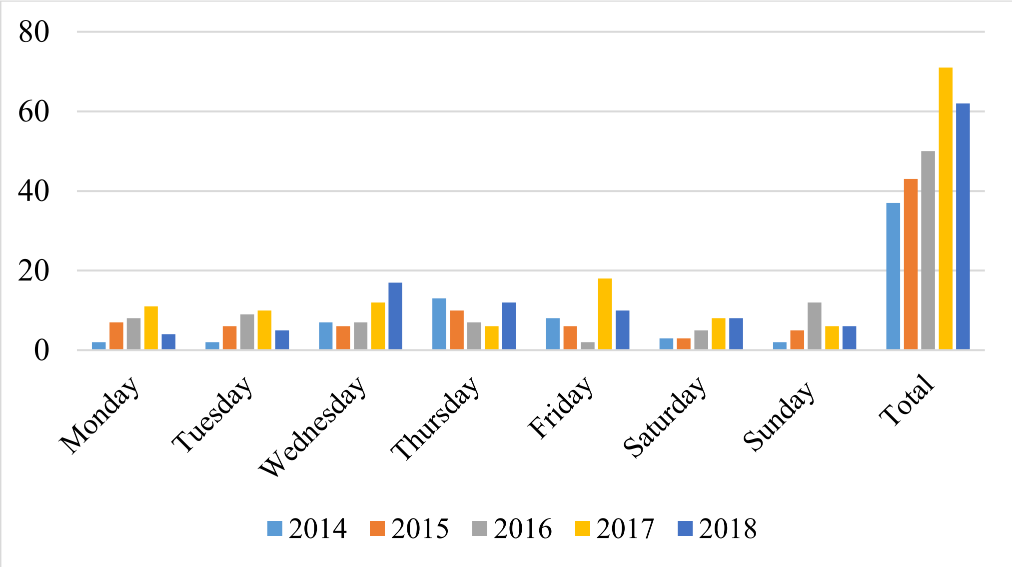

Figure 4.13. Accident distribution by working days (2014-2018)

According to the accident distribution by day graph, employees have mostly an accident in Thursday by 18.88 percent, and Wednesday by 18.15 percent and Friday by 17.77 percent respectively. There is no exact data for the days of accident to justify the cause of accidents except tiredness towards to the weekend.

Table 4.14. *Accident data about months (2014-2018)*

Year	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**10th**	**11th**	**12th**	**Total**
2014	3	1	3	1	6	1	3	1	1	2	6	9	37
2015	4	7	9	5	2	3	1	2	0	6	1	3	43
2016	5	8	10	6	2	3	1	2	1	8	1	3	50
2017	2	7	4	9	4	10	9	6	6	9	1	4	71
2018	2	3	4	4	2	6	6	9	8	10	2	6	62

According to the accident distribution by month graph, the most accident has occurred in October by 13.31 percent, in March by 11.41 percent and in February by 9.89 percent respectively.

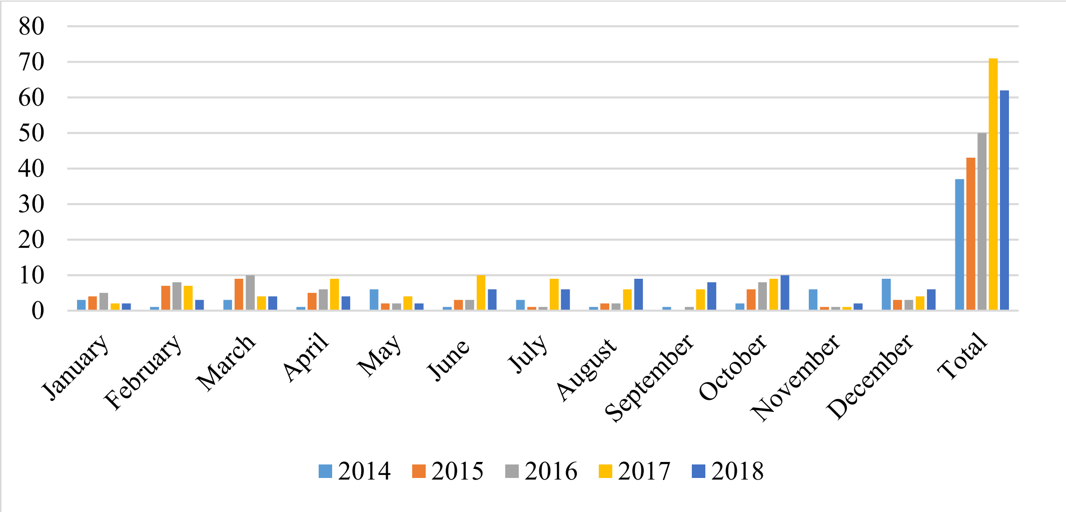

Figure 4.14. Accident distribution by months (2014-2018)

Table 4.15. *Data about accident frequency rate (2014-2018)*

Month	**2014**	**2015**	**2016**	**2017**	**2018**
January	48.71	37.93	45.73	17.99	40.60
February	15.88	66.84	36.77	58.25	45.77
March	44.77	82.34	27.93	36.57	50.30
April	14.23	43.1	28.85	72.46	44.42
May	77.30	16.66	9.70	36.54	35.86
June	12.04	25.99	28.23	85.17	45.05
July	35.57	8.36	35.79	77.48	41.26
August	10.98	17.42	27.25	51.64	30.58
September	10.12	0.00	34.68	32.80	21.34
October	19.16	52.38	8.95	74.98	40.42
November	56.31	9.01	45.43	9.47	32.76
December	86.21	27.28	127.19	35.85	80.88
Annually	36.56	31.68	38.24	49.10	42.44

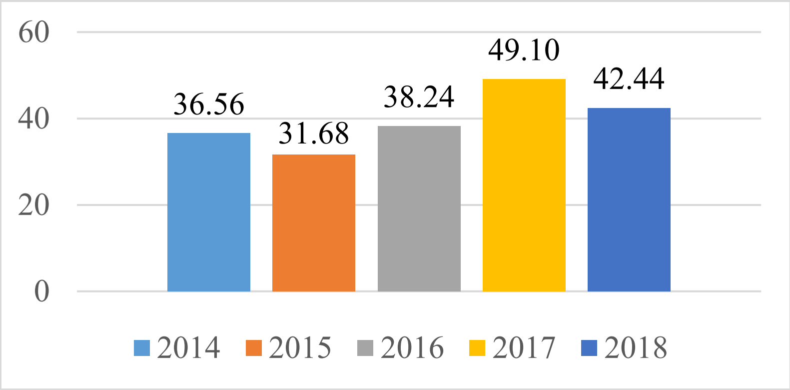

Figure 4.15. Accident frequency rate (2014-2018)

Accident frequency rate formula is the multiplying the number of accident in the reporting period with 200,000 then dividing the employee total hours worked in the reporting period. According to the accident frequency rate, there is no high difference inter-annual. The highest accident frequency rate is 49.10 in 2017 means; in every million hour working, 49.10 number of accident occurs.

Table 4.16. *Data about accident severity rate (2014-2018)*

Months	**2014**	**2015**	**2016**	**2017**	**2018**
January	0.00	0.04	0.00	0.00	0.14
February	0.59	0.32	0.19	0.79	0.47
March	0.31	0.00	0.31	0.00	0.08
April	0.00	0.00	0.00	0.17	0.80
May	0.00	0.00	0.00	0.44	0.11
June	0.00	0.00	1.06	0.00	0.00
July	0.50	0.00	0.01	0.09	0.00
August	0.00	0.00	0.01	0.00	0.00
September	0.02	0.00	0.03	0.00	0.74
October	0.03	0.00	0.00	0.00	0.06
November	0.92	0.00	0.07	0.00	0.13
December	0.11	0.00	0.41	0.27	0.21
Annually	0.21	0.03	0.17	0.15	0.25

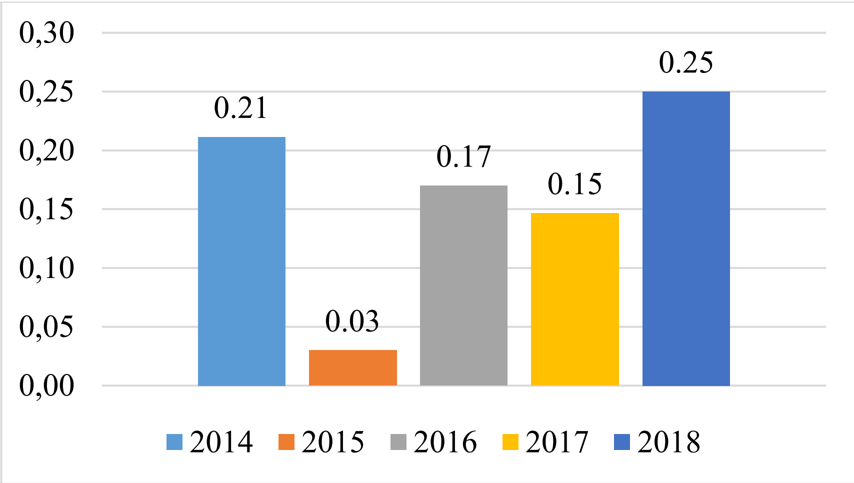

Figure 4.16. *Accident severity rate (2014-2018)*

Accident severity rate formula is the multiplying total loss of working days in the reporting period with 200,000 then dividing the total hours worked in the reporting period. In 2015, there is work accident that low loss of working days. The highest accident severity rate is 0.25 in 2018 means; in every billion working day, 0.25 number of loss of working day occur.

4.2. Summary and Discussions

Accident data analysis of high pressure acid leach of nickel process plant between years 2014 and 2018 reveals that according to the departments and working areas, the most risky area is process plant and HPAL area respectively.

According to the occupational group, employees are more prone to have an accident due to lack of occupational health and safety culture. Concordantly, poorly educated employee has more accident risk. 10 years and above experienced worker whose age range is 36 and 40 has more accident due to vocational blindness and conventional working habits.

Falling and hand injury are the most frequent type of injury and effected organ respectively, because unsafe behaviors are mostly causing accident in the plant.

Unsafe situation has created less accident environment owing to mechanized system and also accidents have the least degree of fifth thanks to the automatization.

Many accident occurs at the time of 15:00-17:00 corresponds to the second shift. Accident distribution, according to the day and month, people have more accident in Thursday and in October respectively. However, the monthly big bag production has no effect on accident distribution because MHP production varied from month to month and year to year. Moreover, there is no production in October in 2015. Nearly 9 percent of the production made in October for years 2016, 2017 and 2018 respectively. Approximately 35 blue-collar and 25 white-collar employees at three shifts are working in the process plant.

CHAPTER 5

WHAT IF ANALYSIS OF HIGH PRESSURE ACID LEACH PLANT

5.1. Introduction

In this chapter, risk assessment was performed for the 11 process circuits described in Chapter 3. Node or circuit can be defined as an established process design connected with the other particular process equipment working as a team in the process plant. The risk assessment is also defined as the study to determine substantial hazards or hazards coming from outside and to analyze the risks caused by hazards and the causative factors that hazards turn into risk and to rank the risks and to determine the control measures.

The purpose of the risk assessment report of the nickel project was to identify, analyze, and document potential safety hazards to personnel, environment and operations of the project. The first step of the risk assessment is the hazard identification. Hazard identification involves broad scale of process industry operations that requires research and development, engineering studies at different phases, routine operation of plants, accident investigations. Among the process hazard analysis (PHA) techniques, hazard and operability study (HAZOP) and failure modes and effects analysis (FMEA) are substantially utilized though these techniques display some deficiencies because of their complicated mold when applied to particular operations (Perret and Adrian, 2001).

What-if analysis is brain storming approach and one of the most commonly used methods for carrying out a (PHA) and the oldest method of PHA techniques of a hazardous chemical process. It is used so widely because making a PHA is simpler than the others (Collins, 2014). For these reasons, what-if analysis was used for this study.

In this study, 4x4 risk matrix was used because moderately low level is an optional and the determination of level between low risk and the moderate risk with assigning the severity and likelihood will be difficult without experienced team.

Worksheets were composed with respect to the identified process nodes of hazards, associated causes, consequences, safeguards and recommendations. 11 nodes were analyzed in 21 subtitles and 155 what-if questions, 130 safeguards, and 115 recommendations were documented in Appendix A. Risk ranking tables was formed in before and risk reduction with the method of what-if analysis. The HPAL area of the plant was identified to be the one most prone to hazards due to the high temperature and pressure conditions inherent in its operation.

5.2. Description of the Process Plant

The working principle of the process plant area is explained in Chapter 3 in detail. The interactions between the circuits, used chemical agents and the operation principles are described under the 11 headings. Recovery stages of nickel and cobalt in hydroxide form is illustrated in Figure 3.4 with the flowchart.

The processes and their nodes that were listed below are analyzed according to the supposed hazards (high pressure, low pressure, high level, low level, high temperature, low temperature, high flow, low flow, leak and rupture, inadequate mixing and equipment malfunction).

Process 1: Ore preparation

- Drum scrubber
- Middlings treatment
- Ore Thickening

- Flocculant Preparation

Process 2: HPAL Area:

- Preheating Circuit
- Pressure Leach Autoclave
- Pressure Acid Leach Scrubber
- CO_2 Scrubber

Process 3: Primary Neutralization

- Recycle Leach and SMBS Tanks
- Primary Neutralization Tanks

Process 4: CCD Circuit

- CCD Thickener

Process 5: Secondary Neutralization

- Secondary Neutralization Tanks
- Limestone Storage and Transfer

Process 6: MHP 1 Circuit

- MHP Precipitation Tanks; MHP Surge Tanks
- MHP 1 Area Thickener and Hose Pumps

Process 7: MHP 2 Circuit

Process 8: Manganese Removal

Process 9: Final Neutralization

Process 10: Sulphuric Acid Storage

- Sulphuric Acid Storage and Transfer

Process 11: Plant Air

- Plant Air System

5.3. Hazard Identification

Hazards, causes, consequences, safeguards, and recommendations are designated according to the list below. Physical (high and low pressure, temperature, level, flow *etc*.) chemical (leak, rupture) and external environment hazards are investigated and listed in risk assessment table.

- Investigate the hazards with regard to circuits.
- Indicate essential equipment and chemical agents used in the study area.
- Analyze the working principle of each unit and decide possible causes, consequences, safeguards and recommendations and risk ranking (before and after risk reduction) of each relevant hazard are written in prepared risk assessment table in terms of process area and are shown in Appendix A.

According to the almost 500 incidents results in the oil and chemical industries, nearly half of the incidents were about maintenance that 15% were related with shutdowns, 14% with startups, 10% with maintenance, and 11% with attending to prevent shutdowns.

Half of incidents could have been avoided with a successful HAZOP but the incidents related with the mechanical breakdowns and installation of the unsuitable material of construction could not been avoided. 22% of the incidents occurred in storage and blending areas, 10% of the incidents realized because of flammable mixtures in the vapor space, 10% of the incidents happened because of mixing a hot liquid and a cold volatile one, 10% of the incidents occurs due to leakage through seals on floating roof.

Like storage tanks, pressure vessels, piping systems associated with corrosion have more risk. 23% of the accidents based on ignition that the source was unkown, while nearly 30% of the ignition based accidents had a source of auto-ignition. Prevalent sources are: flames, hot sources, sparks, lightning, static electricity, and electrical equipment (Kletz, 1999).

As a result, sulphuric acid storage unit, pressure valves, chemical agents, piping systems, and confined spaces like tanks, autoclave were essential worthy of notice areas in the process hazard analysis study.

5.4. The Risk Ranking Assessment

The risk ranking (RR) is based on the consequences of each hazard. It is decided from the severity (S) of the hazard and the likelihood (L) that the hazard will happen, all based on collective judgement of the what-if team.

5.4.1. Severity Table

The severity of a consequence is designated a ranking from 1 (lowest) to 4 (highest). The lowest value of 1 is generally called near miss accident situation. At the highest value of 4, the detrimental effect on health and environment is occurred. A description of the severity ranking is illustrated in Table 5.1.

Table 5.1. *Severity description table (Hyatt, 2003)*

Severity	Description
1	No injury or health impacts
	No damage to the environment
	Negligible process disruption with no flow/low cost of repair/maintenance
2	Minor injury or minor health impacts (reportable incident with no loss of man hours)
	Short-term damage to the environment with a small relapse contained within the plant area
	Minor process disruption with minor cost of repair/maintenance
3	Major injury or major health impacts (reportable incident with some loss of man hours)
	Short-term damage to the environment with a small relapse contained within the plant area
	Major process disruption with high cost of repair/maintenance
4	Death (single or multiple); severe injury or health effects
	Major release to the environment affecting general public and surroundings
	Catastrophic process disruption resulting in a total plant shutdown

5.4.2. Likelihood

The likelihood term is the probability of exist of the defined risk. An indication of the prospective interval with which an accident happens. The likelihood of a consequence is given a ranking between 1 (improbable) and 4 (frequent). A description of the likelihood in Table 5.2.

Table 5.2. *Likelihood description table (Hyatt, 2003)*

Likelihood	Description
1	No expectation of existence of defined risk in process life
2	The defined risk can occur 1-2 times in process life
3	The defined risk can exist several times in process life
4	The defined risk can frequently occur in a year

5.4.3. Risk Ranking

The risk ranking (RR) for each hazard is examined by interpolating between the level of severity and likelihood from the risk matrix that illustrates the acceptability of the risk level. The description of the risk ranking is shown in Table 5.3.

Table 5.3. *Risk ranking description table (Hyatt, 2003)*

Risk Ranking	Description
A	Acceptable – No necessity of control measures.
C	Admissible with Control- The situation is admissible only providing safety measure. May need to incorporate operating procedures to minimize risk.
N	Not desirable- Safeguards should be carried in definite time period. Safeguards in place are not sufficient, may need to introduce more safeguards.
U	Unacceptable – The cases that require immediate action as soon as possible. May result in a major design change.

The Benchmark of the Acceptability: Acceptable risk level means that the situation not results in incident, loss of life and property and corresponds to the legal obligations and avoidance policy of the firms. The decision of the benchmark of the acceptability requires cost/benefit analysis rather than assigning a money worth on human life. All the parameters must be stated in the identical terms in order to guarantee that the risk ranking is defined fairly. Thus, absolute criterion of the risk assessment with regard to main hazards needs sensitivity in decision mechanism (Bjordal, 1980). Consensus on the benchmark of the acceptability level with the Occupational Health and Safety team is very crucial for enchancing risk assessment methods for process plants (Cox, 1982). The acceptability of risk level is described with the severity and likelihood values that is shown in Figure 5.1. Green colored parts are acceptable (low level), yellow colored parts are acceptable with control (medium level), orange colored parts are at high risk level, red colored parts are in extreme risk level that requires urgent safeguards.

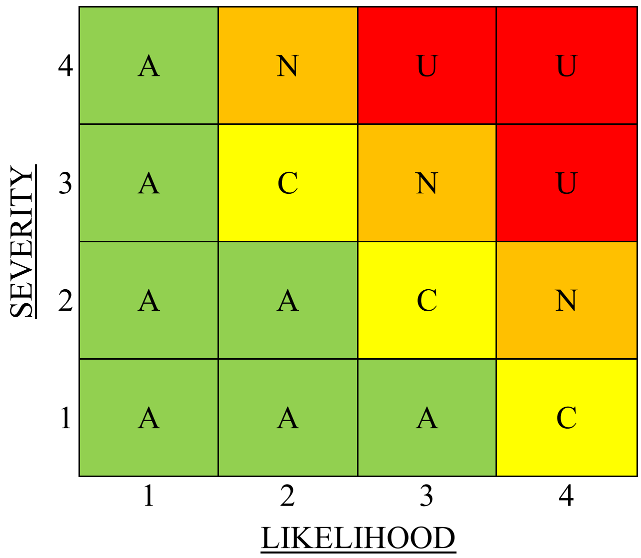

Figure 5.1. Risk assessment matrix (Hyatt, 2003)

The most risky area of the process plant is HPAL unit due to high pressure and temperature conditions inherent in its operation. Risk assessment of HPAL area is illustrated in four tables below. The HPAL area is divided into four area as preheating circuit, pressure leach autoclave, acid leach scrubber and CO_2 scrubber unit. The definitions of hazards are high and low pressure, high and low temperature, high and low level and high and low flow, leak or rupture. Consequences of hazards and risk ranking before risk reduction is assigned with severity and likelihood values. The risk ranking is the result of the nominative standard of judgements with the occupational health and safety team. Risk ranking after risk reduction is determined with regard to safeguards and recommendations in the next stage. The same procedure is applied to other ten nodes' risk assessment tables. The other ten nodes' risk assessment tables are shown in Appendix A.

Hazards were defined with respect to the circuit characteristic. For instance, pressure, temperature, level variances are very important for HPAL area. Possible causes, consequences, safeguards and recommendations were defined in terms of previous studies conducted in this process plant and similar plants risk assessment studies.

In the Table 5.4, high flow of steam from flash vessels can cause high pressure and it can result in overpressure of vessels causing rupture. Since major process disruption with high cost maintenance ranks as 3 and this hazard can occur on an annual basis or more often, severity was ranked as 3 and likelihood was ranked as 4. All safety-critical equipment protection interlocks must be active as a safeguard and including start-up and shutdown requirements for HPAL train to standard operating procedures as a recommendation can decrease the likelihood value to 2 (could occur once during facility life). The high pressure hazard due to closed pressure valve is resulted in shut down or start up of the HPAL area. The severity is assigned as 3 due to major process disruption with high cost maintenance is ranked as 3, and the likelihood is assigned as 2 before risk reduction based on previous studies and engineering judgement. When inherent pressure design of system can be arranged as a safeguard and changing pressure safety valve set point to lower pressure value as a recommendation, the likelihood value can decrease to 1 (not expected to occur during facility life) after risk reduction part.

Loss of high pressure steam from flash drums can cause low pressure and low temperature and they can result in potential brick implosion and equipment damage due to rapid depressurization. Since major process disruption with high cost maintenance ranks as 3 and this hazard can occur several times during facility life, severity was ranked as 3 and likelihood was ranked as 3. Level valve was preferred as a safeguard and pressure valve can be stroked in normal operation as a recommendation, the likelihood value can decrease to 2 (could occur once during facility life)

Gasket or line failure can cause leak or rupture that can bring about personnel injury to death or significant property damage. Since death or severe injury or health effects and major release to environment affecting general public and surroundings rank as 4 and these hazards can occur once during facility life, severity was ranked as 4 and likelihood was ranked as 2. All instruments must have double sleeve with pressure and temperature indication as a safeguards and making HPAL area as controlled – access and providing preventative maintenance includes line wall thickness check as a recommendation could not change the value of severity and likelihood value.

Table 5.4. *Risk assessment of preheating circuit on HPAL area before risk reduction*

What if	**Causes**	**Consequences**	**Before Risk Reduction**		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Pressure valve fails closed	1.Shut down or start up (cooling fluid down but flashes generating pressure)	3	2	C
	2. High flow of steam from flash vessels due to start-up (MP&HP flash vessels)	1.Overpressure of MP & HP vessels causing potential rupture (HP steam is 5400 kPa)	3	4	U
2.Low pressure	1.Loss of HP steam to flash drums	1.Potential brick implosion & equipment damage due to rapid depressurization	3	3	N
3. High flow	1. High flow of HP steam to flash drums	1.Overpressure of MP & HP vessels causing potential rupture (HP steam is 5400 kPa)	3	4	U
4.Low/no flow	1.Leach feed pump failure	1.Potential brick implosion & equipment damage due to rapid depressurization	3	3	N

Table 5.4. *Risk assessment of preheating circuit on HPAL area before risk reduction (Cont.'d)*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
5. High level	1.Blocked discharge on LP heater	1.Mechanical damage to the flash vessel and piping when the slurry passes past the choke tube into the steam piping	4	3	U
	2.Blocked discharge on MP heater	1.Mechanical damage to the flash vessel and piping when the slurry passes past the choke tube into the steam piping	4	3	U
6. Low level	1.Loss of feed to LP heater	1.Loss of slurry feed resulting in loss of consumption of steam from flash vessel and high pressure in the system	4	3	U
	2.Loss of feed to MP heater	1. Loss of slurry feed resulting in loss of consumption of steam from flash vessel and high pressure in the system	4	3	U
	3.Loss of feed to HP heater	1.Loss of slurry feed resulting in loss of consumption of steam from flash vessel and high pressure in the system	4	3	U
	4.Loss of feed to LP/MP/HP flash vessels	1.Mixed phase flow to the next flash vessel causing excessive vibration and possible mechanical damage	4	3	U
7.High temperature	1.High flow of HP steam to flash drums	1.Overpressure of MP & HP vessels causing potential rupture (HP steam is 5400 kPa)	3	4	U
8.Low temperature	1.Loss of HP steam to flash drums	1.Potential brick implosion & equipment damage due to rapid depressurization	3	3	N
9.Leak/rupture	1.Gasket failure	1.Personnel injury to death	4	2	N
	2.Line failure	1.Personnel injury to death	4	2	N
		2.Significant property damage	4	2	N
10.Falling of materials or workers	1.Wrong position of deck ladder, the lack of insulation plate in front of the panel, the absence of warning sign at HP flash vessel area	1.Falling of material, personnel injury, electric shock	4	4	N

Table 5.5. *Risk assessment of preheating circuit on HPAL area after risk reduction*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Inherent pressure design of system well above operating pressure	1.Including start-up and shutdown requirements for HPAL train to standard operating procedures 2.Change pressure safety valve set point from 1300 kPa to 1265 kPa	3	1	A
	1.All safety-critical or equipment protection interlocks are active when in manual or local	1.Including start-up and shutdown requirements for HPAL train to standard operating procedures	3	2	C
2.Low pressure	1.Level valve can close limiting pressure loss	1.Pressure valve is stroked in normal operation (e.g. 1/week)	3	2	C
3. High flow	1.All safety-critical or equipment protection interlocks are active when in manual or local	1.Including start-up and shutdown requirements for HPAL train to standard operating procedures	3	2	C
4.Low/no flow	1.Level valve can close limiting flow loss	1.Pressure valve is stroked in normal operation (e.g. 1/week)	3	2	C
5. High level	1.Two level detectors are in place for each vessel	1.Integrate the high-high level on all three flash vessels into the Emergency Shut Down function to shutdown the HPAL	3	2	C
	1.Two level detectors are in place for each vessel	1.Integrate the high-high level on all three flash vessels into the Emergency Shut Down function to shutdown the HPAL	3	2	C
	1.Inherent pressure design of system well above operating presuure	1.Including start-up and shutdown requirements for HPAL train to standard operating procedures	3	1	A

Table 5.5. *Risk assessment of preheating circuit on HPAL area after risk reduction (Cont.'d)*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
6. Low level	1.Vent valves in place	1.Level control valve on leach surge tank in place to control level of LP heater MP flash in place to control level of HP flash	3	2	C
	1.Vent valves in place	1.Level control valve on LP heater in place to control level of MP heater MP flash in place to control level of HP flash	3	2	C
	1.Vent valves in place	1.Level control valve on MP in place to control level of HP heater MP flash in place to control level of HP flash	3	2	C
	1.High integrity level detection in place	1.Provide low level alarm monitoring for flash vessels	4	1	A
7.High temperature	1.All safety-critical or equipment protection interlocks are active when in manual or local	1.Including start-up and shutdown requirements for HPAL train to standard operating procedures	3	2	C
8.Low temperature	1.Level valve can close limiting pressure loss	1.Pressure valve is stroked in normal operation (e.g. 1/week)	3	2	C
9.Leak/rupture	1.Maintenance procedures to include the checking the cladding thickness underneath the vessels	1.Searching flange guards for high pressure and high temperature systems 2.Make HPAL area as controlled - access	4	2	N
	1.All instruments have double sleeve with pressure and temperature indication	1.Make HPAL area as controlled - access 2.Providing preventative maintenance includes line wall thickness check	4	2	N

Table 5.5. *Risk assessment of preheating circuit on HPAL area after risk reduction (Cont.'d)*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
10.Falling of materials or workers	1.Changing the way of deck ledder, placing insulation plate in front of the panel and warning sign on the panel	1.Signage warning of electric shock to be placed in all applicable areas	4	1	A
	1.Making platform for accessing the connection point with flange	1.Review the design of access of vessels' conection points in case of emergency	4	1	A

Table 5.6. *Risk assessment of pressure leach autoclave node on HPAL area before risk reduction*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.High flow of HP steam	1.Overpressure of autoclave	4	1	A
2.Low pressure	1.Pressure valve is fully open	1.Poor leaching and high steam consumption	1	3	A
	2.Hand drive valve is fully open	1.Rapid depressurization of autoclave leading to equipment damage and loss of containment	4	2	N
3.High flow	1.High slurry flow from autoclave feed pumps	1.High level in autoclave leading to overpressure	4	3	U
4. Low/no flow	1.Loss of feed from HP heater (pump shut off, valve fail closed)	1.Possible backflow of acidified slurry towards autoclave feed pumps	2	1	A
	2.Loss of sulfuric acid feed	1. Acid lance heats up; enables long-term corrosion of acid lance leading to loss of containment	3	3	N
	3.Loss of HP steam	1.Backflow of acidified slurry towards steam system	4	3	U

Table 5.6. *Risk assessment of pressure leach autoclave node on HPAL area before risk reduction (Cont.'d)*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
4. Low/no flow	4. Loss of air	1.Backflow of acidified slurry towards steam system	4	3	U
		2.Unable to purge acid lance during shutdown	4	2	N
5.High level	1.Blocked discharge	1.Overpressure of autoclave	4	1	A
6. Low level	1.Loss of feed from HP heater (pump shut off, valve fail closed)	1.Damage to vessel due to concentrated acid not being adequately mixed	2	1	A
7.Leak/rupture	1. Low/ no flow of seal water	1. Loss of containment around agitators	3	3	N
	2. Low/no flow of cooling water	1. Loss of containment around agitators	3	2	C
	3. Low/no flow agitator flush water	1. Loss of containment around agitators	2	2	A
	4. Flange gasket failure	1.Personnel injury up to death	4	3	U
	5.Loss of sulphuric acid feed	1.Acid lance heats up; enables long-term corrosion of acid lance leading to loss of containment	3	3	N

Table 5.7. *Risk assessment of pressure leach autoclave node on HPAL area after risk reduction*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Design pressure of autoclave is same as high pressure steam design	1. Confirm pressure and temperature variances in steam supply	4	1	A
2.Low pressure	1.Pressure monitoring and control on the autoclave	1. Level valve can close limiting pressure loss	1	3	A
	1.A software lock limits max valve opening %; limit is based on autoclave pressure	1.Manually monitor pressure of the acid supply line at determined points during upset conditions	4	2	N
3.High flow	1.Level indicate control is on high alarm and interlock	1. Add an additional pump to accommodate the increased flow pump to accommodate the increased flow.	4	1	A
4.Low/no flow	1.Pressure safety valve to prevent overpressure of autoclave	1.Consider anti-rotation device on heaters	2	1	A
	1.Temperature indicate with high alarm on acid lance line	1.Manually monitor temperature of the acid supply line at determined points during upset conditions	3	2	C
	2.Automated sequenced air purge on low differential pressure	1.Check the design of acid lance to include possible pressure monitoring			
	1. Related pressure differential indicate with high alarm on acid lance line	1.Ensure hand valve close on low related pressure differential indicate	4	2	N
	1. Related pressure differential indicate with high alarm on acid lance line	1.Ensure hand valve close on low related pressure differential indicate	4	2	N
	1.Air reservoir associated with autoclave feed pump package	2.Confirm sufficient air available from vendor package air reservoir for acid lance purges and short term operation of agitator seal water pumping	4	1	A
5.High level	1.Design pressure of autoclave is same as high pressure steam design	1.Confirm pressure and temperature variances in steam supply	3	2	C

Table 5.7. *Risk assessment of pressure leach autoclave node on HPAL area after risk reduction (Cont.'d)*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
6. Low level	1.Pressure safety valve is sized in flash vessel	1. Emergency Shut Down function to shut down acid pump operation	2	1	A
7.Leak/rupture	1. Surge capacity in the Ekato seal water system	1.Ensure agitator and seal water vendor package provide adequate alarms and interlocks to safely shutdown system with respect to interfaces outside the package and power failures	3	3	N
		1.Ensure agitator and seal water vendor package provide adequate alarms and interlocks to safely shutdown system with respect to interfaces outside the package and power failures	3	2	C
	1. Surge capacity in the Ekato seal water system	1.Ensure agitator and seal water vendor package provide adequate alarms and interlocks to safely shutdown system with respect to interfaces outside the package and power failures	2	2	A
	1.All instruments have double sleeve with pressure indication	1.Investigate flange guards for high pressure and high temperature systems	4	3	U
		2. Make HPAL area as controlled access	4	3	U
	1.Temperature indicate with high alarm on acid lance line	1.Manually monitor temperature of the acid supply line at determined points during upset conditions	3	2	C
	2.Automated sequenced air purge on low differential pressure	1.Check the design of acid lance to include possible pressure monitoring	3	2	C

Table 5.8. *Risk assessment of pressure acid leach scrubber node on HPAL area before risk reduction*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Failure of level indicator-transmitter floods vent scrubber leg	1.Loss of venting in recycle leach resulting in overpressure and potential rupture	3	3	N
2.Low pressure	1.Vacuum build-up during shutdown and cooling of equipment	1. Equipment damage	4	4	U
3.High flow	1. High flow of water into the venturi	1.The emission criteria is exceed	4	4	U
4. Low flow	1. Pump failure	1.High level in venturi scrubber	3	3	N
		2.Loss of venturi scrubber spray, causing loss of heat recovery, loss of venturi and rod deck spray leading to environmental issues	3	3	N
5. High level	1.Failure of level indicator-transmitter floods vent scrubber leg	1.Loss of venting in recycle leach resulting in overpressure and potential rupture	3	3	N
6. Low level	1.Insufficient make-up water	1. Pump cavitation	3	4	U
		2.Environmental release	3	4	U
7.High temperature	1.High temperature resulting in pump cavitation	1.Pump cavitation resulting in equipment damage	4	4	U
8.Leak / rupture	1.Gasket failures	1. Personnel injury to death	4	2	N
	2. Line failures	1.Personnel injury to death	4	2	N
		2.Significant property damage	4	2	N

Table 5.9. *Risk assessment of pressure acid leach scrubber node on HPAL area after risk reduction*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Operating and standby level indicator transmitter	1.Ensure 2*100% pumps with auto-start of second pump on high level of level indicator-transmitter	3	3	N
2.Low pressure	1.Level valve can close limiting pressure loss	1.Pressure acid leach scrubber unit to be vacuum-protected	4	1	A
3.High flow	1.Flow control in place	1.Ensure the flow control loop that is correctly set	4	3	U
4. Low flow	1.Operating and standby pump	1.Ensure 2*100% pumps with auto-start of second pump on high level of level indicator-transmitter	3	2	C
		1.Consider adding a flow alarm on water to spray nozzles inside stack	3	2	C
5. High level	1.Operating and standby level indicator transmitter	1.Ensure 2*100% pumps with auto-start of second pump on high level of level indicator-transmitter	3	3	N
6. Low level	1.Pumps will trip on low low level	1.Make control scheme to regulate the flow into the venturi scrubber and provide make-up flow	3	2	C
7.High temperature	1. Pump NPSH is designed for 95°C	1.Add temperature indicators on the pump discharge	3	4	N
8.Leak / rupture	1.Ensure compatibility of material of construction is adequate to handle minor leaks	1.Searching flange guards for high pressure and high temperature systems	4	2	N
		2. Make HPAL area as controlled - access			
	1. All instruments have double sleeve with pressure and acidic indication	1. Make HPAL area as controlled - access	4	2	N
		2.Providing preven- tative maintenance includes line wall thickness check	4	2	N

Table 5.10. *Risk Assessment of CO_2 Scrubber Node on HPAL Area before risk reduction*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Failure of level valve to control scrubber level	1.High level in CO_2 scrubber exceeding the level of vent nozzle entering the scrubber resulting in overpressure of primary neutralization tanks	3	3	N
2.High flow	1.Process water supply fully open	1.High level in CO_2 scrubber sump resulting in blocking the vent line	4	4	U
3. Low flow	1.Leach vent scrubber pump failure	1.Loss of CO_2 scrubbing capability	2	3	C
	2.CO_2 scrubber pump failure	1. High level in CO_2 scrubber	3	3	N
4. High level	1.Failure of level valve to control scrubber level	1. High level in CO_2 scrubber exceeding the level of vent nozzle entering the scrubberi resulting in overpressure of primary neutralization tanks	3	3	N
5. Low level	1.Insufficient supply of venturi scrubber bottoms	1. Pump cavitation	2	3	C
		2.Environmental release	2	3	C
6.High temperature	1.No flow of demineralised water to demineralised water heater	1.Potential loss of acidic vapour to atmosphere	3	3	N
7. Leak/rupture	1.Gasket failures	1. Personnel injury to death	4	2	N
	2. Line failures	1.Personnel injury to death	4	2	N
		2. Significant property damage	4	2	N

Table 5.11. *Risk Assessment of CO_2 Scrubber Node on HPAL Area after risk reduction*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Pressure safety valve to prevent overpressure of primary neutralization tanks	1.Ensure 2*100% pumps with auto-start of second pump on high level of level indicator-transmitter	3	3	N
2.High flow	1 Relief hatches on primary neutralization tanks	1.Review the requirement for U-tube on overflow	4	1	A
3. Low flow	1.Operating and standby pump	1.Ensure 2*100% pumps with auto-start of second pump on high level of level indicator-transmitter	2	2	A
4. High level	1.High high level trip will shut down the plant	1.Ensure 2*100% pumps with auto-start of second pump on high level of level indicator-transmitter	3	3	N
5. Low level	1.Pumps will trip on low low level	1. Make control scheme to regulate the flow into the CO2 scrubber and provide make-up flow	2	2	A
	2.Process water make up		2	3	C
6.High temperature	1.Process water supply on temperature control	1.Evaluate amount of process water required in the event of demineralised water failure	3	2	C
7. Leak/rupture	1.Ensure compatibility of material of construction is adequate to handle 80all80 leaks	1. Searching flange guards for high pressure and high temperature systems 2. Make HPAL area as controlled – access	4	2	N
	1. All instruments have double sleeve with pressure indication and acidic corrosion	1.Review type of scrubber heat exchanger to minimize fouling issues	4	2	N
		2.Providing preventative maintenance includes line 80all thickness check	4	2	N

5.5. Summary and Discussions

HPAL process, is a high-end technology, which comprises selective dissolution of nickel and cobalt in a titanium alloyed autoclave reactor at 255°C temperature and 46 bar pressure.

In this hydrometallurgical process, the mud which is fed to the high-pressure system, is heated in three stages gradually with recycled vapor from expansion tanks, transferred to the autoclave reactor by pumps and dissolved with sulfuric acid.

The temperature and pressure values of the heaters, autoclave and flash vessels are illustrated in Table 5.12. Because, the values are so high, working mechanism of the system should be confined, monitored and sensor- fitted in every phase.

Table 5.12. *Temperature and pressure values of heaters, autoclave and flash vessels*

Node	Temperature (°C)	Pressure (kPa)
LP Heater	80	Atmospheric circumstances
MP Heater	165	561
HP Heater	198	2000
Autoclave	255	4600
HP Flash Vessel	210	1850
MP Flash Vessel	159	561
LP Flash Vessel	110	90

5.5.1. U (Unacceptable) Area of Process Plant and Possible Resolutions

U – (Unacceptable – Risk control measures should be introduced at the earliest opportunity. May result in a major design change.)

1- HPAL – Pressure Leach Autoclave- Flange gasket failure

Gasket failure can occur because of the poor design and gaskets cannot be robust enough for the application area. Multiple layer steel replacement gaskets and secondary containment can be reliable solution for this situation.

2- Pressure Acid Leach Scrubber- High flow

Flow control mechanism that arranges the flow or pressure of liquid. Flow control is important issue for process plants where there are many control loops that regulate special parameter like flow, temperature, pressure and level. Flow control valves are used to be able to hold flow control properly. With the help of convenient flow control, the quality of the product can be ensured and any corrosion or leakage damage can be avoided.

3- CCD Circuit - CCD Thickener and MHP 2 Circuit- Leak/rupture

The materials and products' features inside the tanks and maximum potential effects must be known in the case of unintended release. Emergency responders that assess the potential outcomes of the problem must eliminate ignition sources and take an action to rescue persons and protect property or the environment with the least risk.

4- Sulphuric Acid Storage- High pressure, low pressure, high flow, high temperature

This corrosive chemical needs specific designed storage systems. Tank material selection to get necessary structural strength, tank size and tank configuration play an important role for ensuring safe storage of sulphuric acid. In the event of storage tank leakage, secondary containment can capture the leak before it causes a risk to personnel or facility. Temperature, pressure and flow monitoring in the storage tank considerably reduces the any risk.

5- Plant air- High temperature, no/low flow, high level

Temperature and flow monitoring in compressors can reduce the problems related with the temperature and level.

6- General – Operational/ Maintenance issues - Moving, rotating, energized equipment

Providing protection machinery safeguarding like fixed, interlocking guards, automatic adjusting guards; control panels placed at safe distances and sensors, gates and shields can be used additionally according to the equipment's specialties.

Emergency stops must always be in working order. Safe work procedures can be enhanced and used in training that only authorize persons can carry out the work around the equipment.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusion

In this process plant, the metallurgical process is operated to extract the nickel and cobalt elements in solution with the method of high pressure acid leach and to settle nickel and cobalt in hydroxide form.

In this study area, the risk assessment of the extraction of nickel and cobalt by high pressure acid leaching (HPAL) of a refractory limonitic nickel laterite ore from the Gördes region of Manisa in Turkey was performed.

Worksheets were composed with respect to the identified process nodes of hazards, associated causes, consequences, safeguards and recommendations. 11 nodes were analyzed in 21 subtitles and 155 what-if questions, 130 safeguards and 115 recommendations were documented in Appendix A.

The compulsory risk assessment is submitted to Ministry of Family, Labor and Social Services in 2018 includes only physical hazards like deformation of barriers, falling of materials. In addition, previous study of mini HAZOP was conducted by SNC-Lavalin in 2013. This study involves the parameters about human safety, production safety and efficiency and also the analysis of accident data within 5-years period.

The answers of the research questions of this study are stated in first chapter are given below:

- How can the hazards be defined for more hazardous units?

The previous accident data results guided to define the hazardous units and high level of risks. Pressure and temperature related hazards, leak or any rupture, hazards related sulphuric acid storage was the priority for the study because explosion, fire and toxicity are the main issues of the hazard identification.

- Where are the risky areas of the HPAL plant?

The most risky area is HPAL area due to working principle by high pressure and high temperature and widespread impact area. Sulphuric acid storage area and plant air unit are the second risky area due to high number of unacceptable risk ranking definition. Mixed hydroxide product 2 unit (MHP 2) and then counter current decantation unit (CCD) follow this sorting. Ore preparation area, MHP 1, primary and secondary neutralization have similar risk importance. Finally, manganese removal and final neutralization have approximate value of risk ranking.

- What can be the safeguards to prevent the potential hazards?

Some hazardous units have unacceptable level of risk in the process plant that can be decreased by level, flow, pressure, temperature monitoring, control valves, secondary containments, interlock systems, spare pumps, level alarms *etc.* The safeguards of each unit hazards are illustrated in the what-if analysis shown in Appendix A.

Results of the what-if analysis and analysis of accident data show that:

i. HPAL area is the most risky area due to high pressure and temperature conditions inherent in its operation.

ii. The hazards that have unacceptable level of risk are:
Flange gasket failure at pressure leach autoclave in HPAL area, high flow at pressure acid leach scrubber in HPAL area, leak or rupture at CCD thickener

in CCD circuit and MHP 2 circuit, high and low pressure, high flow and high temperature at sulphuric acid storage, high temperature, no/low flow, high level at plant air and moving, rotating, energized equipment for whole process area. The expected risky areas which were mentioned in hazard identification part are suitable with the analysis results.

iii. Level, flow, pressure, temperature monitoring, control valves, secondary containments, interlock systems, spare pumps, level alarms, closed circuit camera system can be effective safeguards for preventing or decreasing the high level of risks.

iv. The accident occurred mostly in HPAL area and the process plant among the departments owing to its complicated structure.

v. 83% of the accidents occurred due to unsafe behavior and the falling is the most common injury type. If physiological effects of tiredness and distractibility can be evaluated with the characteristic feature and psychological situation of the worker, the reasons of the accidents will be found exactly. In addition, almost all accidents can be prevented by proper training, development of safety culture and administrative management.

vi. Elementary school graduated worker has mostly an accident a 43.73 percent generally low perception of risk because of lack of consciousness and education.

6.2. Recommendations

The main recommendations concerned with hazard analysis and risk assessment study are:

i. More detailed and quantitative risk assessment methods such as HAZOP should be conducted for this plant for future studies.

ii. Accident data sources should be enhanced to include missing data and specific details about the incidents. For instance, accidents must be classified in terms of near miss and loss time. All accidents must be analyzed in detail with regard to occurrence of accident and injured worker's characteristics.

iii. Modelling of major hazards and concurrence about technical issues and frequency statistics and benchmark of acceptability is a vital subject for the further development of this study.

iv. The specific study of human health risk assessment including environmental pollution and exposure to toxic chemicals by inhalation, ingestion, and skin contact should be conducted for the further enhancement of this study.

v. It must be ensured that signage warning of hot equipment to be placed in all applicable areas periodically.

vi. Occupational health and safety team must ensure that all steel constructions, electrical equipment are grounded from multi point and cable plug and socket connection.

vii. Occupational health and safety training for highly hazardous workplaces, on-the-job training after work accident and occupational illness, on-the-job training includes methods and procedures of safe working for the departments, first aid training organized by Local Health Authority, fire-fighting training, search and rescue training organized by Disaster and Emergency Management Presidency, vocational trainings organized by Vocational Qualifications Authority and Public Education Center, orientation training for the all employees about operations between units are arranged in the process plant. In addition to these, training to be provided for personnel allowed in the HPAL area. Each employee should receive special training about his/her working area.

viii. Work permit required areas must be determined in detail and special training must be arranged to this authorized employees in regular basis.

ix. Consequence modelling scenarios of release of sulphuric acid and slurry can be studied in the future.

x. The maintenance program especially for flange leakages have to be scheduled with industrial hygienist in order to improve surveillance program for all plant area.

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APPENDICES

A. APPENDIX A

Table A.1. *Risk assessment of drum scrubber node on ore preparation process before risk reduction*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.Low/No flow	1.Motor failure around drum scrubber	1.Loss of feed to ore thickener and possible shut- down of HPAL	3	3	N
	2. Loss of feed to the drum scrubber	1.Loss of feed to process	2	4	N
	3.Plugged drum scrubber trommel	1.Loss of feed to process	2	4	N
	4. Loss of feed of water from ore thickener overflow	1.Insufficient wetting of ore resulting in plugging of drum scubber	2	3	C
	5. Loss of ore thickener overflow to drum scrubber discharge screen	1. Plugging of screen due to inadequate washing	3	3	N
	6.Damaged scrubber	1.Loss of feed to processs	3	3	N
	7.Drum scrubber cyclone feed pump failure	1.Loss of feed to cyclone	2	3	C
		2. High level in drum scrubber discharge pump box leading to over-flowing and loss of containment	2	3	C
	8. Rejects pile conveyor failure	1.Unable to discharge rejects from drum scrubber discharge screen resulting in overflowing	2	3	C
2.High flow	1. High flow of raw ore to drum scrubbers	1.Overfilling of drum scrubber leading to potential damage around drum scrubber	2	4	N
	2. Ore thickener overflow feed valves fully open	1. Poor quality of slurry due to inefficient scrubbing	2	3	C
		2. Potential damage to drum scrubber due to overfilling	2	3	C

Table A.1. *Risk assessment of drum scrubber node on ore preparation process before risk reduction (Cont.'d)*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
2.High flow	3. Flow control valve of overflow fully open to drum scrubber discharge pump box	1.Overfilling of drum scrubber pump box leading to overflow	2	3	C
	4. High flow of overflow to drum scrubber discharge screens	1. Potential damage to conveyor systems	2	3	C
		2. High level in drum scrubber discharge pump box leading to overflow	2	3	C
3.Screen damage	1. Plugging of screen	1. Loss of ore to reject pile	2	4	N
	2. Rupture of screen	1. Reject ore into process leading to potential pump damage	2	3	C
		2. Potential large particle size transfer to cyclone system affecting cyclone seperation efficiency	2	3	C
	3.Mechanical damage to screen resullting in leakage	1. Loss of slurry containment	2	3	C
4. Falling of material	1. No protection around the area	1. Injury, damage of equipment	4	2	N
5.Falling of material	1. Falling of materials to walking platform due to low bunker border	1. Injury, damage of equipment	4	3	U
6.Lack of hygiene	1.Unclean container	1. Being ill due to lack of hygiene	3	3	N
7.Deformation of barriers	1.Force on barriers with material or equipment	1. Falling, injury of worker	3	4	U
8.Falling of materials or workers	1.No barrier around take-up pulley	1. Squeezing, injury	3	4	U
9.Absence of platform	1. No platform for entering the scrubber screen	1. Slipping, falling and injury of worker	4	4	U

Table A.1. *Risk assessment of drum scrubber node on ore preparation process before risk reduction (Cont.'d)*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
10.Absence of protection	1.No protection under the belt for prevent falling any material	1. Injury of workers	3	4	U
11.Incorrect position of cable	1.Bonding the cable that enters into the combo conduit box to the barrier and steel grate	1. Electric shock, leakage of electricity	4	3	U
12.Incorrect position of electrical panel	1.Assembling the electrical panel to the barrier, no insulation plate in front of the panel	1. Electric shock, death, falling of material	4	3	U

Table A.2. *Risk assessment of drum scrubber node on ore preparation process after risk reduction*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.Low/No flow	1.Adequate ore surge capacity in ore thickener to feed HPAL	1.Supply of a second drum scrubber feeding to a seperate screen	3	2	C
	1.Adequate capacity in leach feed surge tank and ore thickener to run process until feed can be regenerated	1.Supply of a second drum scrubber feeding to a seperate screen	2	3	C
	1.Adequate capacity in leach feed surge tank and ore thickener to run process until feed can be regenerated	1.Supply a rock- breaker available at ore beneficiation area	2	3	C

Table A.2. *Risk assessment of drum scrubber node on ore preparation process after risk reduction (Cont.'d)*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.Low/No flow	1. Spare pump at ore thickener available 2.Bypasses around control valves provided	1.Interlocking supply of raw ore to shutdown in the event of loss of thickener overflow feed to drum scrubber	2	2	A
	1.Spare pump at ore thickener available 2.Bypasses around control valves provided	1. Using high pressure water source, such adding a seperate high pressure pump to the ore thickener overflow for providing high pressure washing to the drum scrubber discharge screen	3	2	C
	1.Adequate capacity in leach feed surge tank and ore thickener to run process until feed can be regenerated	1.Supply of a second drum scrubber feeding to a seperate screen	3	2	C
	1.No damage to cyclone due to loss of feed	1.Supply of a second drum scrubber feeding to a seperate screen	2	2	A
	2.Automated switchover to on line spare pump		2	2	A
	1.Directed overflow from discharge pump box		2	2	A
	2. Adequate surge capacity in ore thickener and leach feed surge tanks		2	2	A
	1. Motor status on conveyor 2.Weight indicators 3.High level alarms on the drum screen hopper to conveyor	1. Closed circuit television (CCTV) monitoring at drum scrubber discharge screen	2	2	A
2.High flow	1.High level alarm in drum scrubber feed trommel	1. Stopping ore feed on high level in drum scrubber trommel	2	3	C

Table A.2. *Risk assessment of drum scrubber node on ore preparation process after risk reduction (Cont.'d)*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
2.High flow	2. Closed circuit television (CCTV) monitoring at drum scrubber trommel	2. Stopping conveyor operation interlocked to level of drum scrubber trommel	2	3	C
	1.Level control and indication on the overflow tank	1. Meeting with drum scrubber vendor on impact of overfilling drum scrubber with excess water	2	2	A
	1.High level alarm in drum scrubber discharge box	1. Stopping ore feed on high level in drum scrubber discharge box	2	2	A
	2. Closed circuit television monitoring at drum scrubber discharge box	2. Stopping conveyor operation interlocked to level of drum scrubber discharge box			
	1. Weight sensors present on conveyor to stop all upstream process	1. Closed circuit television monitoring at drum scrubber discharge screen	2	2	A
3.Screen damage	1.Vibrating screen	1. Change the design of screen with respect to minimising plugging	2	3	C
	1.Monitoring the power draw of the scrubber	1. Standart operating procedures to include routine walk -downs and visual inspection of vibrating screen operation	2	2	A
	1.Monitoring the power draw of the scrubber	1. Adding closed circuit television monitoring at the drum scrubber screen	2	2	A
	1.Local operator and camera in place	1. Check the compatibility of electrical code around drum scrubber and pumps	2	2	A
4. Falling of material	1. The area must be isolated	1. Only authorized people can be accessed to the area	4	1	A
5.Falling of material	1. The bunker borders must be raised in order not to material debris to walking platform	1. Only authorized people can be accessed to the area	4	2	N
6.Lack of hygiene	1.Cleaning of container must be done at the end of each shift.	1.Controlling the cleaning trace program at each shift by shift engineers	3	2	C

Table A.2. *Risk assessment of drum scrubber node on ore preparation process after risk reduction (Cont.'d)*

What if	**Safeguard**	**Recommendations**	**After Risk Reduction**		
			Severity	Likelihood	Risk Ranking
7.Deformation of barriers	1.Changing deformed barriers and extending the barriers	1.Controlling the positon of barriers at each shift	4	2	N
8.Falling of materials or workers	1. Surrounding the take up pulley with guard	1.Controlling the positon of guards at each shift	3	2	C
9.Absence of platform	1.Making platform for entering the scrubber screen	1. Closed circuit television (CCTV) monitoring at drum scrubber screen for extensive visual range	4	2	N
10.Absence of protection	1.Making protection under the belt in order not to prevent falling any material	1.Placing guard box with sensor and controlling the working mechanism at each shift	3	2	C
11.Incorrect position of cable	1. Excess cable must be cut and tied with conduit box directly	1.Controlling the related situations of conduit box surround at each shift	4	1	A
12.Incorrect position of electrical panel	1.Additive assembly must not be on the barriers 2. Insulation plate must be put in front of the panel	1. Only authorized people can be accessed to the locked electrical panel	2	1	A

Table A.3. *Risk assessment of middlings treatment node on ore preparation process before risk reduction*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High flow	1.High flow of feed from source	1. Reduced efficiency of cyclone operation	2	3	C
2.Low/No flow	1. Loss of feed to cyclone due to pump failure	1.Potential vacuum build up in cyclone, causing cyclone damage	2	3	C
3. High pressure	1. High flow of feed from source	1.Reduced efficiency of cyclone operation	2	3	C
4.Low pressure	1.Loss of feed to cyclone	1.Potential vacuum build up in cyclone, causing cyclone damage	2	3	C

Table A.4. *Risk assessment of middlings treatment node on ore preparation process after risk reduction*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High flow	1.Pressure indicators	1. Provide differential pressure monitoring across cyclone with high and low differential pressure alarms	2	3	C
		2. Keep cyclone and middlings seperation as part of the ore beneficiation area	2	2	A
2.Low/No flow	1.Automated vacuum breaker to open on vacuum build-up in cyclone	1. Provide differential flow monitoring across cyclone with high and low differential flow alarms	2	3	C
3. High pressure	1.Pressure indicators	1. Provide differential pressure monitoring across cyclone with high and low differential pressure alarms	2	2	A
4.Low pressure	1.Pressure indicators	1.Conceive fail-open position on vacuum breaker	2	2	A
	1.Automated vacuum breaker to open on vacuum build-up in cyclone	1.Provide differential pressure monitoring across cyclone with high and low differential pressure alarms			

Table A.5. *Risk assessment of ore thickening node on ore preparation process before risk reduction*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Excess feed from scrubber or underflow pumps malfunction	1.Problematic thickener operation and possibility of damage to equipment or thickener mechanism tripping	3	4	U
2.Low pressure	1.Inadequate thickener bed density due to low flocculant addition	1.Problematic thickener operation and possibility of solids in the overflow tank resulting in plugging in vent scrubber spray nozzles	2	3	C
3. High flow	1.Overdosing of flocculant	1.Potential to "gum up" thickener, resulting in damage to rake and other equipment	2	4	N
	2. High feed of slurry to ore thickener	1.Under-flocculation results in waste of nickel product	2	3	C
		2. High level resulting in loss of containment	2	3	C
	3. Process water addition	1.High level in overflow tank leading to loss of containment	2	3	C
4. Low flow	1.Low flow from pumps due to solidified/gelled ore thickener contents	1.Potential to "gum up" thickener, resulting in damage to rake and other equipment	2	4	N
	2. Under-dosing of flocculant	1.Under-flocculation results in waste of nickel product	2	3	C
	3. Ore thickener overflow pump failure	1.High level in ore thickener overflow tank	2	3	C
5. High level	1.High bed level in thickener (e.g. due to overflow pump failure)	1. Potential damage to rake	2	3	C
		2.Reduced efficiency of ore beneficiation	1	3	A
			1	3	A
	2.Thickener underflow pump failure	1. Potential solid build up in ore thickener and damage to rake	2	3	C
	3. Thickener overflow pump failure	1. High level in ore thickener overflow tank causing loss of containment	2	3	C
		2. Loss of feed to drum scrubber area	2	3	C

Table A.5. *Risk assessment of ore thickening node on ore preparation process before risk reduction (Cont.'d)*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
6. Low level	1. Loss of feed to overflow tank	1. Potential pump cavitation	2	3	C
	2. Ore thickener underflow pumps fail	1. Loss of feed to leach feed tanks causing potential pump cavitation	2	3	C
		2. Low level bringing on agitator damage	2	3	C
7. Leak/rupture	1. Mechanical failure	1.Personnel injury to death	4	2	N
	2. Line failure	1.Personnel injury to death	4	2	N
		2. Significant property damage	4	2	N
8.Equipment failure	1.Rake mulfunction of thickener	1.Thickener off line for long period of time	3	4	U

Table A.6. *Risk assessment of ore thickening node on ore preparation process after risk reduction*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Running and standby underflow pumps	1.Consider location of flow and mass measurement to ensure operation during recycle of ore prep thickener area	3	1	A
2.Low pressure	1.Overflow tank can be included with internal pressure safety valve	1.Change the design of thickener tank with respect to minimising plugging	2	2	A
3. High flow	1.Amperage monitoring on the rakes	1.Include clean-out procedures in the event of solidification/gelling of ore thickener bottoms	2	3	C
	2. Interlock in place to lift or stop rakes on high amperage	2. Assess the impact of including excessive flocculant that can be solid carry - over with the overflow			
	1. Routine sampling of solution / slurry at several points	1.Include routine sampling of solution of overflows and underflows	2	3	C

Table A.6. *Risk assessment of ore thickening node on ore preparation process after risk reduction (Cont.'d)*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
3. High flow	1. Level monitoring in ore thickener overflow tank to close process water system 2. Overflow tank at a higher elevation than the thickener (overfilling tank will overflow thickener into the process water pond	1.Include routine sampling of solution of overflows and underflows	2	2	A
	1. Overflow tank at a higher elevation than the thickener (overfilling tank will overflow thickener into the process water pond	1.Conceive fail-close position	2	2	A
4. Low flow	1.Amperage monitoring on the rakes 2. Interlock in place to lift or stop rakes on high amperage	1.Include clean-out procedures in the event of solidification/gelling of ore thickener bottoms 2.Assess the impact of including excessive flocculant that can be solid carry - over with the overflow	2	3	C
	1.Routine sampling of solution/slurry at several points	1.Include routine sampling of solution of overflows and underflows	2	2	A
	1.Overflow tank at a higher elevation than the thickener (overfilling tank will overflow thickener into the process water pond	1.Conceive fail-close position	2	2	A
5. High level	1.Bed level monitoring	1.Include routine sampling of solution of overflows and underflows	2	2	A
	1.Interlock in place to lift or stop rakes on high amperage	1.Include routine sampling of solution of overflows and underflows	1	3	A
	2.%100 spare undeflow pump in place		1	3	A

Table A.6. *Risk assessment of ore thickening node on ore preparation process after risk reduction (Cont.'d)*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
5. High level	1.%100 spare pump in place	1.Include routine sampling of solution of overflows and underflows	2	2	A
	1. On line spare pump in place	1.Provide high level alarms monitoring for thickener area	2	2	A
	1. Possibility of sending process water in the event of overflow pumps failure	1.Adding a seperate high pressure pump to the ore thickener overflow for obtaining high pressure washing to the drum srubber discharge screen	2	2	A
6. Low level	1. Pumps trip on low level	1. Provide high and low levels alarms monitoring in leach feed tanks	2	2	A
	1. Pumps trip on low level	1. Provide high and low levels alarms monitoring in leach feed tanks	2	2	A
	1. Spare underflow thickener pump in place		2	2	A
	2. Level indications in leach feed tanks				
	3. High vibration to trip agitator motor				
7. Leak/rupture	1. Check for compatibility of mechanical code around drum scrubber and pumps	1. Searching flange guards for high pressure and high temperature systems	4	2	N
		2. Make ore thickening area as controlled – Access			
	1. Closed circuit television (CCTV) monitoring at drum scrubber screen for extensive visual range to respond to the failure	1.Make ore thickening area as controlled - access	4	2	N
		2.Providing preventative maintenance includes line wall thickness check	4	2	N
8.Equipment failure	1.Surge capacity between thickener and the plant is available	1.Consider bypassing the ore prep thickener for short period of time in the event of rake malfunction	3	3	N

Table A.7. *Risk assessment of flocculant preparation node on ore preparation process before risk reduction*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Plugged discharge	1.Overpressure due to blocked air flow from the blower leading to equipment damage	2	4	N
	2.Blocked mixing pump discharge	1.Potential rupture or damage to piping	2	3	C
	3.Blocked flocculant pump discharge	1. Potential rupture or damage to piping	2	3	C
		2.Loss of flocculant supply	2	3	C
2.Low pressure	1. Blower failure	1.Unable to transfer flocculant into mixing tank	2	3	C
	2.Mixing pump failure	1.Batch process	2	3	C
	3.Flocculant pump failure	1.Loss of flocculant feed to thickener	2	3	C
3. Low/no flow	1. Mixing pump failure	1. Batch process	2	3	C
	2.Flocculant pump failure	2. Loss of flocculant feed to thickener	2	3	C
	3.Low level storage tank	3.Loss of flocculant feed to thickener	2	3	C
4.High level	1.Addition of excessive process water to mixing tank	1.Overfilling mixing tank leading to loss of containment	2	4	N
5. Incorrect batch	1.Agitator failure	1. Settling of flocculant at the bottom causing potential agitator damage	2	3	C
		2.Incorrect concentration of flocculant in storage tank due to inadequate mixing	2	3	C
	2.Excessive addition of process water	1.Diluted flocculant solution	1	4	C
	3.Inadequate aging time	1.Efficiency of flocculant in thickeners reduced	1	4	C
6. Pouring the flocculant material	1. Being poured the flocculant material to the ground and slippery ground due to lack of attention	1.Lapsing, falling, striking, injury	4	3	A
7. Falling of big bag	1.No platform for workers while the big bag is hanged or in any intervention required time	1.Falling of big bag, injury of hand, falling of workers	3	3	N

Table A.8. *Risk assessment of flocculant preparation node on ore preparation process after risk reduction*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Two tanks draining at the same time	1.Obtain high pressure alarm and trip to blower 2.Use gooseneck at a safe elevation for closed tank	2	4	N
	1.Using pressure safety valve to protect pump discharge	1.Ensure type of pump for mixing and provide adequate relief protection 2.Ensure pressure indicator with alarms on mixing pump discharge 3. Use gooseneck vent at a safe location for closed storage tank	2	3	C
	1.Using pressure safety valve to protect pump discharge	1.Ensure type of pump for mixing and provide adequate relief protection	2	2	A
	2.Flow monitoring on pump discharge	1.Operating procedures to include frequent monitoring of flocculant systems for switching over from on-line pump to spare monitoring of flocculant systems for switching over from on-line pump to spare.	2	3	C
2.Low pressure	1.Spare flocculant blower in place	1.Consider making manuel blower into the mixing tank as lock open	2	2	A
	1.Amperage monitoring in place	1. Operating procedures to integrate frequent monitoring of flocculant systems for switching over from on-line pump to spare	2	2	A
	1.Spare flocculant pump in place	1.Check the necessity for locking open all manual discharge valves	2	2	A
3. Low/no flow	1.On line spare pump in place	1.Ensure pumps are provided with temperature monitoring	2	2	A
	1.Spare flocculant pump in place	1.Operating procedures to include frequent monitoring of flocculant systems for switching over from on-line pump to spare	2	2	A
	1.Interface level measurement of the thickener	1.Provide level moni toring in storage tank	2	2	A

Table A.8. *Risk assessment of flocculant preparation node on ore preparation process after risk reduction (Cont.'d)*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
4.High level	1.Flow control of water addition to flocculant	1.Obtaining overflow lines on both mixing and storage tanks 2.Providing level monitoring in mixing tank. (During pre paration of a batch, automating process water can shut-off on high level)	2	4	N
5. Incorrect batch	1.Pump design allow high solid carryover	1.Providing high vibration and high amperage trips on agitator motor	2	3	C
		2.Providing procedures for draining and cleaning flocculant mixing storage tank	2	3	C
	1.Flow control of water addition to flocculant	1.Providing means for monitoring concentration of flocculant	1	4	C
	1.Automatic time planning system can be replaced	1.Standart operating procedures to include procedures for preparation of flocculant batch	1	4	C
6. Pouring the flocculant material	1.The cleaning of the ground must be done when the flocculant is poured and provided suitable waste disposal	1.Provide the ground cleaning control at certain intervals, clean up procedures to be in place for all flocculant areas.	1	4	C
7. Falling of big bag	1.Making suitable platform for workers for intervention of the big bag	1.Only authorized people can be accessed to the area	1	1	A

Table A.9. *Risk assessment of recycle leach and smbs tanks node on primary neutralization before risk reduction*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1. Venturi on SMBS mixing tank is closed	1.Potential overpressure of tank resulting in rupture	3	3	N
	2.Blower failure	1.Potential for backflow of primary neutralization vents into mixing tank	3	3	N

Table A.9. *Risk assessment of recycle leach and smbs tanks node on primary neutralization before risk reduction (Cont.'d)*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	3.Blocked vent	1.Potential overpressure leading to rupture in recycle leach tank	3	3	N
2.Low pressure	1.Pressure valve fails closed; blower pulls a vacuum	1.Vacuum is generated in SMBS tank resulting potential rupture	3	3	N
3. High flow	1.Both autoclave feed pumps running at max capacity	1.Overflow of the tank	4	4	N
4. Low flow	1.Blower failure	1.Potential for backflow of primary neutralization vents into mixing tank	4	4	N
	2.SMBS pump failure	1. Batch addition	4	4	N
5.High temperature	1.High ambient temperature	1.Operating PLS pond at high temperatures leading to membrane stretching	2	3	C
6.Low temperature	1.Extended shutdown of HPAL	1.Limestone utilization is low leading to increased operating costs	2	4	C
7. High level	1.High flow into recycle leach tank exceeding over-flow capacity of recycle mix tank	1.Potential rupture due to overpressure	3	3	N
	2.High level in SMBS mix tank	1.Potential rupture due to overpressure	2	3	C
		2. Loss of containment	2	3	C
8. Low level	1.Batch runs out while SMBS pumps continue to run	1.Potential pump cavitation	2	3	C
9. Leak/rupture	1.Gasket failure	1.Personnel injury to death	4	2	N
	2. Line failure	1.Personnel injury to death	4	2	N
		2.Significant feature damage	4	2	N
	3. Corrosion of the tank due to process conditions	1. Loss of containment of tank contents	4	2	N
10. Inadequate mixing	1.Agitator failure in SMBS tank	1.Uncontrolled concentration causing potential overdosing of SMBS in leach solution	1	3	A
	2.Agitator failure in recycle leach tank	1.Solid formation in bottom of tank resulting in potential plugging and overfilling of recycle leach tank	2	3	C

Table A.10. *Risk assessment of recycle leach and smbs tanks node on primary neutralization after risk reduction*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Pressure safety valve to prevent overpressure of tank	1.Trying several density and pressure values to verify the maximum throughput capacity of the system	3	2	C
	1.Pressure safety valve to prevent overpressure of tank	1.Consider anti-rotation device on SMBS vent blower	3	2	C
	1.Rupture disk provided on tank to prevent overpressure	1.Trying several density and pressure values to verify the maximum throughput capacity of the system	3	2	C
2.Low pressure	1.Pressure safety valve to prevent generating vacuum	1.Vent line can be sized for this situation	3	2	C
3. High flow	1.High level switch on the LP flash tank in place	1.Trying several density and pressure values to verify the maximum throughput capacity of the system	4	2	C
4. Low flow	1.Pressure safety valve to prevent overpressure of tank	1.Consider anti-rotation device on SMBS vent blower	4	2	C
	1.Spare pump available	1.Review type of SMBS pump	4	2	C
5.High temperature	1.Temperature control in place on the PLS pond discharge to control flow of steam	1.Confirm the maximum allowable operating temperature for HPDE lined ponds	2	3	C
6.Low temperature	1.Ability to drain and bypass tanks	1.Start up operating procedures for cold conditions to be generated	1	3	A
7. High level	1. Overflow line to seal pot 2.Pressure relief hatch	1.Trying several density and pressure values to verify the maximum throughput capacity of the system	3	1	A
	1.Overflow line to seal pot	1.Trying several density and pressure values to verify the maximum throughput capacity of the system	2	1	A
8. Low level	1.Pumps trip on low low level	1.Make control scheme to regulate the flow into the recycle leach tank and provide make-up flow	2	2	A

Table A.10. *Risk assessment of recycle leach and smbs tanks node on primary neutralization after risk reduction (Cont.'d)*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
9. Leak/rupture	1.Ensure compatibility of material of construction is adequate to handle minor leaks	1.Searching flange guards for high pressure and high temperature systems	4	2	N
	1.All instruments have double sleeve with pressure indication	1.Make recycle leach area as controlled - access	4	2	N
		2.Providing preventative maintenance includes line wall thickness check	4	2	N
	1.Alloy 31 is material of construction	1.Operating procedures to include conducting regular thickness tests on the recycle leach tank	4	2	N
10. Inadequate mixing	1.Soluiton level control monitoring at recycle leach tank	1.Ensure supply of limestone is closed in the event of agitator failure	1	3	A
	1.Motor status on agitator	1.Provide a spare agitator shaft on hand	2	2	A

Table A.11. *Risk assessment of primary neutralization tanks node on primary neutralization before risk reduction*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Blocked vents	1.Overpressure leading to potential rupture	3	3	N
	2.Large instantenous CO_2 evolution due to starting agitator with a stratified tank	1.Overpressure leading to potential rupture	3	2	C
2.Low pressure	1.Potential build up of vacuum due to condensation & cooling	1.Damage to tank leading to rupture	3	3	N
	2.Loss of feed while pumping continues	1.Damage to tank leading to rupture	3	3	N

Table A.11. *Risk assessment of primary neutralization tanks node on primary neutralization before risk reduction (Cont.'d)*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
3. High flow	1.High liquid flow	1.High level in tank resulting in overflow and potential personnel injury	4	4	U
4. Low flow	1.Limestone supply pump off	1.Inadequate neutralization process upset	2	4	N
		1.Damage to downstream equipment through acidic attack	3	4	U
5. High level	1.High liquid flow	1.High level in tank resulting in overflow and potential personnel injury	4	4	U
6. Low level	1.Low input while pumps/agitators continue running	1.Pump cavitation	2	3	C
		2.Agitator damage-agitator running partially submerged. Potential damage to tank.	3	2	C
7.Low temperature	1.Extended shutdown of HPAL	1.Limestone utilization is low leading to increased operating costs	1	4	C
8. Leak/rupture	1.Gasket failure	1.Personnel injury to death	4	2	N
	2. Line failure	1.Personnel injury to death	4	2	N
		2. Significant property damage	4	2	N
	3.Seal failure around agitators	1. Loss of containment leading to oxygen depletion and possible injury, including death	4	2	N
	4. Tank failure due to corrosion	1.Tank taken off line for repairs requiring vessel entry into possibly CO2 atmosphere	4	3	U
9. Inadequate mixing	1.Agitator failure	1.Potential settling of unreacted limestone at the bottom that may result in a potential explosive mixture when agitator is restarted	4	3	U
		2.Sanding of the tank and loss of neutralization efficiency	3	3	N

Table A.12. *Risk assessment of primary neutralization tanks node on primary neutralization after risk reduction*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Relief hatches on each tank	1.Change venturi valves currently marked NO to locked open	3	1	A
	1.Relief hatches on each tank	1.Consider unquantifiable pressure wave from this circumstance when sizing viscosity point switch valve	3	1	A
2.Low pressure	1.Relief hatches on each tank	1.Change venturi valves currently marked NO to locked open 2.All tanks to be vacuum-protected	3	2	C
	1.Relief hatches on each tank	1.Change venturi valves currently marked NO to locked open 2.All tanks to be vacuum-protected	3	2	C
3. High flow	1.High level alarms on primary neutralization tanks	1.Review the requirement for U-tube on overflow	4	2	N
	2.High level alarm on recycle leach tank	1.Standart operating procedures to ensure de-scaling schedule as a part of planned maintenance			
4. Low flow	1.Low pH alarm in place	1.Consider provision for manual limestone addition into the last primary neutralization tank	2	3	C
	1.Spare limestone in place	1.Provide facilities to back up limestone with slaked lime	3	3	N
5. High level	1.High level alarms on primary neutralization tanks	1.Review the requirement for U-tube on overflow	4	2	N
6. Low level	1.Level monitoring in primary neutralization tanks	1.Consider low level trips on agitators	2	2	A
	1.Low level trips on pumps		3	2	C
7.Low temperature	1.Ability to drain and bypass tanks	1.Start- up operating procedures for cold conditions to be generated	1	4	C

Table A.12. *Risk assessment of primary neutralization tanks node on primary neutralization after risk reduction (Cont.'d)*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
8. Leak / rupture	1.Ensure compatibility of material of construction is adequate to handle minor leaks	1.Searching flange guards for high pressure and high temperature systems 2.Make primary neutralization area as controlled-access	4	2	N
	1.Maintenance procedures to include checking the cladding thickness under neath the primary neutralization tanks	1.Make primary neutralization area as controlled-access	4	2	N
	1.Confined space entry procedures to be put in place	1.Confirm with agitator vendors with leakage rates and appropriate instrumentation 2.Standart operating procedures to perform gas surveys in this area periodically during low wind weather periods	4	2	N
	1.Additional nozzles in place for ventilation	1.Confined space entry procedures to be put in place	4	2	N
9. Inadequate mixing	1.Rupture disk/ Relief hatch in place	1.Ensure supply of limestone is closed in the event of agitator failure	4	2	N
	1.Tanks can be bypassed		1	3	A

Table A.13. *Risk assessment of CCD thickener node on CCD circuit before risk reduction*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Excess feed from scrubber or underflow pumps malfunction	1.Problematic thickener operation and possibility of damage to equipment or thickener mechanism tripping	3	4	U
2.Low pressure	1.Inadequate thickener bed density due to low flocculant addition	1.Problematic thickener operation and possibility of solids in the overflow tank resulting in plugging in vent scrubber spray nozzles	2	3	C

Table A.13. *Risk assessment of CCD thickener node on CCD circuit before risk reduction (Cont.'d)*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
3. High flow	1.Overdosing of flocculant	1.Potential to "gum up" thickener, resulting in damage to rake and other equipments	2	4	N
	2.High feed of slurry to CCD	1.Under flocculation leads to contamination of nickel product	2	3	C
4.Low/no flow	1.Low flow from pumps due to solidified CCD contents	1.Potential to "gum up" thickener, resulting in damage to rake and other equipments	2	4	N
	2.No flow of underflow from thickener due to malfunction of undeflow pump	1.Solids carryover to PLS pond	3	3	N
5. High level	1.High bed level in thickener	1.Potential damage to rake	2	3	C
		2. Poor quality due to iron contamination in the overflow	2	3	C
	2. Pump failre	1.Potential overflowing of overflow tank resulting in loss of product	2	3	C
6. Low level	1.Loss of feed to overflow tank	1.Potential pump cavitation	2	3	C
7.Low temperature	1.Long shutdowns	1.Problematic CCD operation resulting in low wash efficiencies	3	4	U
8. Leak/rupture	1.Equipment damage due to excessive sulphuric acid addition	1.Injury to personnel due to contact with acid	4	3	U
		2.Potential death to personnel in deep sump areas	4	2	N
		3. Loss of containment	4	3	U

Table A.14. *Risk assessment of CCD thickener node on CCD circuit after risk reduction*

What if	**Safeguard**	**Recommendations**	**After Risk Reduction**		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Running and standby underflow pumps	1.Consider location of flow and mass measurement to ensure operation during recycle of ore prep thickener area	3	1	A
2.Low pressure	1.Overflow tank can be included with internal pressure safety valve	1.Change the design of thickener tank with respect to minimising plugging	2	2	A
3. High flow	1. Ability to by pass a CCD	1.Standart operating procedures to include clean-out procedures in the event of solidification/gelling of CCD bottoms	2	3	C
	2.Amperage monitoring on the rakes	1.Assess the impact of adding excessive flocculant that over-flocculation will not result in solid carry-over with the overflow			
3. High flow	1.Routine sampling of solution/slurry at several points. Sampling points to be added to P&IDs	1.Standart operating procedures to include routine sampling of solution of overflows	2	3	C
4.Low/no flow	1. Ability to by pass a CCD	1.Standart operating procedures to include clean-out procedures in the event of solidification/gelling of CCD bottoms	2	3	C
	1.CCD 1 can be utilized as a clarifier by bypassing neutralised slurry to CCD 2	1.Assess the requirement for future clarifier (CCD system)	3	2	C
5. High level	1.Bed level monitoring	1.Standart operating procedures to include routine sampling of solution of overflows	2	2	A
	1.100% spare underflow pump in place		2	3	C
	1.100% spare pump in place	1.Confirm surge capacity in overflow tanks and time allowed for operators to switch pumps	2	2	A

Table A.14. *Risk assessment of CCD thickener node on CCD circuit after risk reduction (Cont.'d)*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
6. Low level	1.Pumps trip on low low level	1. Make control scheme to regulate the flow into the thickeners and provide make-up flow	2	2	A
7.Low temperature	1.Ability to drain and bypass CCD tanks	1.Start-up operating procedures for cold conditions to be generated	3	3	N
8. Leak/rupture	1. Safety showers in place	1.Review the bunded area for each CCD thickener and philosopy for sumpage and add a handrail around the sump	4	3	U
	2.Bunded area provides secondary containment		4	2	N
			4	1	A

Table A.15. *Risk assessment of CCD thickener node on CCD circuit before risk reduction*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Blocked vents	1.Overpressure leading to potential rupture	3	3	N
2.Low pressure	1.Loss of air due to compressor failure	1.Inefficient oxidation of iron resulting in iron contamination in product	2	3	C
		2.Potential for liquid carry- over to air-lines resulting in plugging	2	3	C
3.Low/no flow	1.Scale formation in limestone supply line	1.Low or loss of feed of limestone to neutralization tank resulting in delay in reaction time and loss of product	2	3	C
		2.High acidic solution to MHP circuit resulting in higher consumption of magnesia	2	3	C
4. High flow	1.Flow control valves on limestone left fully open	1.Overdosing of limestone resulting in loss of product	2	3	C

Table A.15. *Risk assessment of CCD thickener node on CCD circuit before risk reduction (Cont.'d)*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
4. High flow	2. High flow of feed to secondary neutralization tank	1.Potential overflowing leading to loss of product	2	3	C
		2.Insufficient residence time in thickener resulting in loss of quality	2	3	C
5.High temperature	1.PLS heater left running during HPAL operation	1.High temperature of PLS solution causing damage to tank	4	3	U
6. Low temperature	1. Low temperature of PLS solution	1. Reduced efficiency of neutralization	2	4	N
7. Inadequate mixing	1. Agitator failure	1. Potential high pH zones resulting in product quality issues	2	3	C
		2. Potential solid formations in tanks resulting in plugging of feed to riser in each tank	2	3	C
8. Leak/rupture	1.Damage to piping/tank	1. Loss of containment of low pH solution	4	3	U
9. Compressor mulfunction	1.Mechanical damage to compressor	1. Loss of air supply to the tank resulting in contamination of product and loss of nickel to tailings	2	4	N

Table A.16. *Risk assessment of CCD thickener node on CCD circuit after risk reduction*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1. Relief hatches on each tank	1.Change venturi valves currently marked NO to locked open	3	1	A
2.Low pressure	1. Check valves in place	1.Size of pressure safety valve loads to include potential plugging of line	2	2	A
	1.All compressors to be provided with internal pressure safety valves 2.Flow monitoring on air to the neutralization tanks	1. Review design of air sparger to minimize scaling and means of monitoring airflow dissipation through the solution	2	2	A

Table A.16. *Risk assessment of CCD thickener node on CCD circuit after risk reduction (Cont.'d)*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
3.Low/no flow	1. Ability to recycle thickener overflow back to the start of the secondary neutralization process	1.Assess impact of increasing recycles in any of the area	2	3	C
	2.pH monitoring and control on limestone	2.Confirm sizing of PLS pond is adequate for containment as per surge requirements	2	3	C
4. High flow	1.pH monitoring and control on limestone	1.Standart operating procedures to ensure de-scaling schedule as a part of planned maintenance	2	2	A
	2.Ability to cut back on limestone addition on other secondary neutralization tanks	2. Review quality and flow of limestone supply	2	2	A
	1.Overflow lines provided to each tanks	1.Include routine sampling of solution of secondary neutralization tanks	2	2	A
	1.Level monitoring in mixing tank 2. Level monitoring in secondary neutralization overflow tank	1. Review quality and flow of limestone supply in the final risk assessment	2	3	C
5.High temperature	1.Temperature control in place on the PLS pond discharge to control flow of steam	1.Confirm the maximum allowable operating temperature for HPDE lined ponds	4	2	N
6. Low temperature	1. Flow from CCD to the pump suction is short circuited	1. Consider putting temperature indicator on neutralization discharge tank	2	3	C
7. Inadequate mixing	1. Overflow in each tank	1. Interlock limestone addition to agitator operation	2	3	C
	1. pH is higher in secondary neutralization than in primary leading to lower heat of reaction		2	3	C

Table A.16. *Risk assessment of CCD thickener node on CCD circuit after risk reduction (Cont. 'd)*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
8. Leak/rupture	1.All tanks are in bunded area(secondary containment)	1.Review the bunded area for each neutralization tanks	4	2	N
9. Compressor mulfunction	1.Ability to use manganese compressor to supply air to secondary neutralization tanks	1.Review need for an air receiver between compressor and the secondary neutralization tanks	2	3	C

Table A.17. *Risk assessment of limestone storage and transfer node on secondary neutralization before risk reduction*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Pressure valve fully closed	1.High pressure in limestone supply loop resulting in potential damage to pump	2	3	C
2.Low pressure	1.Pressure valve fails open	1.Potential loss of feed of limestone to the primary and secondary neutralization tanks	2	2	A
3.Low/No flow	1. Pump trip	1.Loss of feed of limestone to primary/secondary neutralization	2	3	C
4. High flow	1.High flow of limestone supply	1.Potential high level resulting in overflowing of limestone tank	2	3	C
5.High temperature	1.PLS heater left running during HPAL operation	1.High temperature of PLS solution causing damage to tank	4	3	U
6.Low temperature	1.Low temperature of PLS solution	1.Reduced efficiency of neutralization	2	4	N
7. Inadequate mixing	1.Agitator failure	1.Lack of homogenization of slurry leading to potential plugging issues	2	3	C
8. Leak/rupture	1.Damage to piping/tank	1. Loss of containment of low pH solution	4	3	U
9.Off-spec limestone	1.Off-spec limestone from supply	1.Product quality issues	2	3	C

Table A.18. *Risk assessment of limestone storage and transfer node on secondary neutralization after risk reduction*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Flow monitoring on the limestone circulation loop	1.Provide high pressure alarm monitoring in limestone tanks	2	3	C
2.Low pressure	1.pH indication shows lower pH	1.Consider sizing pressure valve for 50% of flow range	2	2	A
3.Low/No flow	1. Spare pump in place 2. Flow monitoring on supply of limestone to primary and secondary neutralization	1.Consider provision for manual limestone addition into the last primary neutralization tank	2	2	A
4. High flow	1.Overflow provided	1.Review quality and flow of limestone supply in the final risk assessment	2	3	C
5.High temperature	1.Temperature control in place on the PLS pond discharge to control flow of steam	1.Add temperature indicator on PLS pond	4	2	N
6.Low temperature	1. Flow from CCD to the pump suction is short circuited	1.Consider putting temperature indicator on neutralization discharge tank	2	3	C
7. Inadequate mixing	1. Motor status on agitator 2.Addition of process water to suction of pumps for flushing	1. Change the design of limestone storage tank with respect to minimising plugging of pump suction or damage to impeller due to solid formation at bottom	2	3	C
8. Leak/rupture	1.All tanks are in bunded area (secondary containment)	1.Review the bunded area for limestone while storing and transferring	4	2	N
9.Off-spec limestone	1.Automated switchover from discharge to recycling back to the limestone tanks	1.Review quality and flow of limestone supply in the final risk assessment	2	3	C

Table A.19. *Risk assessment of MHP precipitation Tanks, MHP surge tanks on MHP 1 circuit before risk reduction*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.Low/No flow	1.No/low flow of secondary neutralization overflow to the mixers fails closed	1.Loss of addition of magnesia to the process resulting in loss of product to the tailings	2	4	N
2.High flow	1.High flow of magnesia powder to mixers	1.Overdose of magnesia leading to increased cost of production	1	4	C
3. High level	1.Failure of MHP 1 filter	1. No flow from MHP surge tank resulting in overfilling and loss of containment	3	4	U
	2.High level in tank due to reduced discharge from the tank and constant feed from the upstream tank	1.Overflow and loss of containment	3	4	U
4. Inadequate mixing	1.Agitator failure	1.Potential process upset	3	2	C
5. Leak / rupture	1.Damage to piping/tank	1. Loss of containment of low pH solution	3	3	N

Table A.20 *Risk assessment of MHP precipitation Tanks, MHP surge tanks on MHP 1 circuit after risk reduction*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.Low/No flow	1.Control valve is set to fail last	1.Both magnesia mixers to be designed for providing magnesia either tank 1or tank 2 in MHP 1 circuit	2	2	A
2.High flow	1.pH monitoring and sampling in place	1.Compare with the solid magnesia addition into the mixers and the slurry magnesia addition to the tanks for providing the flow split required on a continuous basis	1	4	C

Table A.20. *Risk assessment of MHP precipitation Tanks, MHP surge tanks on MHP 1 circuit after risk reduction (Cont.'d)*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
3. High level	1.12 hours residence time per tank available	1.Consult with MHP filter vendor for expected down times to do various repairs and maintenance	3	3	N
	1.Overflow to secondary containment in place	1.Consider adding level monitor on all open gravity flow tanks	2	3	C
4. Inadequate mixing	1.Pump design allows for high solid carryover	1.Maintenance procedures to obtain regular tensioning of titanium bolts on agitators	3	2	C
5. Leak/rupture	1.All tanks are in bunded area (secondary containment)	1.Review the bunded area for each MHP tank	3	2	C

Table A.21. *Risk assessment of MHP 1 area thickener and Hose pumps on MHP 1 circuit before risk reduction*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Blocked discharge	1.Overpressure of piping/hose leading to damage and possible loss of containment	3	3	N
2.Low/No flow	1.Low solid content in the thickener underflow	1.Inability for hose pump to pump (viscosity of slurry is too low)	1	4	C
3.Low temperature	1.Operating during winter	1.Potential damage to hose due to freezing conditions	2	4	N
4. Leak/rupture	1.Rupture of hose	1.Loss of containment resulting in personnel injury due to splashing	3	4	U
5.Thickener upset	1.Upset in underflow of thickener	1.Off-spec product	2	4	N
		2.Low density of underflow resulting in inefficient filtering of product	2	4	N

Table A.22. *Risk assessment of MHP 1 area thickener and Hose pumps on MHP 1 circuit after risk reduction*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Rupture disk in place on hose pump discharge side	1.Operating procedure for hose pump switchover to include opening manual valves to correctly priming pump prior to switching to the spare	3	2	C
2.Low/No flow	1.Flow monitor in place on both undeflow and seed pumps	1.Level control valve on thickener in place to control level of slurry	1	4	C
3.Low temperature	1.Pumps are lubricated with 99% glycerin	1.Consider adding temperature indication on MHP 1 circuit	2	2	A
4. Leak/rupture	1.Puncture detection	1.Consider interlocking hose pump operation with system included as part of the pump	3	3	N
5.Thickener upset	1.Automated switchover from discharge to recycling back to the thickener	1.Assess the interlock inputs for automated switchover of MHP 1 slurry underflow from sending it to the filter to recycling it back to the thickener	2	3	C

Table A.23. *Risk assessment of MHP precipitation tanks, MHP thickener, MHP pumps on MHP 2 circuit before risk reduction*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High flow	1.Overdosing of slaked lime	1.Precipitation of manganese leading to product contamination in recycle	2	4	N
2. No flow	1.No/low flow of slaked lime	1.Loss of precipitation leading to loss of recovery of recycle	1	4	C
3.High level	1.High level in tank due to reduced discharge from the tank and constant feed from the upstream tank	1.Overflow and loss of containment	3	4	U

Table A.23. *Risk assessment of MHP precipitation tanks, MHP thickener, MHP pumps on MHP 2 circuit before risk reduction (Cont.'d)*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
4.Leak/ rupture	1.Failure of pinch valves for slaked lime addition	1.Personnel injury due to contact with slaked lime	3	4	U
5. Inadequate mixing	1.Agitator failure	1.Potential process upset	3	4	U
6.MHP 2 thickener malfunction	1.Thickener mechanism malfunction	1.Potential shutdown of the plant	2	4	N

Table A.24. *Risk assessment of MHP precipitation tanks, MHP thickener, MHP pumps on MHP 2 circuit after risk reduction*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High flow	1.pH monitoring and sampling in place	1.Do a chromium 6+ profile throughout the whole plant and tailings system after plant start-up	2	4	N
2. No flow	1.On line spare pump in place	1.Interlocking supply of slaked lime to shutdown in the event of loss of recovery of recycle	1	3	A
3.High level	1.Overflow to secondary containment in place	1.Consider adding level monitor on all open gravity flow tanks	2	4	N
4.Leak/ rupture	1.Safety showers are in place	1.Review safety shower and eyewash station locations for accessibility during risk assessment review	3	4	U
5. Inadequate mixing	1.Pump design allows for high solid carryover	1.Provide high and low levels alarms monitoring in MHP 2 circuit	3	3	N
6.MHP 2 thickener malfunction	1.Density monitoring on undeflow in place	1.Operating procedures to include means for bypassing the MHP 2 thickener and minimizing solid content in slurry by closing slaked lime addition	2	4	N

Table A.25. *Risk assessment of manganese removal tanks, manganese removal compressor, manganese removal thickener, manganese before risk reduction*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.Low/No flow	1. No/low flow of air	1. Inefficient precipitation of manganese	2	4	N
2. High flow	1.Excessive slaked lime addition	1. Loss of product recovery in recycle of overflow	2	4	N
3. High level	1.High interface solids level related with thickener malfunction	1. High level of solids recycled to CCD resulting in upset conditions in CCD thickener	2	4	N
4.Leak/ rupture	1.Damage to piping/tank	1.Loss of containment of low pH solution	3	3	N
5. Inadequate mixing	1.Agitator failure	1.Potential process upset	3	4	U
6. Compressor malfunction	1.Mechanical damage to compressor	1.Loss of air supply to the tank resulting in contamination of product and loss of nickel to tailings	2	4	N

Table A.26. *Risk assessment of manganese removal tanks, manganese removal compressor, manganese removal thickener, manganese after risk reduction*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.Low/No flow	1.pH monitoring and sampling in place	1.Do a chromium 6+ profile throughout the whole plant and tailings system after plant start-up	2	4	N
2. High flow	1.pH monitoring and sampling in place	1.Add flow monitor on slaked lime ring main	2	4	N
3. High level	1.Pressure monitoring in place	1.Provide manganese circuit bypass to final neutralization system	2	4	N
4.Leak/ rupture	1. All tanks are in bunded area (secondary containment)	1.Review the bunded area for each manganese removal tank, manganese removal pump, manganese removal compressor, Manganese removal thickener	3	2	C

Table A.26. *Risk assessment of manganese removal tanks, manganese removal compressor, manganese removal thickener, manganese after risk reduction (Cont.'d)*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
5. Inadequate mixing	1.Pump design allows for high solid carryover	1.Keep a spare agitator shaft on hand	3	3	N
6. Compressor malfunction	1.Ability to use manganese compressor to supply air to manganese removal tanks	1.Review need for an air receiver between compressor and the manganese removal tanks	2	3	C

Table A.27. *Risk assessment of final neutralization tanks, tailings pumps on final neutralization before risk reduction*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
1. No flow	1. No/low flow of slaked lime	1. Low pH slurry sent to tailings pond resulting in environmental issues	3	4	U
2.High flow	1.Excessive addition of slaked lime	1.High pH in tailings pond resulting in potential environmental issuses	2	4	N
			2	4	N
3.Low level	1.Both pump circuits run simultaneously	1.Low level in tank resulting in tripping of pump	2	4	N
		2.Potential damage to agitators due to loss of level	2	4	N
4.High level	1.Pump malfunction	1.High level resulting in overflow and loss of containment	3	4	U
5. Inadequate mixing	5.Agitator failure	1.Settlings of solids resulting in plugging of suction lines and potential pump damage	3	4	U

Table A.28. *Risk assessment of final neutralization tanks, tailings pumps on final neutralization after risk reduction*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
1. No flow	1.Spare slaked lime pump in place	1.Operating procedures to include pH monitoring and mitigation at tailings pond	3	2	C
2.High flow	1.Surge capacity of the tailings pond	1.Operating procedures to include pH monitoring and mitigation at tailings pond	2	3	C
	1.pH monitoring and sampling in place	1.Assess potential decanting of tailings pond	2	3	C
3.Low level	1.Low level shutdown of pumps and agitator	1.Operating procedures to include methodology for managing surge capacity for neutralization prosess in final neutralization tanks	2	3	C
4.High level	1.On line spare pump in place	1.Consider automating the transfer feed lines to the tanks	3	3	N
5. Inadequate mixing	1.Pump design allows for high solid carryover	1.Provide plate material/spare blades on hand	3	2	C

Table A.29. *Risk assessment of sulphuric acid storage and transfer on sulphuric acid storage before risk reduction*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Plugged discharge on high pressure acid pumps	1.Overpressure resulting in rupture of piping	4	3	U
	2.Blocked venturi in sulfuric acid tanks	1.Overpressure leading to rupture of sulfuric acid tanks	4	3	U
	3. Blocked low pressure pump discharge	1.Pumps running on plugged discharge which may result in loss of containment	4	3	U
2.Low pressure	1.Blocked vent	1.Damage to tank during pumping out of storage tanks due to vacuum formation	4	3	U

Table A.29. *Risk assessment of sulphuric acid storage and transfer on sulphuric acid storage before risk reduction (Cont.'d)*

What if	**Causes**	**Consequences**	**Before Risk Reduction**		
			Severity	Likelihood	Risk Ranking
3. High flow	1.Wide range of sulphuric acid pump operation	1.Excessive acid carryover through the system through the system	4	4	U
4.Low/no flow	1.Tank discharge, valve closes	1.Loss of feed to supply pumps leading to potential damage	2	3	C
5.Reverse flow	1.Back flow between tanks when switching over	1.Reverse flow to tank reduces capacity for distribution pumps	1	4	C
6. High level	1.Overfilling of sulphuric acid storage tank during transfer	1.Overflow leading to loss of containment	4	4	U
7. Low level	1.Insufficient supply of sulphuric acid from source	1.Potential pump cavitation leading to loss of acid feed to process	1	4	C
8.High temperature	1.Dilution of acid	1.Dilution of acid results in high temperature and equipment damage, leading to loss of containment	4	4	U
9.Contamination of sulphuric acid	1.Contaminated sulphuric acid from source	1.Poor quality of slurry due to inefficient leaching	3	3	N
10. Leak/rupture	1.Leak of sulphuric acid at flanges	1.Loss of containment of sulphuric acid leading to personnel injury/death	4	3	U
		2.Release of acidic material to the environment	3	3	N
	2.Leak of sulphuric acid pump	1.Loss of acid with potential for personnel injury	4	3	U
		1.Release of acidic material to the environment	3	3	N
	3. Tank rupture	1.Loss of containment	4	2	N

Table A.30. *Risk assessment of sulphuric acid storage and transfer on sulphuric acid storage after risk reduction*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Tanks are in a containment zone	1.Provide pressure safety valves on high pressure acid discharge from relief with relief into storage sump	4	3	U
	1.Tanks are in a containment zone	1.Review the need for relief protection on sulphuric acid tanks	4	3	U
	1.Pressure safety valve to prevent over pressure and damage to pump	1.Ensure adequately sized PSVs are provided for the line of sulphuric acid	4	1	A
2.Low pressure	1.Automated vacuum breaker to open on vacuum build-up in tank	1.Review the need for vacuum relief protection on sulphuric acid tanks	4	3	U
3. High flow	1.Flow monitoring on the sulphuric acid	1.Establish procedure for regular monitoring of pH profile through the sulphuric acid storage tank	4	3	U
4.Low/no flow	1.Ability to open valve on second sulfuric acid storage tank	1. Change the working system of switchover to maintain a constant supply of sulphuric acid to the process	2	3	C
5.Reverse flow	1.Consider conversion of fail safe position for valves to fail closed	1.Consider adding check valves downstream of isolation valves on tank discharge to common header	1	4	C
6. High level	1.Permissives on level for starting/stopping transfer pumps	1.Consider automating the transfer feed lines to the tanks	4	2	N
7. Low level	1.Switchover between tanks is automated	1.Operating procedures to include regular checking of the sulphuric acidin the system for efficient leaching system for leaks.	1	3	A
8.High temperature	1.Overflow for sulphuric acid storage tanks in seal-pots containing linseed oil	1.Obtain high temperature alarms on temperature monitoring in storage tanks	4	4	U

Table A.30. *Risk assessment of sulphuric acid storage and transfer on sulphuric acid storage after risk reduction (Cont.'d)*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
9.Contamination of sulphuric acid	1.Routine sampling of solution / slurry at several points	1.Review the impact of contaminated sulphuric acid to the system	3	2	C
10. Leak / rupture	1.Spray guards provided on all sulphuric acid flanges	1.Operating procedures to include regular inspection of flanges and connections in the sulphuric acid system for leaks	4	2	N
	1.Secondary containment in place	1.Perform thickness checking on sulphuric acid piping particulary on elbows	3	2	C
	1.Special safety showers will be in place	1.Acid discharge piping trench to be lined for acid compatibility	3	2	C
	1.Secondary containment and sump in place	1.Provide spray guards on all flanges on acid suction and discharge lines	2	2	A
	1.Tank within containment area	1. Review strategy for handling emergency spillage and contaminated acid	4	2	N

Table A.31. *Risk assessment of plant air system on plant air before risk reduction*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.Both compressors running at the same time	1.Overpressure leading to rupture, leading to damage of piping	3	3	N
	2.Plugged discharge	1.Overpressure leading to rupture, leading to damage of piping and equipment	3	3	N
2.Low pressure	1.Failure of compressor operation	1.Low pressure resulting in loss of instrument air and air to process	4	3	U
3.High temperature	1.Loss of cooling water supply	1.High temperature leading to compressor damage	3	3	N
	2.High humidity	1. High temperature of compressor operation leading to potential damage	3	4	U

Table A.31. *Risk assessment of plant air system on plant air before risk reduction (Cont.'d)*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
4.Low/no flow	1.Plugged filters	1.Damage to compressors due to loss of suction	3	4	U
	2.Compressor failure	1. Low flow resulting in loss of instrument air and air to process	4	3	U
5.High flow	1.Both compressors running at the same time	1.High flow leading to rupture, leading to damage of piping and equipment	3	3	N
6.High level	1.Failure of traps on receivers	1.Overfilling of receivers causing build up of pressure, causing damage to equipment and loss of air supply to plant	4	3	U

Table A.32. *Risk assessment of plant air system on plant air after risk reduction*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
1.High pressure	1.All equipment sized with pressure safety valves where required	1.Ensure adequately sized PSVs are provided for the compressors, filter, both receivers and dryers	3	3	N
		1.Ensure adequately sized PSVs are provided for the compressors, filter, both receivers and dryers	3	3	N
2.Low pressure	1.On line spare compressor in place	1. Consider automatic start-up of second compressor in the event of low pressure and/or compressor air failure	4	2	N
		2.Provide high and low pressure alarms on both air pressure indicators	4	2	N
3.High temperature	1. Air reservoirs to provide supply for safe shutdown of process	1.Provide high temperature trips on compressors	3	2	C
	1.Cooling water supply to compressors	1.Ensure supply of cooling water is adequtae of highest expected conditions	3	3	N

Table A.32. *Risk assessment of plant air system on plant air after risk reduction (Cont.'d)*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
3.High temperature	1.Cooling water supply to compressors	2.Ensure compressor are specified for extreme waether condition	4	3	U
4.Low/no flow	1.On line spare compressor in place	1.Ensure filters are located such as to minimize plugging occurences	3	4	U
		1. Consider automatic start-up of second compressor in the event of low pressure and/or compressor air failure	4	2	N
5.High flow	1.All equipment sized with pressure safety valves where required	1.Ensure adequately sized PSVs are provided for the compressors, filter, both receivers and dryers	3	3	N
6.High level	1.Flow monitoring on receivers	1.Provide level monitoring for all receivers	4	3	U

Table A.33 *General issues about the process plant before risk reduction*

What if	Causes	Consequences	Before Risk Reduction		
			Severity	Likelihood	Risk Ranking
1. Power failure	1.General power failure	1.Unsafe process shutdown	4	4	U
2. Fire	1.Electrical fire	1.Damage to adjacent equipment	4	2	N
		2.Personnel injury	4	2	N
	2.Equipment fire	1.Equipment damage	4	2	N
3. Operational/ Maintenance Issues	1.Operation of vehicles in proximity to equipment including electrical substations	1.Damage to adjacent equipment	4	4	U
		2.Personnel injury	4	4	U
	2.Use of fixed and mobile cranes in operating plant	1.Damage to equipment	4	4	U
		2.Personnel injury	4	4	U
	3.Moving, rotating, energized equipment	1.Personnel injury	4	4	U
	4.Water and PLS in open ponds	1.Slips and falls resulting in drowning	4	2	N

Table A.34. *General issues about the process plant after risk reduction*

What if	Safeguard	Recommendations	After Risk Reduction		
			Severity	Likelihood	Risk Ranking
1. Power failure	1.Providing generator sets for all critical equipment in place	1.Prepare and analyze the list of all equipment to be placed on emergency backup power	4	1	A
	2.Multiple sources of electrical power with all transformers interconnected	2.Operating procedures to include routine maintenance and testing of power generators			
2. Fire	1. Relief valves in place on critical equipment	1.Ensure fire fighting training is provided for personnel	4	1	A
	2.Safety systems in place according to with National Fire Protection Association necessities		4	2	N
	1.Hydrants in place for National Fire Protection Association necessities	1.Review layout of conveyors and identify need for fire hydrants and yard hydrants	4	2	N
3. Operational / Maintenance Issues	1.Very limited access for vehicles	1.Assess the need for barriers around all heavy electrical equipment during the risk assessment review	4	1	A
		2.Assess the need for barriers around pumps and tanks	4	1	A
	1. Fixed cranes in place for all critical equipment	1.Ensure all fixed cranes come equipped with proximity sensors to physically limit travel speed and distance of the cranes	4	2	N
	1. Fixed cranes in place for all critical equipment	2.Operating procedures and training to include correct equipment hook-up to the cranes for lifting	4	2	N
	1.Safety barriers provided wherever required	1.Review accessibility around high presuure, high temperature and elevated equipment during risk assessment review	4	3	U
	1.All ponds have fencing	1.Ensure adequate signage and flotation devices are provided around ponds	4	1	A