

## Declaration of Authorship

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“I declare in lieu of oath that, the entire contents of this thesis is my own work except where otherwise indicated. All references and literal extracts have been quoted clearly. Information sources of figures, charts and tables have been acknowledged. This thesis has not been submitted to any other institution and has not been published”.

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## Acknowledgement

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## Abstract

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This research describes the Feasibility study of Aynak copper deposit with special consideration on Infrastructure, logistics, processing and auxiliary operations. Due to that, mining project are mostly located in remote area, where, there is lack of infrastructure, water and power availability. The investigation is carried out based on technical and economical comparison through assessing the infrastructure required for the project.

Moreover, the technical planning for auxiliary facilities including fuel and explosive storages, accommodations, offices, workshops and maintenance facilities required for the project is considered based on technical and economical comparison to propose the most feasible option.

In addition, considering that Aynak copper deposit contains both sulfide and oxide ore, the study on mineral processing is conducted through reliable geological information to achieve the most feasible options for ore recovery. The result of study is estimated based on technical factors and cost analysis.

**Key words:** *Copper concentrate, power supply, infrastructure, auxiliary facilities, Site layout*

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## List of Abbreviations

<b>Abbreviation</b>	<b>Definition</b>
ACD	Aynak copper deposit
AOI	Area of Interest
GOA	Government of Afghanistan
MOMP	Ministry of Mines and Petroleum
MOIC	Ministry of Information and Culture
AGS	Afghanistan Geological Survey
MCC	Metallurgical Corporation of China
DAFA	French Archeological Mission in Afghanistan
ROM	Run of Mine
ANFO	Ammonium Nitrate Fuel Oil
AFFF	Aqueous Film Forming Foam
USGS	United States Geological Survey
DEM	Digital Elevation Method
ICCS	In Pit Crushing and Conveying System
ADB	Asian Development Bank
LVR	Light Vehicle Road
PV	Photovoltaic Cells
°	Degree
C	Celsius
µm	Micrometers

d	Day
a	Year
m	Meters
Km	Kilometer
t	Tons
tph	Tons per hour
tpd	Tone per day
h/d	Hours/day
MW	Megawatt
Kw	Kilowatt
Kwh	Kilowatt hour
Kwh/t	Kilowatt hour per ton
km <sup>2</sup>	Square Kilo meters
Mt	Million tons
Hp	Horse Power
m <sup>3</sup>	Cubic meters

## Chapter 1. Introduction

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It is evident that, copper (Cu) is the first metal used by human. For its heat and electric conductivity, it is widely applied for industrial uses as well as in household either direct or indirect where as example the application for electric manufacturing and industrial uses are vast. The largest copper resources in the world are formed within porphyry deposit and the main ore mineral formed copper are chalcopyrite ( $\text{CuFeS}_2$ ), bornite ( $\text{Cu}_5\text{FeS}_4$ ) and chalcocite ( $\text{Cu}_2\text{S}$ ).

Aynak Copper Deposit (ACD) is the largest sediment-hosted copper deposit in Logar province of Afghanistan. The ACD was first identified by Soviet Union geologist and then explored by Afghanistan geological survey (AGS) with corporation of Soviet Union geologists between 1974-1989 [1]. In recent years, the project is contracted with Metallurgical Corporation of China (MCC), while, the extraction of the deposit is not started yet.

As any other mining projects, for development of ACD the feasibility study of the deposit which, estimates the significant of the project in term of technical and economical approximation is required. In other word feasibility study of project helps for proper decision making in which, it will get clear either to start mining operations and run the project or to stop investment until the project is economically extractable.

Considering that, mining projects are mostly locating in a remote area. Aynak project likewise most of the mining projects is located in least developed areas, where there is significantly lack of infrastructure and other auxiliary facilities including power and water supply for the project, fuel and explosive storage, workshops, service centers, warehouses, and other auxiliary facilities are necessary for the project, which each of these parameters can technically and e economically influence in mining operations. Therefore, depth study for the feasibility study of Aynak copper deposit in the areas of mineral processing, infrastructure, logistics and auxiliary operation planning is required

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## 1.1. Aim and Objective

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The objective of this study is to investigate the technical and economic feasibility of Aynak copper deposit, through assessing the infrastructure, logistics, processing and auxiliary facilities for the project.

The infrastructure including roads network, water supply and power supply are assessed to optimize the production rate as well as supply and transportation. In addition, sufficient auxiliary facilities including fuel storage, explosive storage, maintenance, accommodation and laboratory for the project are investigated based on technical requirement for the mining and sufficiently supporting the optimal mining and processing plant.

Moreover, the logistical possibilities of concentrate ore are to examine and the finest options from analysis are considered in order to recommend the most suitable option for concentrate recovery within safe and economical processing method for Aynak copper mine.

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## 1.2. Methodology

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This research is carried in three parts, (a) the data collection, (b) investigating the literatures for the existing project as well as for similar project, (c) estimation and analysis are considered based on the existing data and literature and (d) At last the writing up the summary of this study.

The primary data related to the research topic was collected from Afghanistan Geological Survey (AGS) and Ministry of Mines and Petroleum (MoMP). Their data relay on the previous findings which was handled by Soviet Union Socialist Republic (USSR), United States Geological Survey (USGS) and some information is gathered from feasibility study and technical reports presented by Chines Metallurgical Company (MCC).

In addition, some information for preparing of this feasibility study is gathered from technical reports and feasibility studies of open-pit copper mining projects, including (Minto Carlo) Canada. In addition, the findings and research papers of the (Bureau of mine) United

State of America and (Transport and Vehicle Engineering) Chile were found to be helpful. The mentioned data as a secondary data for this research, including Surface mining journals, SME book and reports related to the research are considered

It is taken into account vital to accomplish this research based on a suitable research method. Different types of method can be applied, since the most reliable and feasible method of attack has been considered. Comparison method for analysis of the result is remarked in this research, due to persistent output of the analysis. Considering the security situation of Afghanistan, the site visit was not conducted which is particularly leads to assumptions. However, the issue is partially unneglectable due to trustworthy information's obtained from the first sources. On other hand for planning this issue couldn't be ignored, which produces less accurate assessment than the visited research.

At last, the parameters considering the objective of the study is estimated through methods applicable and the results are evaluated based on technical factors and cost analysis for better choice.

Finally, the results of the works and investigation is gathered in this study and the summery of the analysis is developed at last.

## Chapter 2. Description of the Area of Interest (Aoi)

In this chapter the geographical location, accessibility to the deposit, climate and history of the region and the geology of the deposit each in details are described.

### 2.1. Location

Aynak copper deposit (ACD) is the largest sediment-hosted copper deposit located in middle east of Afghanistan, approximately 49 km southeastern Kabul in Logar province as shown in

*Figure 2.1–1* [2]. The geographic coordination of Aynak copper mine are with the Latitude:  $34^{\circ} 15' 58''$  and Longitude  $69^{\circ} 18' 18''$ .

The Aynak copper area is situated in intermountain depression with the altitude of 2275-2675 M. Moreover, the deposit is surrounded by mountains with the elevation up to 3450 M from sea level [3]. The approximate area of the deposit is  $3,439.37 \text{ KM}^2$  [4]. The digital elevation model (DEM) of Aynak copper deposit is shown in *Figure 2.1–2*.

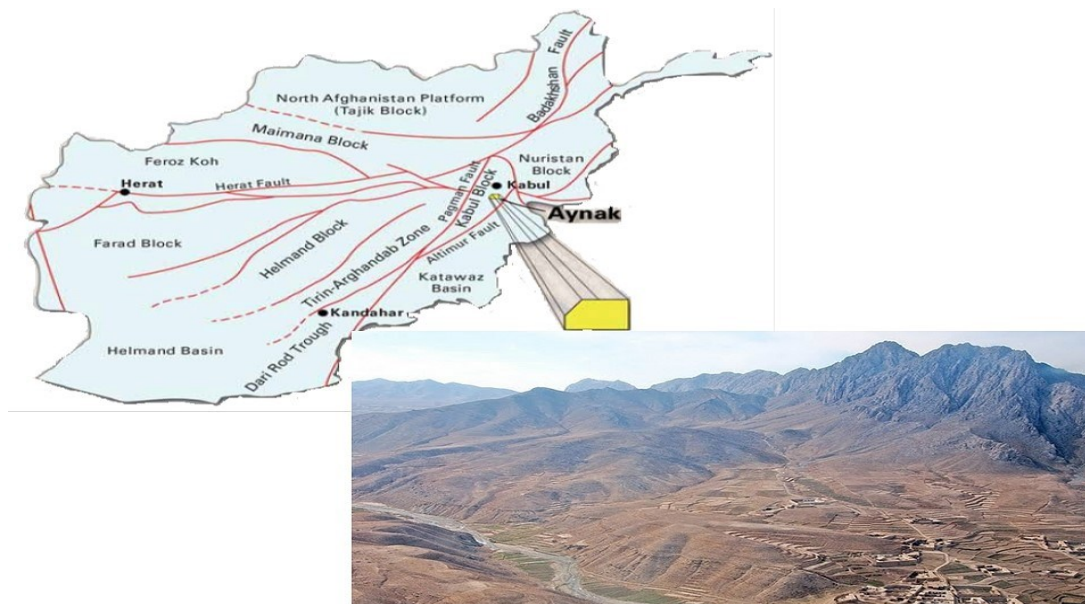


Figure 2.1–1 Location of Aynak copper mine [2]

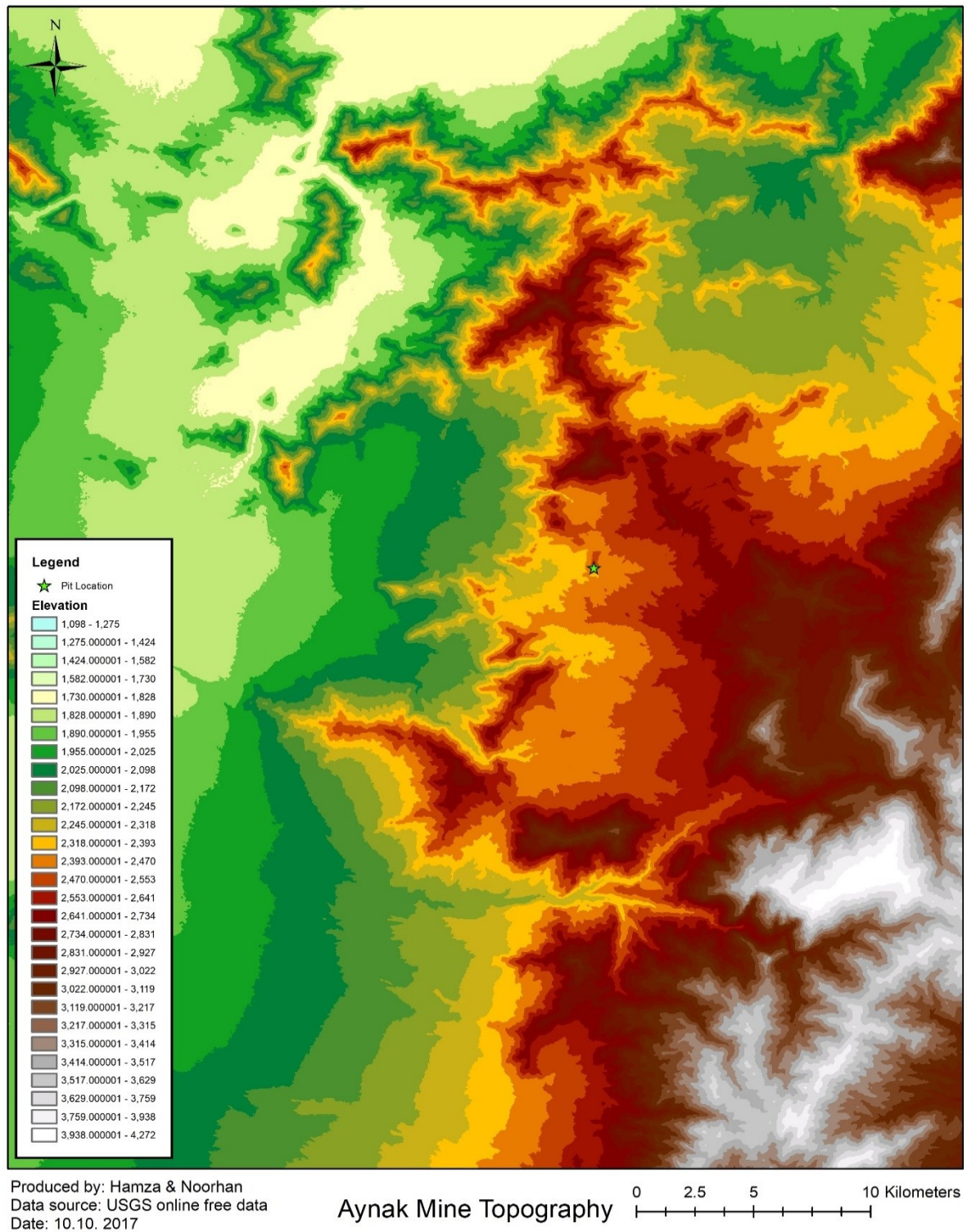


Figure 2.1–2 The Digital Elevation model (DEM) of Aynak copper mine

## 2.2. Accessibility

Aynak copper mine is located in the southeastern of Kabul in Logar province. The mine site is accessible through 34 km Kabul-Gardiz highway, following by a 15 km gravel road to the deposit. (Figure 2.2–1) illustrates the mine-accessing road.

The mentioned roadway is the only possibility for accessing the ore site. Currently there is no available railroad within the mine site or in region.

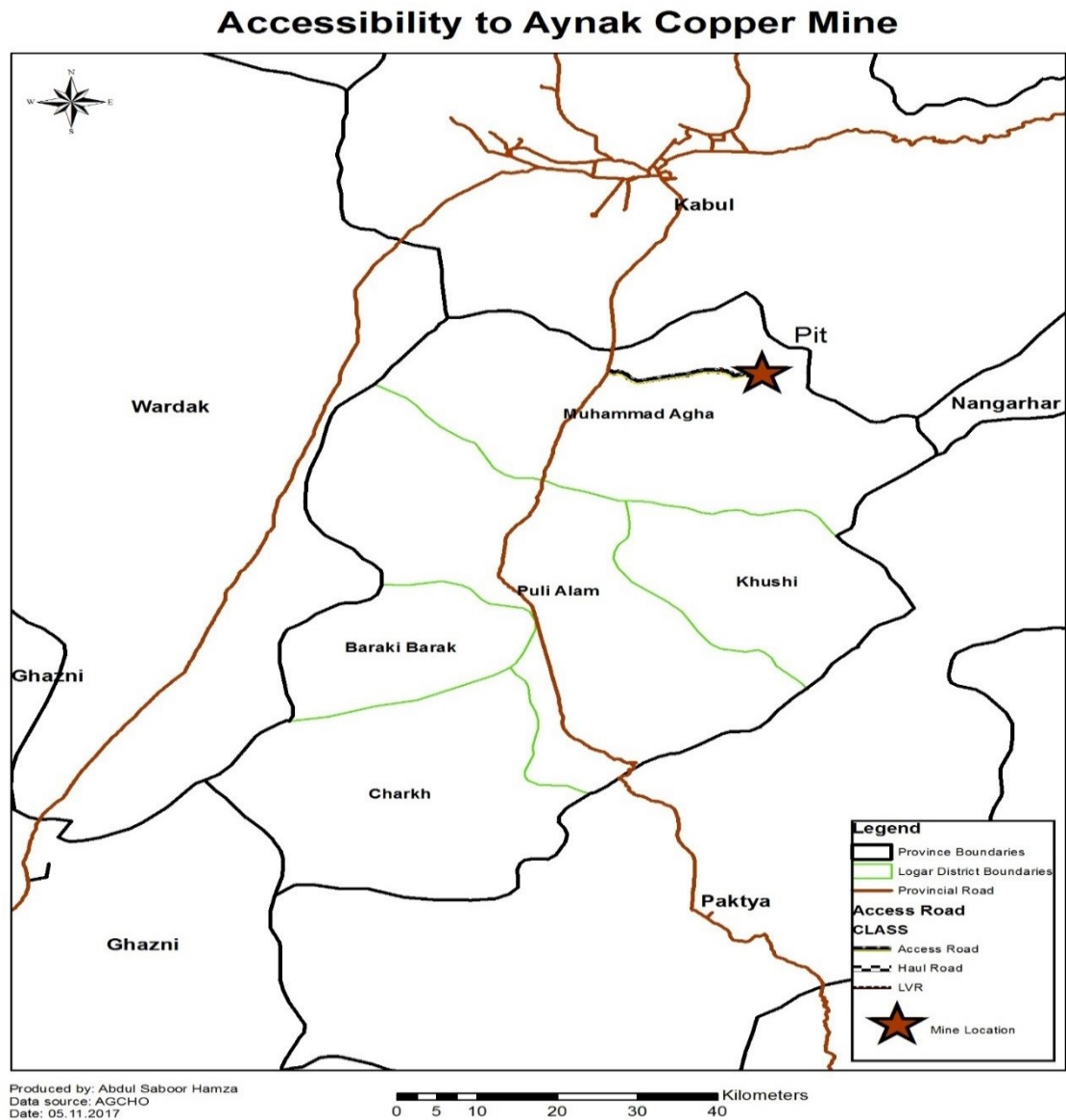


Figure 2.2–1 Accessibility to Aynak copper mine.



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### 2.3. Climate

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Logar province, where Aynak copper mine is located, has a continental climate. Dry and rainless. In summer, it is hot and dry, in winter it is cold with rain and snow [5]. The annual temperature ranges from +10.5 to +12.5 °C, while in January and February the lowest temperature reaches to -15°C. On the other hand, in summer, the temperature ranges from 20 to 24 °C [6]. The regional average temperature is illustrated in Table 2.3-1 [5].

The rainfall occurs from November to April. The average rainfall in the area is from 197.2 to 229 mm [6]. The humidity in Aynak area is highest in winter and lowest in summer and the average humidity ranges from 52-62 % [6].

Table 2.3-1 Average temperature in Aynak copper mine [5]

Average Temperature	In (°C)
Annual average temperature	12.5
Monthly average temperature in Winter	-7
Monthly average temperature in summer	+24
Highest temperature	+36
Lowest temperature	-15

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### 2.4. History

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The history of mineral resources investigation in Afghanistan especially in Kabul block has been carried through different stages by several geologists from different countries [7]. The first mineral resource assessments in Afghanistan were carried out by the British in early nineteenth to twentieth century. The British expressed their interests in mineral resources of Afghanistan [8]. On the second step, geologists from Germany and France carried out geological mapping in Kabul block in addition they investigated on copper and chromite ore until 1963 [9].

Later on, further investigations carried by France archaeologist; it was founded that, the extraction of copper in that region is related to the first century [10]. Within the investigation the huge industrial and metallurgical and blast Furnaces, and coins related to Coshenian period (Coshenian Empire 1<sup>st</sup> -3<sup>rd</sup> century) was founded in the area [10].

In the last stage, the Aynak copper deposit was discovered as the largest copper deposit in the region, while prospecting Kabul block by Akreskan Group in 1973 [9]. In 1974, the Soviet Union began the first detailed exploration in ACD. During their studies former mining, smelter and small ancient historic sites were discovered in Aynak interested area [7].

In 2009, Ministry of Information and Culture (MoIC) with corporation of French Archeological Mission in Afghanistan (DAFA) and Ministry of Mines and Petroleum (MoMP) started discovery and removing of eight historical ancient sites form Aynak copper area. It is planned to transport all the sculptures from site to Afghanistan National Museum and local Museum within three years [11].

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## 2.5. Geology

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The Aynak copper deposit formed by fluid mixing in permeable sedimentary volcanic rocks. Sediment-hosted copper deposits occurs in a narrow range of layers within a sedimentary sequence [12]. The Aynak area is divided in to three parts, Central, West and North Aynak, the focus of this study is considered on central Aynak. The total resource of the deposit is reported approximately 370 MT.

The Geological studies in Aynak copper deposit was carried in two phases from 1974- 1989 [13]. The studies resulted that, two types of ores are visible in Aynak area. One of which is the bornite, that forms the main orebody. The other is chalcopyrite, that forms above and below of the main orebody [14].

The upper parts of the orebody are hosted within carbonaceous quartz-sericite-biotite schists, sandstones and breccia. It contains chalcopyrite, pyrite with sphalerite and molybdenite [12]. The lower parts of the orebody are hosted in carbonaceous quartz-dolomite schists with breccia. It contains chalcopyrite and pyrrhotite [12]. Based on geological studies reported by MCC, the resources in the central Aynak is divided into economic and sub economic resources, as shown in

Table 2.5-1 [15].

Table 2.5-1 Aynak central economic resources [15]

Ore Types	Ore Tonnage (MT)	Cu Grade (%)	Cu Metal Tonnage (MT)
Sulfide	177	2.36	4.177
Mixed sulfide and oxide	7.3	2.5	0.185
Total	185	2.37	4.385

Table 2.5-2 Aynak copper sub-economic resources [15].

Ore Types	Ore Tonnage (MT)	Cu Grade (%)	Cu Metal Tonnage (Mt)
Sulfide	151	0.82	1.24
Mixed sulfide and oxide	11	1.03	0.11
Oxide	21	1.47	0.31
Total	183	1.1	1.67

Table 2.5-3 Total resource of Aynak copper mine [15].

Ore Types	Ore Tonnage (MT)	Cu Grade (%)	Cu Metal Tonnage (MT)
Sulfide	328	1.67	5.4
Mixed sulfide and oxide	18.3	1.8	0.33
Oxide	21	1.47	0.33
Total	368	1.7	6.0

### 2.5.1. Stratigraphy

The ore in Aynak copper deposit contains metamorphosed, upper Proterozoic and Vendian-Cambrian rock [9]. The oldest rocks in Aynak area is considered to metavolcanics Welayati formation, contains of gneiss and amphibolite. This formation is overlain by a thick sequence of Loy Khwar formation contains of dolomite, marble, carbonaceous, quartz and schist [16]. The copper deposit in Aynak area is divided into two parts, central Aynak and west Aynak. The focus of this study is on central Aynak.

### 2.5.2. Mineralogy of the Ore

The main ore minerals of Aynak copper deposit are bornite and chalcopyrite, the secondary minerals are pyrite and sphalerite. The minerals including cobaltite, smaltite, pentlandite and molybdenite are among very limited and rare minerals of Aynak copper deposit [9].

Bornite is a high-grade ore with an average copper content of 2.30 % [9]. Bornite occurs in rocks that are rich in quartz and feldspar. The grain size of bornite ranges from few mm to centimeters in diameter [9].

Chalcopyrite is the second abundant ore mineral in ACD. The copper content is 1 %, the grain size is ranges from few mm to some Centimeters [9]. In the central Aynak chalcopyrite is correlating with bornite and in very few amounts with pyrite and cobaltite [9]. Studies and investigation by USSR geologist shows that, bornite and chalcopyrite have the following mixtures as illustrated in Table 2.5-4 [9].

Table 2.5-4 Investigated on bornite and chalcopyrite

Minerals	Elements in (%)						
	Cobalt (Co)	Nickel (Ni)	Vanadium (Va)	Silver (Ag)	As	Zinc (Zn)	Indium (In)
Bornite	0.004-0.01	0.0001-0.0003	0.001	0.0002	0.005	0.0003	0.001
Chalcopyrite	0.002-0.05	0.0001-0.0002	0.002	0.0003-0.001	0.003-0.01	0.0003	-

Based on report by MCC (2015), the sulfide and oxide ore have a clear boundary. The oxide and mixed ore formed 10.7% of the total ore in central Aynak. The copper content based on degree of oxidation is illustrated in Table 2.5-5 [15].

Table 2.5-5 Degree of oxidation [15].

Degree of oxidation	Copper content in (%)		
	From	To	Average
Sulfide	0,69	4,34	2.5
Mixed	0,76	3,69	2.2
oxidized	1,27	3,51	2.2

## Chapter 3. Mineral Processing

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The term processing is used for upgrading and recovering of minerals from ore through the following steps [17].

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### 3.1. Processing Steps

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- i. **Size reduction:** crushing and grinding is used to reduce the size of ore in order to detach valuable mineral from the ore body.
- ii. **Size separation:** once the ore is crushed and grounded classifiers and screeners are used to separate the ore based on practical size. As a result, the coarse materials move back to the previous steps and the fine material pass through next steps.
- iii. **Concentration:** based on definition by Maurice (2011), “physicochemical properties of mineral are used in concentration operation” [17]. Operations including froth flotation, gravity concentration, magnetic and electrostatic concentration are involved in mineral processing concentration. The Froth flotation is used in mineral processing to separate the mineral from ore. The Gravity separation is used to separate minerals based on their density.
- iv. **Dewatering:** the process of separation of solid elements from water through thickeners and filters is dewatering in mineral processing.

In general, copper ore is classified into three separate groups, (a) native copper, (b) sulfide copper and (c) oxide copper. The beneficiation technologies used worldwide for copper recovery are froth flotation for sulfide ore and acid leaching for oxide ore. The two-major flow chart of copper processing as shown in (Figure 3.1–1) are pyrometallurgical and hydrometallurgical process [18]. The comparison for characteristics of pyrometallurgical and hydrometallurgical process is illustrated in (Table 3.1-1) [19].

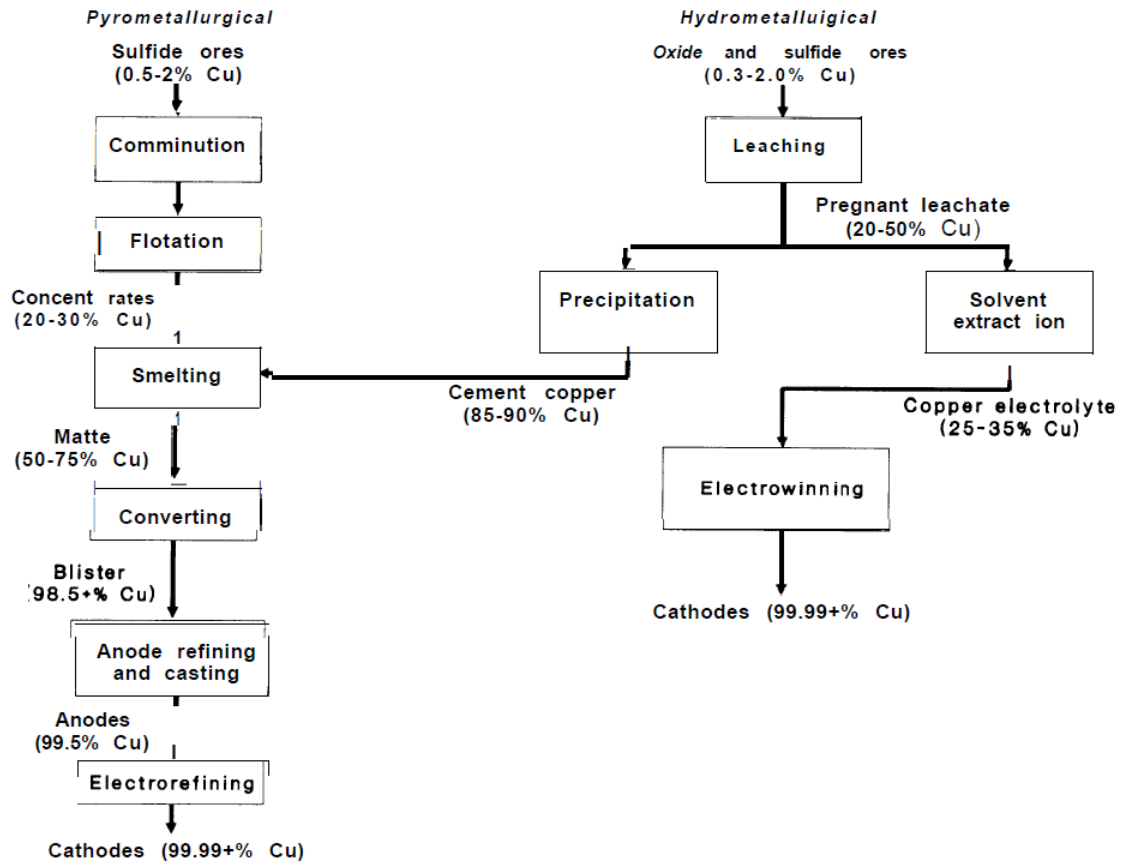


Figure 3.1–1 Copper processing flow sheets [18].

As it is obvious from (Table 3.1-1) for high-grade ore within a large deposit, the pyrometallurgical process is economically recoverable. In addition, the concentration yield from pyrometallurgical process is higher than hydrometallurgical process. Therefore, the processing plant design is based on pyrometallurgical process.

Table 3.1-1 Characteristics comparison of pyrometallurgical and hydrometallurgical process [19]

Based on term	Description	
	Pyro-metallurgy	Hydrometallurgy
High grade ore	More economical	Less economical
Low grade ore	Unsuitable	Suitable
Economic process	Suitable for large scale operations	Suitable for small scale operations
Treatment of sulfide ore	Generate sulfur oxide	Possibility of treatment without sulfur dioxide
Reaction rate	Carried out by high temperature	Carried out by low temperature
Output	Very high	low

The proposed processing plant for Aynak copper deposit is designed based on geological properties of the deposit and the provided information by MCC. According to the information provided by MCC (2009), the daily extraction in Aynak copper deposit is reported as 35,000 T from which 30,000 t is sulfide ore and 5,000 t are mixed sulfide and oxide ore [1]. Considering the given information, the processing plant is scheduled for 24 h/d within 330 d/a.

### 3.2. Crushing

The ore size reduction is carried out first through blasting in the mine site and then the ore size is reduced by crusher. The location of primary crusher is a critical question in mineral processing. It can be located either as mobile, semi mobile or stationary. Therefore, the following options are considered for ore crushing.

- A. In Pit Crushing and Conveying System:** The ore is crushed in the mine site and transported to stockpile via a belt conveyer. The secondary crusher will be installed in the processing plant. Through this option a mobile or semi-mobile crusher with the capacity of 2000 t/h is required. Advantages and disadvantages of IPCC are:

Table 3.2-1 Advantages and disadvantages of IPCC

Advantages:	Drawbacks:
<ul style="list-style-type: none"> <li>a) Less number of personnel</li> <li>b) Low Operating Costs</li> <li>c) Higher Production Rate</li> <li>d) Less Environmental Hazards</li> <li>e) High Safety for Staff</li> </ul>	<ul style="list-style-type: none"> <li>a) High Capital Costs</li> <li>b) Equipment Interface</li> <li>c) Influence on Mine Planning</li> <li>d) Not Flexible</li> <li>e) Lacks Operational Reliability</li> </ul>

- B. Stationary crushing system:** The crushing and grinding process will be done in the processing plant. The flow diagram as shown in (Figure 3.2–1) is proposed for size reduction through the following three corresponding crushers:

- 1) Jaw Crusher – Primary crusher
- 2) Gyratory Crusher – Secondary crusher
- 3) Cone Crusher – Tertiary crusher

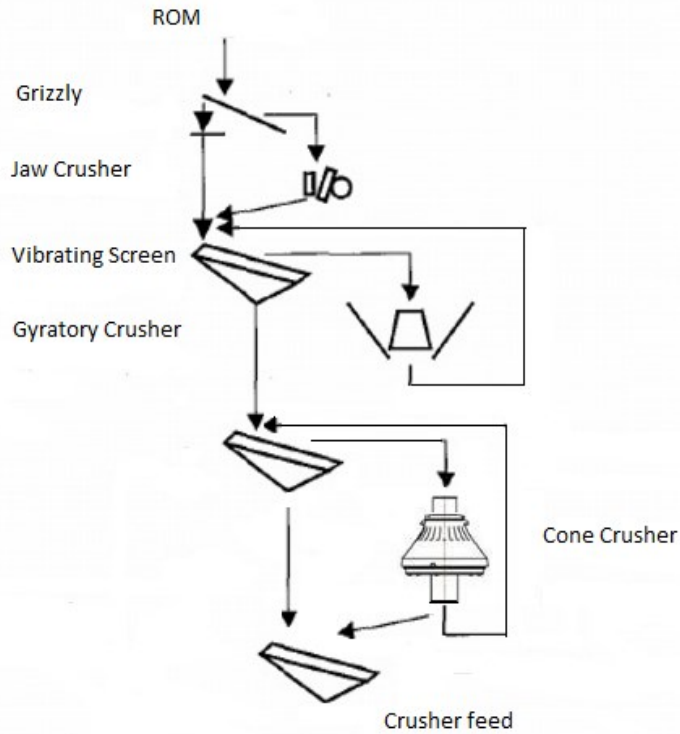


Figure 3.2–1 flow diagram for ore crushing in Aynak copper mine

Figure 3.2–1 indicates, a flow diagram of ore crushing for Aynak copper mineral processing. Run of mine with maximum diameter up to 1 m are feed to primary Jaw crusher. Then the ore is reduced to maximum 200 mm in diameter, while 80% passes through 50-100 mm. Through screeners the materials which are smaller than 50 mm in diameter will pass to tertiary crusher. The ore from 57-200 mm is reduced via secondary gyratory crusher. The last size reduction will be done by tertiary cone crusher with the product of 100 mm passing through 13 mm [20]. Through this option the daily production of 35,000 t/d will be crushed by the following crushers as illustrated in

Table 3.2-2:



Table 3.2-2 Description of crusher for mixed sulfide and oxide

No	Ore types	Location	Motor (Hp)	Crushing rate (t/h)	Power (kwh/t)	Shifts (day)	(t/d)
1	Primary Jaw crusher	processing plant	500	2,000	N. A	3	35,000
2	Secondary gyratory crusher	processing plant	500	2,000	N. A	3	35,000
3	Tertiary cone crusher	processing plant	500	2,000	N. A	3	35,000

### 3.2.1. Jaw Crusher

Jaw crusher can either be used as primary crusher or secondary crusher. The input of crusher is obtained through division of the crushing rate (t/d) by crusher activity (h/d). The crushing input is estimated as below:

$$q = \frac{35,000 \text{ t/d}}{24 \text{ h/d}} = 1,458 \text{ t/h}$$

In the formula above, q is the input of crusher.

The number of crushers is calculated based on input of crusher divided by crushing rate.

$$n = \frac{1,458 \text{ t/h}}{2,000 \text{ t/h}} = 0.72 \sim 1$$

In the formula above, n is the number of crusher.

Therefore, one jaw crushers with crushing rate of 2000 t/h is proposed for Aynak copper mineral processing.

### 3.2.2. Gyratory Crusher

Gyratory crusher can be used either as a primary or as a secondary crusher.

Table 3.2-3) illustrates the gyratory crusher descriptions. [21].

Table 3.2-3 Description of Gyratory crusher [21]

Ore Type	Location	Motor (Hp)	Crushing Rate (t/h)	Power (kwh/t)	Shifts (day)	Crushing rate (Ton/day)
Sulfide	processing plant	250-500	2000	-	3	30000

The number of crusher is obtained as below:

$$n = \frac{1666.6 \text{ t/h}}{2000 \text{ t/h}} = 0.83 \sim 1$$

Therefore, one gyratory crusher is needed to crush the ore.

### 3.2.3. Cone Crusher

Cone Crusher is used as a secondary or tertiary crusher to reduce the grain size. As a reason that the crushing cost is much lower than grinding process, the secondary and tertiary crusher is used to produce the finest crushed ore.

The MP 1000 standard cone crusher with the size of 1830-2420 mm will be applied as tertiary crusher. The treatment capacity of crusher is assumed to be 2000 t/h and the crusher output is CSS = 10mm, where 70-80% of the ore is passing through this size. One cone crusher is required as a secondary crusher

$$n = \frac{1666.6 \text{ t/h}}{2000 \text{ t/h}} = 0.83 \sim 1$$

---

## 3.3. Stockpile of Crushed Ore

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The stockpile of crushed ore can be subtitled for both proposed alternatives:

➤ **option A: In Pit Crushing and Conveying System:**

The crushed ore will be delivered from open pit through conveyor belt with approximately 1500-2000 m length to the processing plant stockpile. The stockpile should always accept the incoming material. The size of stockpile depends on size of ore, transport reliability and weather conditions. The height of stockpile is also limited by types of equipment need to

place the material. Therefore, it is assumed that, crushed ore stockpile with the top width of 1 m, the length of 100 m and height of 10 m stockpile capacity of approximately 100,000 m<sup>3</sup> crushed ore is designed for the project.

➤ **For option, B the Stationary crushing system:**

The Run of Mine (ROM) can be directly loaded to the primary crusher.

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### 3.4. Grinding

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The grinding is considered as a last effective method for size reduction. In milling operations, the crushed ore is further reduced in size through wet or dry, open or closed-circuit via a ball and AG/SAG mill [20]. There are many factors influence on selection of grinding process. These factors are including size of fraction, hardness and resistance of the ore, lifetime of mine, extraction method, available labor, and available grinding media and wear parts [20]. The following types of grinding circuits are mostly used in mineral processing industries.

#### 3.4.1. Ball Mill

In ball mill the ore is grinding by steel or iron grinding media and it is mostly used to grind the abrasive ore. When the moisture is less than 1% by weight dry process is used and the wet process is used to prepare a slurry of the feed material for further operations such as flotation or leaching. No flotation is returned to ball mill in open-circuit grinding while, the discharge of ball pass directly to the next stage without requiring for screener and classifier. In closed-circuit grinding, the grounded ore is classified by using screens to separate the size which requires for further grinding [22]. For Aynak copper mineral processing, the wet process with closed circuit is proposed. See Figure 3.4-1 [20].

#### 3.4.2. Rod Mills

In rod mill steel, rods are used as grinding chamber for grinding. In industrial minerals rod mills are used as primary grinding to prepare feed for ball mill. While, in some mineral processing plant rod mills produce the final products ground ore. In rod mills the steel are

bolted to a rotating cylindrical drum. The wearing surface from rod mill-head liners are higher than ball mill in abrasive due to resistant from ore which are not broken [22].

3.4.3. Autogenous (AG)/Semi-Autogenous (SAG) Mills

AG/SAG mills are used in most large grinding circuits, and the result of milling product is obtaining through impact breakage. Differences between AG and SAG mill is that, a SAG mill requires higher installed power than AG mill, and an AG mills provide finer grind than a SAG circuits. in addition, in term of operation cost due to lower expenditure in wearing media AG circuits is better but, SAG mills provide lower cost in terms of [capital cost per metric ton of throughput] [20].

The following milling process for Aynak copper mine is proposed as given in (Table 3.4-1). A SAG or AG mill is used as a primary grinding, which grind the ore that 80% passing through 1,000 µm. A screener is used to separate the particle size, the oversized particles crushed again through pebble crusher. A pebble crusher is used to crush the hard ore to reduced wearing and decreased maintenance cost of primary grinding.

In most processing plants, the feed of SAG mill followed by one or two ball mills [23]. Therefore, for mineral processing in Aynak copper mine, the undersize particle pass through secondary ball mill to obtain finer grinded particles. By using of secondary ball mill with ability of P80 passing through 75 µm the finer particles will obtain as shown in Figure 3.4–1

Table 3.4-1 Description of milling Circuits

Milling types	Equipment size (m)	Capacity (t/d)	Installed power (mw)	Grinding size (µm)
SAG/AG	9.8 × 4.2	37,000	5.2	1,000
Ball mill	-	-	10	75

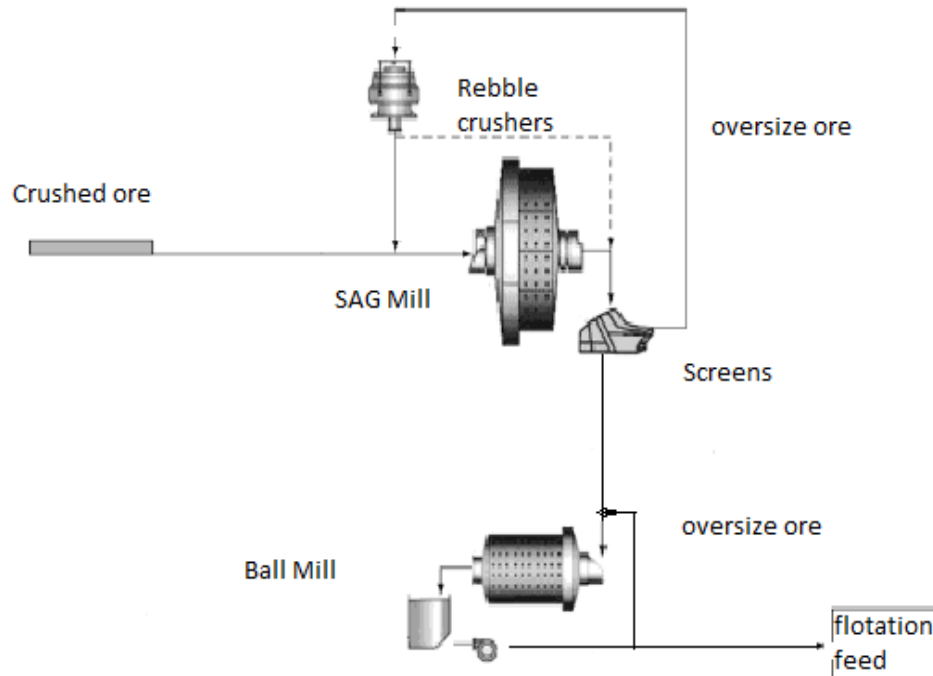


Figure 3.4–1 Grinding flow sheet for Aynak copper mine

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### 3.5. Screening

As it is defined by Matthews (2011), screening is used to separate or classify particles based on size [24]. In addition, screening is used for dewatering, trash removal and scalping small amount of over size. For ACD vibrating surface screener is proposed for size separation in processing plant.

---

### 3.6. Ore Concentration

Once the comminution process is completed. The ore concentration is carried on through the following options:

- A. Recovery of sulfide ore through flotation and oxide through heap leaching.
- B. Separate recovery of sulfide and oxide ore through flotation.
- C. Treatment of blending sulfide and oxide ore together through flotation.

#### 3.6.1. Froth Flotation

Froth flotation is used for separating of ore particles physically in slurry form [25]. In copper mineral processing froth flotation is used for separation of sulfide from silica gangue. In

froth flotation air bubbles are generated within vessel to collect and remove the hydrophobic particles. While the wetted particles stay in liquid phase. The flotation process is shown in Figure 3.6–1 [25].

The flotation feed is carried out for further cleaning through the following steps. Rougher is used to separate the valuable minerals from gangue then followed by screener which is used for reprocessed the valuable mineral. In addition, the scavenger is used to recover the valuable minerals from gangue produced by rougher. The number of cleaners and scavengers is depending on the nature of separation of value able minerals [25].

To measure the performance of flotation following equation is used [25]:

$$\text{Ratio of concentration} = F/C \quad (3.6-1) [25]$$

From the above formula:

$$F = \text{total weight of the feed}$$

$$C = \text{total weight of the concentrate}$$

Considering that, Aynak copper ore contains roughly 2.0 % Cu, after carrying froth flotation, assuming the minimum copper concentrate obtained from recovery of copper is 30 % Cu (c=30). Assuming that, the weight of concentrate is 10 % (C=10%) and weight of tailing is (T=90%). It is assumed that, tailing contains 0.1 % Cu (t=0.1). From above equation, the following parameters obtained as below [25].

A. The ratio of concentrate is obtained through

$$\frac{f}{c} = \frac{100}{10} = 10$$

It shows that, from 10 t of feed 1 t of concentrate is obtained [25].

B. Copper recovery is obtained by the following equation [25].

$$\text{Copper recovery} = 100(c/f)/(f - t)/(c - t) \quad (3.6-2)$$

$$\text{Copper recovery} = 100(30/2)/(2 - 0.1)/(30 - 0.1)$$

$$\text{Copper recovery} = 95.3\%$$

- C. Percent metal loss: is obtained by subtracting the copper recovery from 100% feed as below.

$$\text{percent copper loss} = 100 - 95.3 = 4.68\%$$

In Froth flotation collectors are used to adsorb onto the surface of particles. In for Aynak copper mineral processing considering that, the copper ore is associated with sulfide and mixed sulfide oxide ore, which occurs separately the following collectors is proposed [25].

- **Anionic collectors:** for sulfide minerals, sulfhydryl collectors such as xanthates and dithiophosphates are among the most common collectors used for sulfide ore [25]. The collectors used for oxide mineral flotation such as oxyhydryl is not as selective as it is used for sulfide ore flotation due to adsorption of some collectors in minerals. The oxyhydryl collectors includes (Alkyl sulfates, Hydroxamates phosphonic and phosphoric acids) are used for flotation of oxide minerals [25].
- **Depressants:** is used to increase the selectivity of mineral from floating, Cyanide and lime is used for sulfide mineral flotation, furthermore, organic depressants are used as flotation depressants [25].

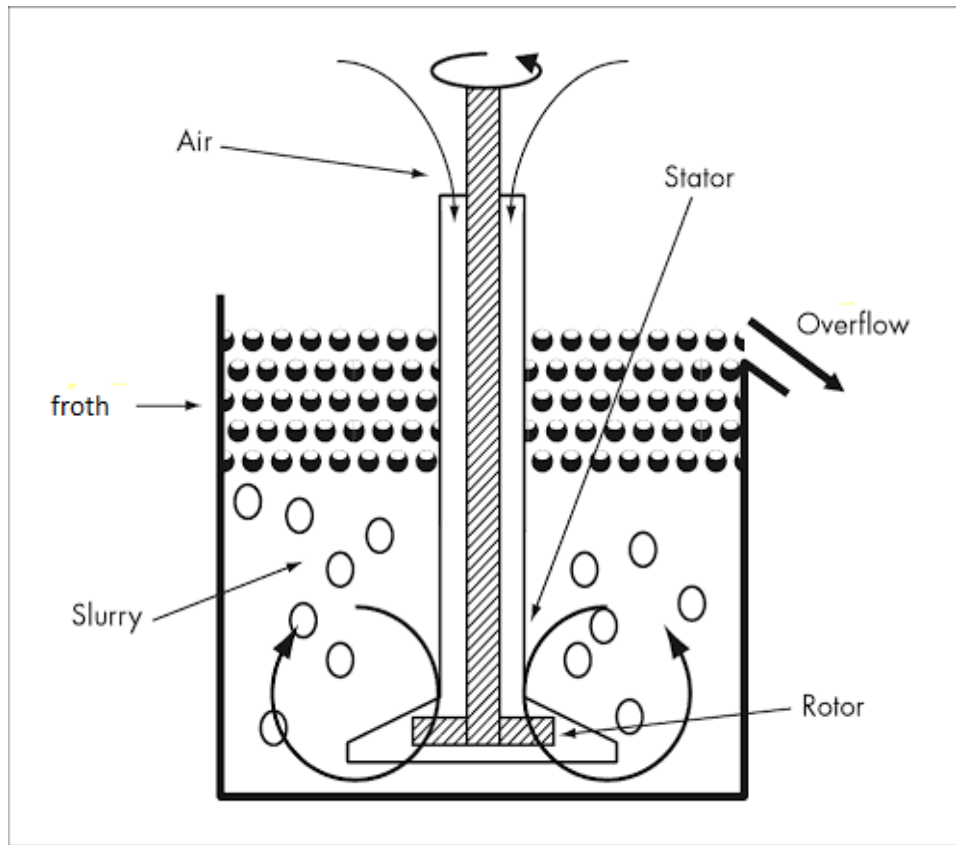


Figure 3.6–1 Flotation cell [25]

### 3.6.2. Heap Leaching

Hydrometallurgical process such as heap leaching involves low temperature chemical processing [18]. The leaching process involves size reduction, agglomeration and sulfuric acid composition. The grain size required for heap leaching is mostly 10-20 mm.

#### 3.6.2.1. Design of Heap Leaching

The (Figure 3.6–2) shows the flow diagram for heap leaching [26]. The crushed ore is mixed with sulfuric acid and stacked on heap leaching. The leaching chemistry including solution agent, gas and heat will be added to heap leach process. The leaching process takes months to year until the final recovery is obtained. The heap leach proposed for Aynak may covers an area of approximately 50 ha with height of approximately 30 m for approximately 10 million-m<sup>3</sup> material.



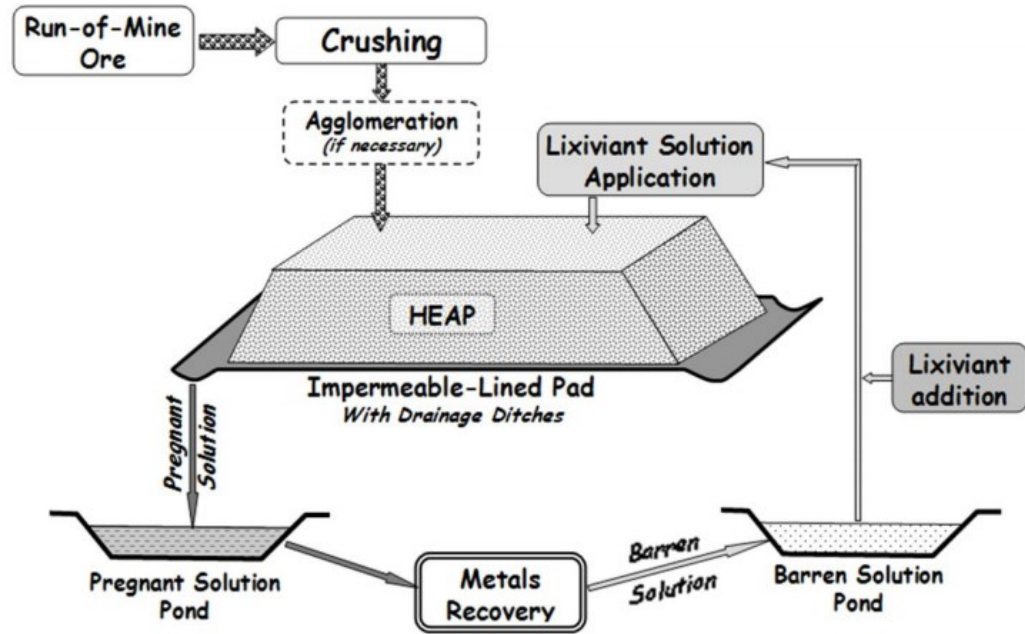


Figure 3.6–2 Flow diagram of Heap leaching process [26].

The disadvantages of hydrometallurgical are: Hydrometallurgical process operates more like chemical plants and requires sophisticated control scheme. Moreover, engineering of hydrometallurgical process is more complex and produce solid wastes that may cause disposal problems.

### 3.6.3. Methods of Ore Recovery

For copper concentration in Aynak copper deposit the following options are proposed:

- A. Recovery of sulfide ore through froth flotation and oxide ore through heap leaching: In application of this option sulfhydryl collectors such as xanthates is used for recovery of copper sulfide, and acid leaching such as sulfuric acid is used for recovery of oxide ore.
- B. Treatment of copper sulfide and copper oxide separately by forth flotation: The most common oxyhydryl collectors used for oxide minerals are Alkyl either sulfates or hydroxamates.
- C. Treatment of blend sulfide and oxide ore together: As stated by Mclean (2008), where, the ore were mined from separate copper sulfide and oxide ore at Minto

copper mine in Canada. From the total ore mined, 70% of ore associated with copper sulfide and 30% are copper oxide. The investigation in Minto copper mine is carried for blend copper sulfide and oxide ore together. The research approved in Minto copper mine, that xanthate collectors can recover sulfide ore. hydroxamate collectors are used for oxide ore. n-octyl hydroxamate collectors (AM28) is used for mixed copper sulfide and oxide ore. Hence, the recovery of sulfide is not reduced [27].

From the above proposed options for mineral processing. Option C: (treatment of blind sulfide and oxide) is recommended due to that Aynak copper deposit have nearly the same characteristic as Minto copper mine in Canada. Where, the investigated in Minto Copper showed that, the produced concentrated obtained by treatment of blind sulfide and oxide will contains the minimum sulfur content, which is the big advantage of treatment of blind copper sulfide and oxide. In addition, the investigated in Minto copper resulted 95.5 % copper recovery through blind sulfide and oxide treatment.

### 3.7. Tailing Storage Facilities (TSF)

Tailing is the mixture of processing waste from mill and concentrator that can be stored as a slurry or solid-form and forming ponds. To design and construct the TSF following criteria should be taken into account:

- Secure contaminant of tailing storage facility over the life of the project.
- No water drainage to the environment

#### 3.7.1. Construction of Tailing Dam

For construction of tailing dam in Aynak copper mine, local material and pit-run material including waste rocks, soil and overburden will be used. Moreover, for construction of embankment of a tailing dam four-side rock fill-dam embankment within the downstream structure is used.

Since the Aynak area is located in Kabul block the downstream structure is recommended for Aynak copper tailing dam, which is associated in a tectonic zone. Furthermore, the plan for raising the embankment in the future is also under consideration. The TSF has been designed for storage of approximately 150 Million Tones tailings.

#### 3.7.2. Chemical Property of Tailing Dam

The chemical property of tailing is directly related to mineralogy of the ore body and properties of slurry [28]. Based on Beijing Research Institute of Mining and Metallurgy, the chemical composition of Aynak copper mine given Table 3.7-1 [15]:

Table 3.7-1 Chemical Composition of tailing [15].

Minerals	Cu	Mo	S	As	Pb	Zn	Fe	C	Au
Content (%)	0.13	<0.005	0.055	0.014	0.006	0.005	1.78	4.91	0.002

#### 3.7.3. Site Selection for Tailing Dam

The site selection for tailing dam depends on the factors mentioned below are indicated in Table 3.7-2.

- Sufficient distance from the mine site and processing plant
- Distance from the Logar River
- Distance from residential area
- Geology, topography and climate of the site
- Cost for construction of tailing dam

Since the Aynak copper mine is located in a remote and mountains area, for completion of this study site visit for the project was not possible. Therefore, it is referred to previous feasibility study, which is completed by MCC [15].

Table 3.7-2 site selection for tailing dam [15].

Site	Distance from Pit (km)	Distance from Logar River (km)	Site Elevation (m)	Total Capacity (m <sup>3</sup> )	Dam Height and Length (m)
South of the Pit	3	13.5	2,250-2,400	155 Million	H=75-100 L=350-500

## Chapter 4. Infrastructure: From Pit to Port

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The infrastructure system in Afghanistan is not well developed. Therefore, accessibility is a big challenge for mining operations in the country. Considering the technical and economical possibilities, the supply of the Aynak copper concentrate to the international ports are to be designed based on either Railway or Roadway transportation networks.

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### 4.1. Railway in Afghanistan

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Currently, there is no railways to connect the entire country, however, regional connections in some of ports are existing. The available railways are along the northern border to Uzbekistan, and there is also a 60-km railway connection with the Iranian border in Herat province in western Afghanistan [29]. For transportation of copper concentrate MCC is committed to construct a railway connection from Hairatan port through Kabul to Torkham. This railway network will connect the northern Afghanistan through central regions to the east of Afghanistan [29].

Afghanistan has borders with six countries and have 8 ports. The most important ports of Afghanistan are listed as:

- Aqina port: bordering to Turkmenistan.
- Sherkhan port: bordering with Tajikistan.
- Hairatan port: bordering with Uzbekistan, road and water ways.
- Torkham port: bordering with Pakistan.

The Government of Afghanistan (GoA) plans to develop the following railway routes to develop the commercial relation with neighboring countries and establishing the old regional transit position of the Silk pass [30]. The planned railway network will be initiated in three phases.

**Hairatan port:** Mazar-e-Sharif border to Uzbekistan, the rail line from Termiz to Hairatan is existing and the extension from Haratan to Mazar-e-Sharif with the total length of 71 km is

the priority for GoA. [30]. The technical studies of the project is completed and the construction works of the projects is progress [30].

**North-West Afghanistan railway:** from Tajik border in Sherkhan-port to Iranian border in Herat province. This railway will connect Central Asia to Middle East with total length of 1100km [30]. In addition, this phase will connect China to Iran through, Kyrgyzstan, Tajikistan and Afghanistan as shown in Figure 4.1–1 [31]

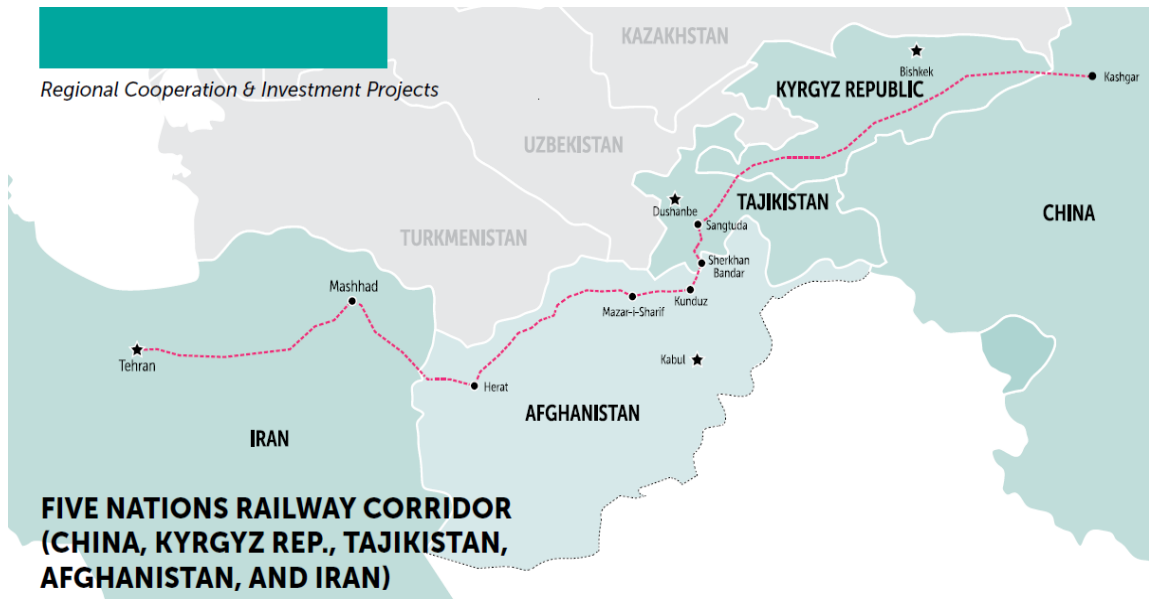


Figure 4.1–1 North-West Afghanistan railway corridor [31].

**North-East-Afghanistan:** from Mazar-e-Sharif north Afghanistan, crossing Kabul and reaches to Pakistan border.

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## 4.2. Road in Afghanistan

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According to Asian Development Bank (ADB), approximately 38,500 km road network are available in Afghanistan, from which, 2100 km are ring road, and the rest is national and regional road [30]. The road map of Afghanistan is shown in Figure 4.2–1.

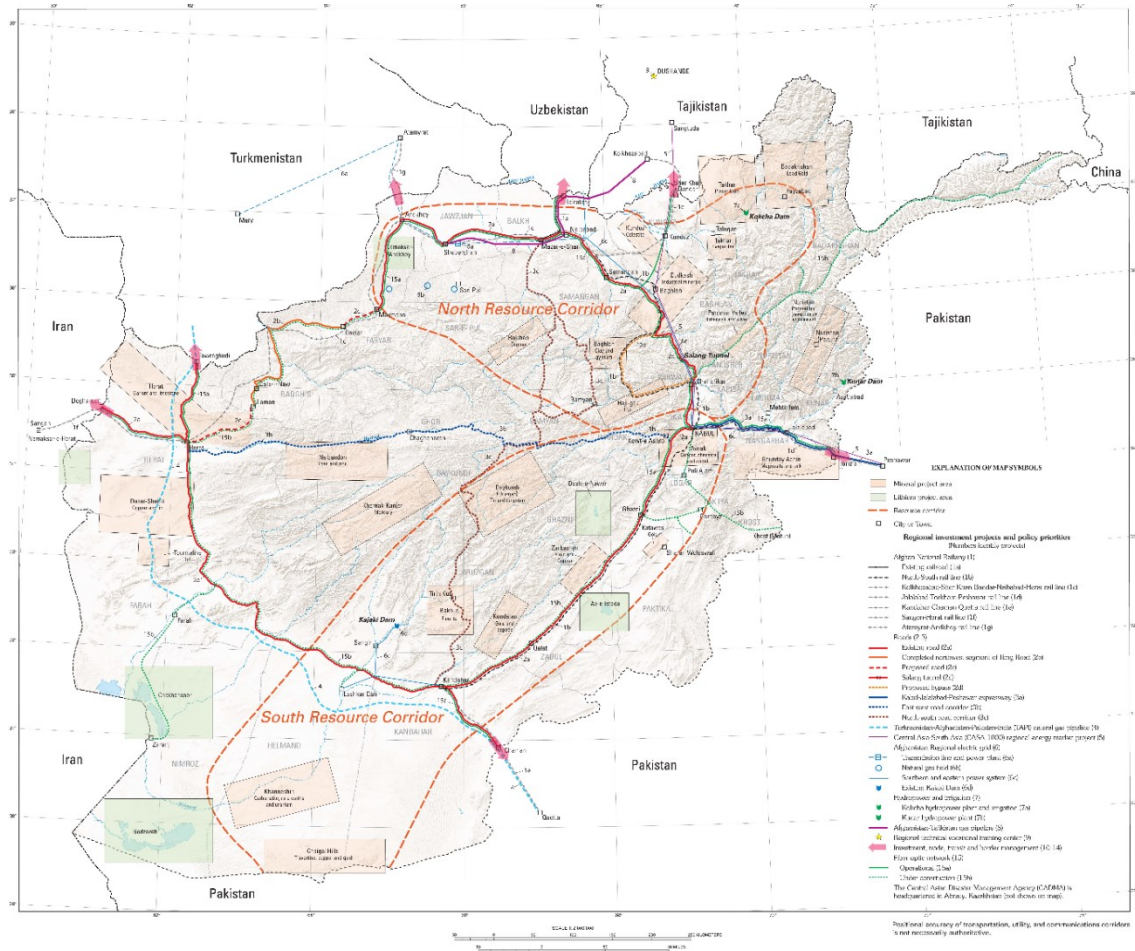


Figure 4.2–1 Afghanistan Road map [32]

Considering the road and railway in Afghanistan, the following options are proposed for transportation of copper concentrate to the international ports.

**First Option:** Transport of copper concentrate from Logar province to Mazar-e-Sharif with the length of approximately 450 km by truck and from Mazar-e-Sharif to China through Uzbekistan and Kirgizstan by train.

This option is proposed considering the current railway transportation system from northern Afghanistan, Mazar-e Sharif to eastern China city of Yiwu through Kazakhstan and Uzbekistan with the length of 7500 km.

The operating cost for transportation of copper concentrate by truck within 450 km is calculated in chapter 6.2.3. Due to that, the railway transportation costs from Mazar-e

Sharif Afghanistan to China is not accessible. Therefore, the evaluation of cost comparison between road and railway transportation is carried out based on transportation comparison in Chilean case reported by Leva (2013), [33].

**Second Option:** Transportation of copper from Aynak to Kandahar border to Pakistan by truck with length of 600 km, then from Chaman port, with length of 1,000 km to Karachi port Pakistan.

**Third Option:** Transportation of copper from Aynak to Torkham border with Pakistan 230 km and from Torkham through Pakistan railways to Karachi port of Pakistan.

In some mining projects, the copper concentrate is transported by local or international logistics companies. I.e. based on Shirriff (2016), in Peru the transportation of copper concentrate is carried out by a logistic company. The distance of transportation is 420 km by roadway and 310 km by railway. A tri-axel truck attached with trailer for transportation of two container with the dimension of 4.0 x 2.4 x 1.85 m, and capacity of 17.5 t is used for transported copper concentrate for transporting of 1.5 Mt/a.



## Chapter 5. Infrastructure and Auxiliary Facilities

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This chapter is focused on infrastructures required within the project. These infrastructures are including, access road to the mine, water and power supply for the project, fuel and explosive storages, fire protection, warehouses, accommodations, offices and laboratories for the Aynak copper deposit as shown in Figure 5.1–2.

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### 5.1. Roads

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Aynak copper deposit is located in Logar province 49 km southeast of Kabul city. The project is connected through 34 Km Kabul-Gardiz highway and 15 km sand stone road [12]. The following three categories (a) Access road, (b) Haul road and (c) Light vehicle road (LVR) are considered for the project.

The access road with the length of 15 km from the main road to the mine site is required to supply the material to the pit and to transport copper concentrate from the pit. The haul road within the mine site is used to facilitate the transportation of ore to the processing plant and waste disposal site. The light vehicle road is used for transportation of personal and staffs within the project.

The roads in Aynak copper mine are designed based on the following design process [34].

- Geometry of the road
- Structure of the road
- Maintenance of the road

#### 5.1.1. Road Geometry

Geometry is the first step of design, focuses on layout and alignment of the road. Construction of safe and sufficient road is designed based on the following factors that are given in Table 5.1-3 [34].

##### 5.1.1.1. Road width

Haul road width in mining is based on the width of the widest vehicle used the road. For safety reason the safety berm and drainage channels are also added to the road width as indicated in Table 5.1-1 [34].

Table 5.1-1 Haul road width [34]

Number of lanes	(Factor × width of largest truck )
1	2
2	3.5
3	5

Considering (Table 5.1-1) and the future development of the project, the haul road excluded the rump in Aynak copper mine is designed in to two lanes with total width of **25.5 m**, as shown in Figure 5.1–1 [35]:

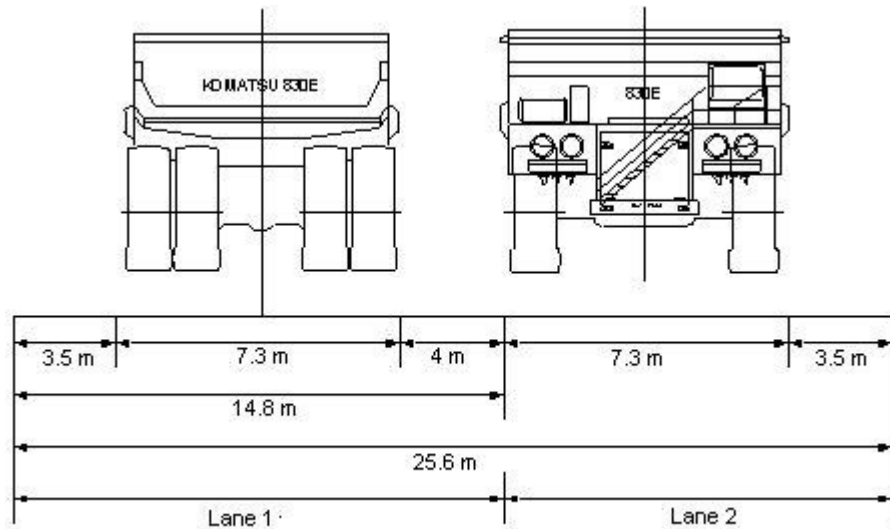


Figure 5.1–1 Haul road width [35].

5.1.1.2. Curve and Switchbacks

Curve and switchbacks are designed based on possible maximum radius. Large curve radius will increase truck speed and safety hauling, while short curve radius is vice versa. The super elevation curve or Banking is used to allow safe maneuvering of the vehicle to pass through the curve considering the centrifugal force between tire and road. Based on speed of vehicle the radius curve and the super elevation is given in

Table 5.1-2 [34].

Table 5.1-2 Radius curve and super elevation [34]

Curve Radius, m	Speed and Super Elevation, m/m Width of Road								
	15 Km/h	20 Km/h	25 Km/h	30 Km/h	35 Km/h	40 Km/h	45 Km/h	50 Km/h	55 Km/h
50	0.035	0.060	0.090						
75	0.025	0.045	0.070	0.090					
100	0.020	0.035	0.050	0.075	0.090				
150	0.020	0.025	0.035	0.050	0.065	0.085			
200	0.020	0.020	0.025	0.035	0.050	0.065	0.080		
300	0.020	0.020	0.020	0.025	0.035	0.045	0.055	0.065	0.080

#### 5.1.1.3. Cross slope

Cross slope in is used to drain the water from surface of the road and to avoid damaging the road. Cross slope in haul road depends on gradient of the road, weather condition and the road surface. Due to that Aynak copper project is located in mountains area and considering the dry climate of the site, the cross-slope may vary from 1-3% [34].

#### 5.1.1.4. Drainage

Drains at the edge of the road is designed to allow the runoff flow under favorable slope. Considering that the rainfall occurs from November to April and the average rainfall in the area is about 200 mm [6]. Therefore, 0.5m V-ditches are recommended for drainage system of roads in Aynak project.

Considering the above parameters, the following (Table 5.1-3) geometry is proposed for Aynak copper project.

Table 5.1-3 geometry of the road

Road type	Road Width (m)	Maximum speed (km/h)	Curve Radius (m)	Cross slope m/m wide of the road	Gradient (%)
Access road	9	50	100-150	-	10
Haul road	25.5	30-50	200	0,08	5-7
Light vehicle road	5	50	100-150	-	10

#### 5.1.2. Road Structure

This part of road design is focused on the ability of the road to carry the imposed load. Based on the California Bearing Ratio (CBR) wearing surface material such as gravel or gravel stone and gravel mixture are used for haul road construction. The construction of haul road is cost-effective, where the blasted waste rock material used for the structure of the road [34].

The following structures are associated with design of the road [34].

- Wearing surface
- Base
- Subbase
- Subgrade

#### 5.1.2.1. Wearing surface

Wearing surface provides traction or higher coefficient of road adhesion and shares transmitted load to base and subbase parts. In addition, it is a surface which prevents under layers against penetration of surface water. The wearing surface can be asphalt, concrete or crushed rock to create smooth surface of the road [34].

#### 5.1.2.2. Base layer

Base layer is a layer of stable material laying under wearing surface and it is used to distribute the stress created by wheel of truck on the wearing surface [34].

#### 5.1.2.3. Subbase

Subbase is layer between base and subgrade, and it is used to distribute the load applying on wearing and base parts.

#### 5.1.2.4. Subgrades

Subgrade is the foundation layer which, supports the entire load applied on wearing surface.

Considering the above structure, the following options are proposed for Aynak copper mine.

- A. Road surface underlined by natural strata:** if the natural strata in the site is able to support the weight of vehicle while passing the road, only wearing surface (gravel or sand stone) will be laid on the surface of the natural strata.

Advantage: It is the most economical means of haul road construction due to low operational cost. Nevertheless, the disadvantage of this option is higher vehicle maintenance is required especially on tire wear because of jugged edged of the surface.

- B. Gravel and crushed stone roads:** this type of road is very common in open pit haul road in United States pf America, because it provides relatively safe road and higher coefficient of road adhesion [36].

The greatest advantage of gravel and crushed stone road is the low operation cost. The waste rock can be use as subbase parts. Considering that, Aynak copper mine located in a mountains area, where the gravel and crushed stone is available. Therefore, option B is proposed for haul road structures.

- C. Asphalt waring surface:** Asphalt waring surface provides safe and high coefficient of road adhesion, in addition, it provides smooth surface and reduce dust pollution. On the other hand, maintenance of surface wearing is easy and requires low cost. The disadvantage of asphalt wearing surface is high operation cost and freezing in wintertime. Because the traffic load in access road is high for supply to the pit and transport of concentrate from pit, Asphalt wearing surface is an option only for access road to the mine.

The following road layout is in consideration for Aynak copper mine as shown in Figure 5.1–2.

- Access road to the mine with length of 15 Km
- Haul road to processing plant and Haul road to waste disposal 5 km
- Road to water and fuel storage within 5 km
- Light vehicle Road to explosive storage roughly 4 km
- Road to accommodation and offices roughly 2 km

### 5.1.3. Road Maintenance

The following road maintenance will be considered for the project

- Damage repairing
- Snow removal
- Rock scaling
- Ditch cleaning
- Graveling and grinding
- Dispatching

Further maintenance planning is described in (chapter6.2.2).

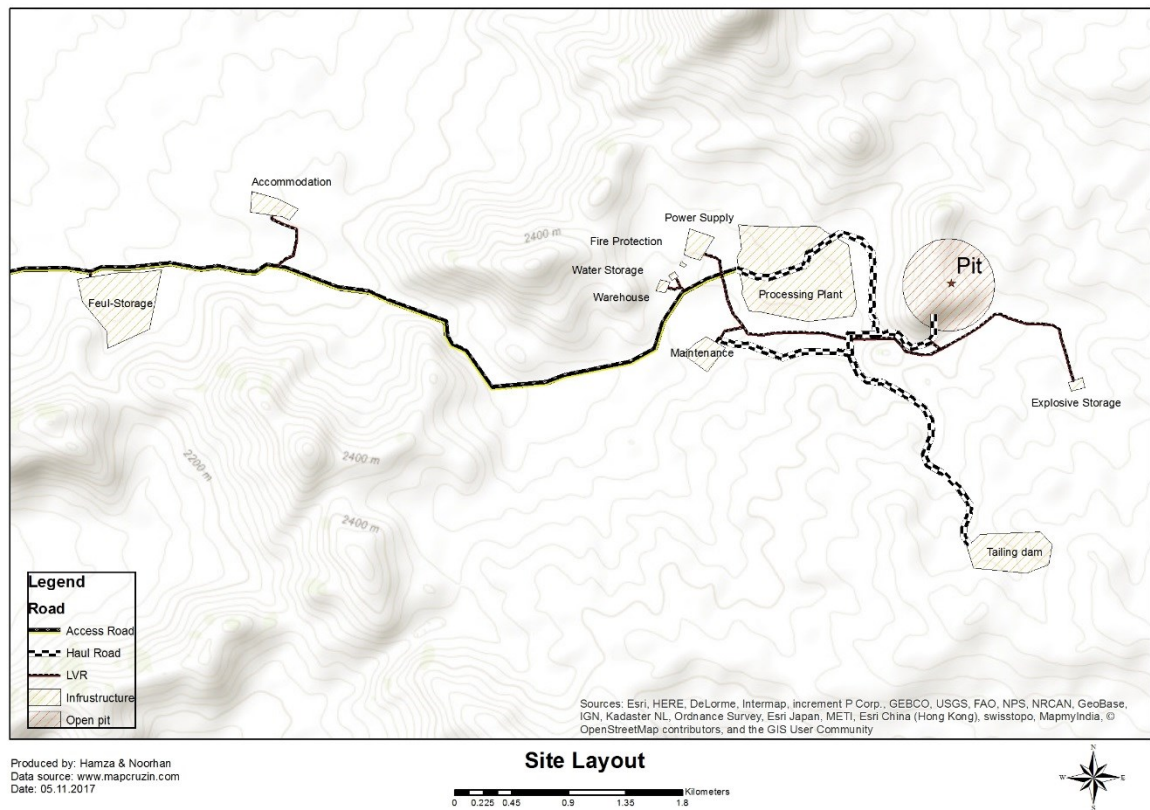


Figure 5.1–2 Site Layout

## 5.2. Water Supply

Water is the most important and a key strategic resource for mining and metallurgical process. In mining and metallurgical process, water is being supplied through surface water

and underground water sources. Due to high consumption of water in mining projects, in recent years most mining projects focused on reuse of water to achieve water efficiency.

In remote area water supply for mining and metallurgy process is depend on groundwater sources. According to the Australasian Institute of Mining and Metallurgy at Sepon mine in Leo, a chines company Lane Xang Minerals LTd (LXML) operate a single site copper and gold mine. For production of 60,000 t/a, the water supply is sourced from rainfall, treatment of water from tailing facilities and pit dewatering, supplemented by pumping from the nearby river in dry season. The average rainfall in Leo is around 2230 mm. a water treatment plant with the capacity of 700-900 m<sup>3</sup>/h was designed and kept in storage facilities for utilizing water in the project [37].

In recent years, mining companies focused on recycle of water, i.e. a copper mining project in Chile utilized a multi staged treatment plant for water recycling. From 216 m<sup>3</sup>/h wastewater, 170 m<sup>3</sup> water around 75 % its total amount treated for mining and agricultural purposes [38].

Water supply for Aynak copper mine is designed based on the following characteristics

#### 5.2.1. Aim and Scope

In Aynak copper project, large amount of water is required for mineral processing. In addition, water is required for mining operations, dust emission control, cooling, road spray watering, offices, firefighting facilities and accommodation buildings.

#### 5.2.2. Water Source

Based on hydrological report of Aynak copper mine, there are two different water sources are available for the project, which is explained in the following [7]:

- 1) **Logar River:** is located approximately 14.5 km on the west side of Aynak copper mine. The river forms from mountain streams and drains to Kabul River [7].

Based on hydrogeological information in Aynak copper, the average annual flow of Logar River ranges from 4.7-17 m<sup>3</sup>/s while, the average flow rate in summer is 2.7 m<sup>3</sup>/s, it

increases in autumn with the flow rate ranges from 10-16m<sup>3</sup>/s, and the highest flow rate is achieved in winter ranges from 17-24m<sup>3</sup>/s [7].

According to hydrogeological studies by USSR, Water supply in Aynak project is maintained via 'Sorkhab' water reservoir with the volume of 890,000 m<sup>3</sup> located about 15 km south of Aynak project [39].

- 2) **Groundwater source:** From 1976 to 1977, geological survey team under supervision of Soviet Union geologist investigated on the water source in Aynak area. The investigation was carried out through electrical sounding system, in addition, several wells was used within the investigation. The investigation resulted that the groundwater in the area can perfectly supply the water demand of the project [7].

According to investigation by USSR and AGS, the water level below surface is located in a depth from 4-42 meters [5]. Moreover, the samples for water quality from surface and groundwater were studied. The result of study approved that the quality of water is good in the area. Moreover, the trace element does not exceed the World Health Organization human-health benchmark [5].

### 5.2.3. Water Consumption

- Water consumption in processing plant.

Based on combination of mining and mineral processing the mined ore will pass through crushing, grinding and flotation. As a rule of thumb, about 50 percent water by mass is required for mailing the ore [40]. i.e., in Aynak copper mining project for processing of 35000 t/d about 17.5 ML/d water is required.

- Water consumption in open pit and other auxiliary facilities

It is assumed that 50,000-100, 000 L/d water will serve for domestic uses, such as offices, accommodation area, canteen, cafeteria, shops, repair shop and warehouse. Additionally, it is assumed that 1,5-2,0 ML/d water is required for mining operations and dust control.



#### 5.2.4. Water Treatment

For processing plant, it is assumed that 50 percent of wastewater will be recycled. The rest of water should be supplied through fresh water.

##### 5.2.4.1. Open Pit Dewatering:

Open pit mines are varying in size, shape and depth. The term open pit dewatering is used for removal of water from pit followed by groundwater flow and surface water runoff [41]. The following options are proposed for pit dewatering [34].

- I. Pit dewatering by using bore pumps located around the pit.
- II. Pit dewatering via sump, pump away collected water from a bottom of the pit.

The factors including water level, density and water flow rate effect on dewatering process and pump selection in addition, place of discharge is a critical factor on pit dewatering.

Based on hydrogeological report on Aynak and considering the geology of the area both option II and I are applicable in open pit dewatering process. In addition, the water supply for Aynak project through underground sources, have the advantage that, not only to supply the required water for the project but also for pit dewatering purposes.

If the depth of the pit is increased, then a storage tank and a second water pump is required on the ground level of open pit for pit dewatering. It is assumed that open pit covers an area of 1km<sup>2</sup> considering the groundwater inflow, the following pit inflow is forecasted for the project as given in Table5.2-1.

Table5.2-1 Pit dewatering

Location	Item	Water Inflow (m <sup>3</sup> /d)
Open pit	Groundwater	6500
	Rainfall	500
	Total	7000

Considering above parameters, the water consumption in processing plant, open pit mine and other auxiliary facilities is estimated 20,000 m<sup>3</sup>/d. The demanded water can be supplied through following options.

- A.** There is a water dam with the volume of 890,000 m<sup>3</sup> within 15 km on the south of the project. This could be an option for water supply in Aynak project, but this option requires a detail study of Logar River during dry season and a social agreement is required, because river sources in Afghanistan is mostly used for agricultural purposes.

However, in most mining projects the surface water is used as source of water for mining and mineral processing. i.e., Michilla and Esperanza copper mining projects in Chile used the seawater for processing of 98000 t/d copper that, 600 l/s water is pumped from the sea to the mine site [42].

- B.** Water supply through underground sources: the required water for Aynak copper project can be supplied by utilizing drill wells. Thus, the water level in the site is located in depth of 4-42 m, and the area is hit by dry climate, therefore, 10 sets of large diameter pump station from large diameter wells roughly 50-55 m depth are proposed for Aynak copper project. Due to shallow water level in Aynak copper mine, the underground source is proposed.

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### 5.3. Power Supply

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The electricity generated in Afghanistan is deficient, it does not exceed to 1,000MW in 2016, approximately, 35% of the Afghan citizens have access to power grid [43]. The electricity in Afghanistan is supported through internal source (hydropower and diesel generator) and external source power line from Iran, Turkmenistan Uzbekistan and Tajikistan. Based on technical assessment in Afghanistan power sector in 2013 nearly 70% of current electricity in Afghanistan is imported from neighboring counties [44].

Due to the above-mentioned reasons, electricity generation in Afghanistan is not sufficient to supply required electricity of the project through power grid. Therefore, the demand for electricity in Aynak copper project should be supplied through an individual power supply system. Following options are considered for power supply for Aynak project.

5.3.1. Solar Photovoltaic

Photovoltaic cells (PV) are used to convert sunlight into electrical energy. According to the report by The National Renewable Energy Laboratory (NREL), Afghanistan has a very good potential of solar energy as shown in Figure 5.3–1 [45].

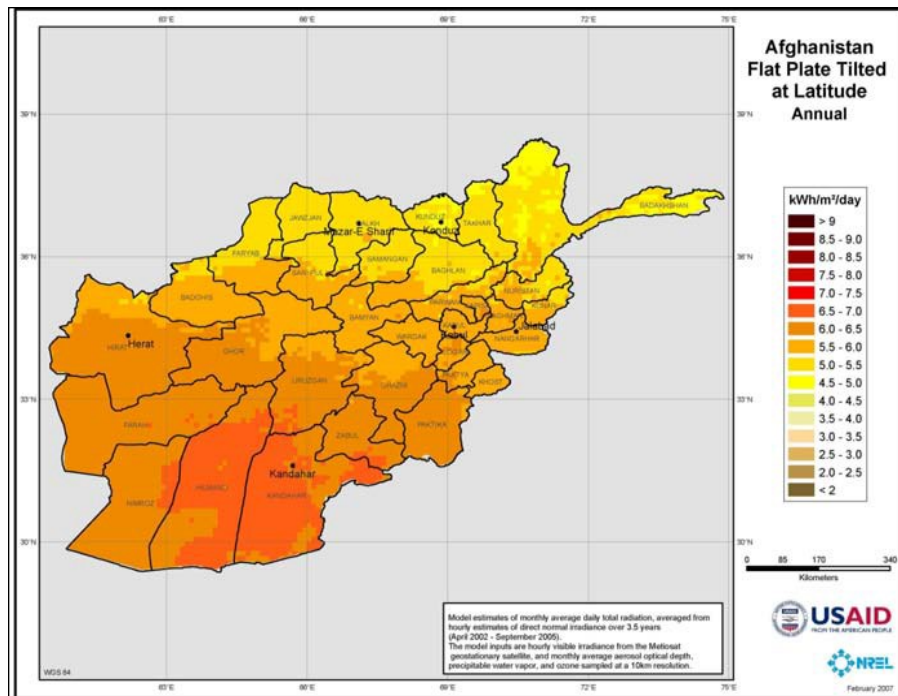


Figure 5.3–1 Afghanistan solar map [45].

The cost for production of one MW solar energy is described in chapter 6.1.2.

5.3.2. Wind Energy

Feasibility of renewable energy in Afghanistan shows that, there is excellent wind energy potential in west part of the country, where the wind blows from Iranian border, as shown in Figure 5.3–2 [45]. The potential of wind energy in Kabul regions seems to be poor and requires technical and economical investigation [45].

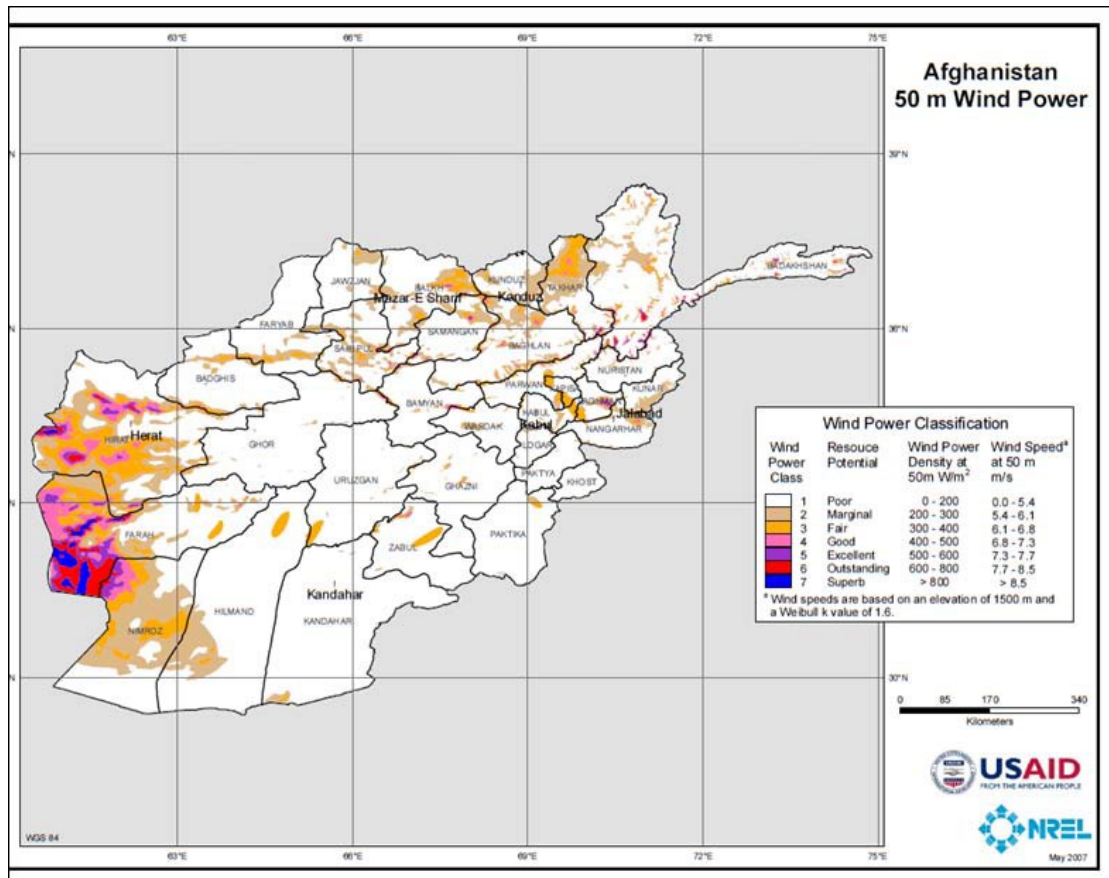


Figure 5.3–2 Afghanistan Wind Energy [45].

Based on renewable energy report in Afghanistan, the cost for generation of 1000 Kw of wind energy are estimated roughly U.S\$ 5 Million [45].

### 5.3.3. Diesel Power Plant

A diesel power plant uses a diesel engine to generate sufficient electricity. Diesel engines uses the heat of compression of air for ignition of fuel in combustion chamber [46].

A diesel power plant may use for the following purposes.

- i. Base: work continuously for generation of electric energy.
- ii. Standby: sometimes running continuously
- iii. Emergency: running for emergency purposes

Technically the most important indicator of diesel power plant, which define the efficiency of power plant, is the quantity of power for such installed power unit. Therefore, the

generators used in a power plant must provide the maximum load [47]. The following points should be considered while design and operation of diesel power plant [47].

- Diesel generators are required to be switched off as a periodically manner for maintenance and repairs.
- Consumers supplied from power plant can be vary in term of power quantity during the day and the season of the year.
- The total capacity of power should be higher than daily peak load. [47].

The demand for electricity is considered based on average power usage in the project. Considering the demand charges for cycle machines such as crushers and for machines operating constantly. It is assumed that Aynak project requires 50 MW electricity. To generate 50 MW electricity, 8 generators each with 6.25 MW power capacity is required to obtain power demand of the project.

Table 5.3-1 Advantage and disadvantages of diesel power

Advantages:	Disadvantages:
<ol style="list-style-type: none"> <li>1. Easy Installation and Quack starts</li> <li>2. Requires less area</li> <li>3. Simple Design and Layout</li> <li>4. High Thermal Efficiency</li> <li>5. Higher Safety for Staff</li> </ol>	<ol style="list-style-type: none"> <li>1. High Capital Costs</li> <li>2. Higher operating cost</li> <li>3. Does not produce overload</li> <li>4. higher Maintenance costs</li> </ol>

Based on size of generator, diesel generators consist of the following equipment.

- Fuel injection
- Piston
- Air filter
- Intake silencer
- Governor: is used to maintain the speed of engine automatically
- Start up

Diesel generators requires the following systems

- Fuel system: completely cleaned fuel
- Oil system:
- Compressed air system
- Water system for cooling

The cost associated for power supply through diesel generators is calculated in chapter 6.2.2.

#### 5.3.4. Coal Fired Power Plant

Coal is the most abundant fossil fuel and it is a key source for production of electricity for long-term projects. Moreover, Afghanistan has a huge potential of coal as illustrated in Figure 5.3–3 [48]. In addition, advanced technology in steam turbine of coal fired power plant introduced an improved for the efficiency of coal fired plant and reduced the emission and the decreased the specific coal consumption for generation of electric power from (3.5 kg/kWh) to only one tenth coal consumption for production of kW/h of electricity [49].

The major influence factor that improved the efficiency of coal fired power plant from 1900-2000 is based on the following factors [49]

- Increasing in steam condition
- Increasing in rating
- Using reheat system
- Increased cooling by hydrogen and water
- Increased in boiler efficiency and size

Operation of coal-fired power plant is based on steam turbine cycle, that smaller coal fired power plant operates with lower pressure up to 17 MPA, and the large coal-fired power plant operates within supercritical pressure up to 38 MPa [50].

i.e., for production of 750 MW electricity from a coal-fired power plant high efficiency supercritical steam generator and reheat steam is required. In addition, one or two double-flow turbines depends on the capacity of power plant is necessary. The main turbine operates as a single-flow turbine with pressure of up to 100 bars, and provides the final

feed-water with the temperature of up to 300 C. The fed water is reheated in boiler before enters to the double flow IP turbine than exhausted with lower pressure to two double flow LP turbine. In addition, a feed-water pump that provides main steam pressure at full load is required [49].

To achieve the higher efficiency the following auxiliary load is required.

- Steam/water cycle pump.
- Cooling system
- Desulfurization system
- Catalytic redactors
- Transformer

Considering the main and auxiliary losses the power plant net efficiency is calculated as below [49].

Thermal cycle efficiency                      49.3 %

Boiler efficiency                                95 %

Auxiliary efficiency                            96 %

Power plant net efficiency =  $0.49 \times 0.95 \times 0.96 = 45 \%$

To supply the demand power from a coal-fired power plant in Aynak copper project the following aspects should be considered.

- Prefeasibility study and feasibility study on a coal fired power plant.
- Budget capital cost and operation cost for new power station project
- Power station design and layout
- Feasibility study on coal resources
- Determination of coal-fired power plant site

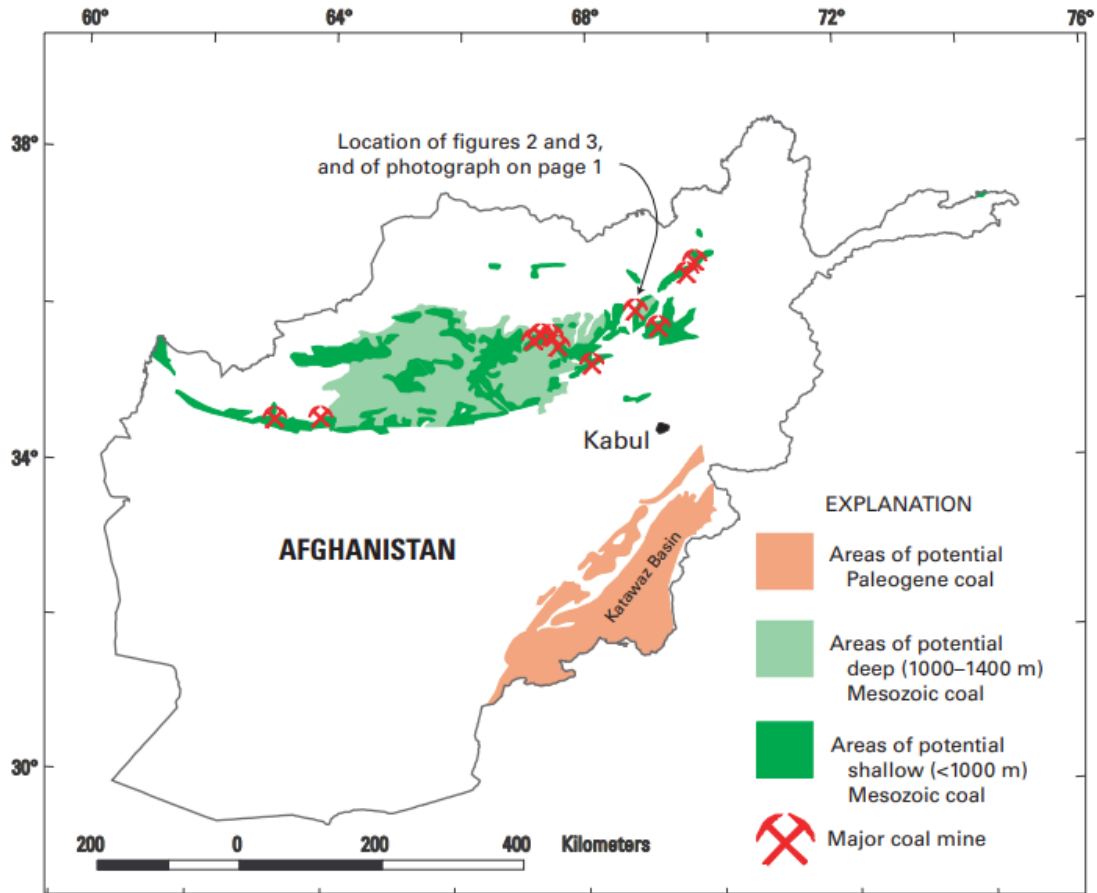


Figure 5.3–3 Coal in Afghanistan [48]

## 5.4. Fuel Storage

A fuel storage is used to serve for daily fuel requirement of the project. In general, fuel is being stored in tanks. The size and the number of storage tanks that are required for the project is directly depends on fuel supplier to the site and fuel consumption in the site. Therefore, a fuel storage with the capacity of 300,000 L is estimated to serve at least for three days fuel requirement of the project. The required fuel for the project will be supplied by a local fuel provider or a fuel supplier company.

The diesel fuel will be unloaded from a tanker truck and pumped to the main fuel station as shown in (Figure 5.4–1) [51]. Through using pipeline with distance of 100-200 meters, the fuel will be pumped to two small fuel (batch) storage. The batch storage will be attached



with fuel pumped to fill the haul tankers used for distribution of fuel. The fuel distribution will be done by two haul tanker trucks to the fuel required engines.

Two small fuel (batch) storages are used to minimize the risk of fire on main fuel storage from ignition source. The fuel storage area will be marked with hazards warning symbols, well lighted and surrounded with fences [51]. The fuel storage tanks can be located on surface or underground. Considering the higher temperature during summer it is recommended to use below ground fuel storage.

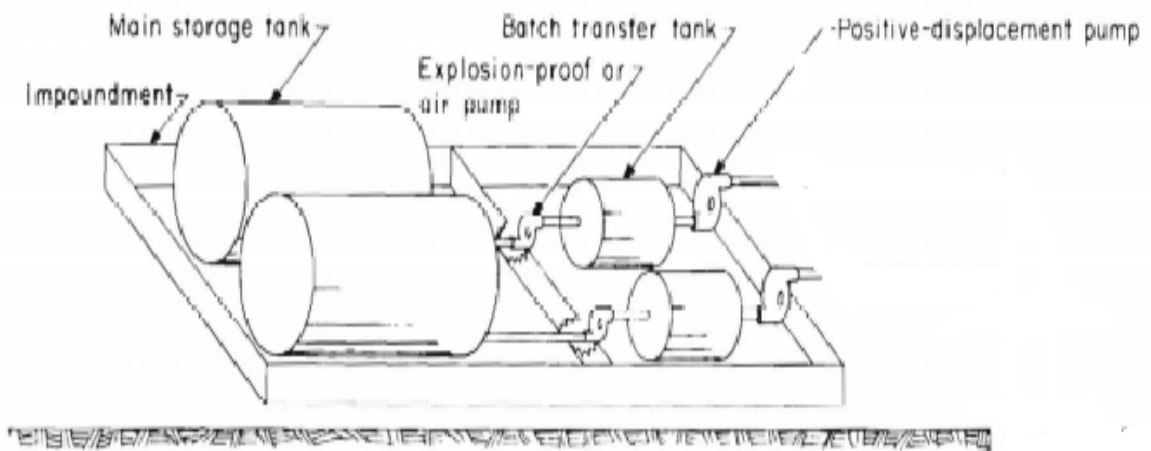


Figure 5.4–1 Fuel Storage Plan [51].

The location of fuel storage tanks within the project is depended on site topography, fuel type, and location of nearby structures. In addition, the following factors should be considered while selecting fuel storage location [52].

- ✓ Tanks size
- ✓ Maximum fire radiation
- ✓ Sufficient distance from neighboring infrastructure
- ✓ Future expansion of plant

Fuel storage layout will be located on the west side of the pit with sufficient distance from processing plant and will be secured against unauthorized entry.

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## 5.5. Fire Protection

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Fire protection systems applied in open pit mine to avoid or decrease the fire risk. The following fire protection systems have mostly common usage in open pit mining.

- Suppression System: including Aqueous Film Forming Foam (AFFF), water, high expansion foam and dry chemical agents [51].
- Controls system: this system includes manual and mechanized operations, and this system works through overhead pipeline and nozzles.
- Detection System: includes detections such as heat, smoke and flame. [51].

The selection of each suppressant system depends on types of fire expected from the site. Among them AFFF, resulted well in USA mining operations, with fast reaction and ability to cover the fire. [51]. On detection system, Heat detection provides high reliability and low maintenance, while smoke detectors reacted much faster than heat detection. The flame detectors are the fastest detectors, which can provide the ultraviolet light omitted by fire [51]. Therefore, the flame detectors are proposed as fire protection system in Aynak copper mine for fuel and explosives storages.

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## 5.6. Explosive Storage

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According to Olofsson (2002), explosives are “chemical mixture that releases gases and heat at high velocity”. The explosives are used in mining, is divided in to high explosive which includes high velocity of detonation, high temperature, pressure and high density, and blasting agents such as mixture of fuel and another oxidizer. In term of safety, explosives are developed under the following generations as listed below [53].

- I. First generation: Dynamite, nitroglycerin
- II. Second generation: Water-gels, nitrate
- III. Third generation: Emulsion explosive

Considering the security situation in Afghanistan, first and second types are not suitable for transportation and handling. Therefore, emulsion explosive is recommended for Aynak copper deposit.

#### 5.6.1. Emulsion Explosive:

Ammonium Nitrate Fuel Oil (ANFO) is a mixture of ammonium nitrate fuel and oil that produced in the worksite. The explosive matrix are stored separately in an explosive hauling truck as shown in Figure 5.6–1 [54]. After the explosive matrix is mixed with fuel oil agent's and pumped to the borehole then the matrix will develop to an explosive agent [55].



Figure 5.6–1 Explosive matrix vehicle [54]

#### 5.6.2. Detonators

The explosives are initiated by the following detonators [53].

- Electric detonator: this type of detonator mostly used in Europe and has a higher degree of safety, but it has higher risk due to thunder storms, additionally, the electric detonator should not place parallel to the power line and for away from radar installation.
- Non-electric detonator: these types of detonator is mostly used in USA, for initiation of explosive.
- Electronic detonator: the electronic detonator provides the blaster an opportunity for each charge shall be detonated.

### 5.6.3. On-Site Storage

In order to increase safety on explosive site, the following factors is considered for Aynak explosive storage site layout [53].

- National and local regulation: considering law and regulation of GoA construction and distance of the storage site will be selected.
- Security of the storage site: only the responsible person is allowed to access the storage site and explosive magazine.
- Ventilation condition: the explosive storages should be kept clean, dry within a sufficient ventilation system.
- A Separate explosive magazine for explosive magazine and detonator is considered for Aynak copper project.

In addition, recent and past magazine explosion at some active mines has been reviewed to identify the condition of explosive storages, causes of hazards and recommendations for improving safety of new site explosive storage.

According to USA Bureau of Mine (1983), in most active mines, some small amount of explosive (ANFO) was stored in the mine site while, the rest of explosives were provided by explosive provider based on requirement of explosive to the site. In most active mines, less than 10,000 Lbs. or 4500 kg of detonator cord and high explosive within 2 magazines was stored in the mine site [56].

fuse lighters can be stored separately ore together with detonator, in case it is stored separately only the risk of fire will be obtained but no explosion occur.

### 5.6.4. Type of Storages

Different types of explosives storage are existed such as, metal magazine, non-metal magazine, masonry magazine, and the earth covered type magazine. All types of magazine require a sufficient ventilation in order to obtain a constant humidity and temperature in explosive magazine. Considering the security situation in Afghanistan for Aynak copper deposit a metal explosive storage is recommended.

5.6.5. Potential Hazards of Explosive Magazine:

The USA Bureau of Mine is reported: “between 1970-1980 there were ten magazine explosions per decades” as a result of fire by lightning, spark and welding during removal of magazine locks, or mixed storage of detonator and explosive agents and some unknown reasons. The following points are possible sources of hazards for an explosive magazine [56].

1. Fire: any types of fire is a great hazard for explosive storage, therefore the magazine area should be free of any types of ignition’s material even the dry grass and brushes.
2. Electric and static electric: lighting, power line and static electricity causes a serious hazard for explosive storage. Thus, explosive storage should be equipped with anti-static shunts and stored in non-conductive containers. In addition, strikes from thunderstorm is also very dangerous for explosive storage therefore lightning protection system is required for all types of explosive magazines.
3. Power line: power line can cause a serious hazard on the wire of electric detonator and the risk of power line is much higher where non-conductive magazine is used. Based on California safety regulation by Bureau of Mine, the storage magazine should be places for away at least 25 feet from law voltage power line and 100 feet from high voltage power line.

For Aynak copper deposit a separate explosive magazine for explosive agents and detonators with approximately one-month storage capacity is recommended as it is shown in Figure 5.6–2 [57].



Figure 5.6–2 Explosive Magazine [57].

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## 5.7. Maintenance

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Maintenance in mining is used to meet the production target safely and economically [58].. The goal of maintenance is not only to keep the efficiency of machinery and equipment at high rate but also to keep the cost of production as low as possible.

### 5.7.1. Maintenance Strategies

Based on definition by Kumar (2011) “maintenance strategies are defined on the basis of failure type and consequence failure”. Following strategies are characterized as below [58].

- Reactive strategy: this type of strategy requires unscheduled maintenance. It is applied when the failure or breakdown occurs unexpectedly.
- Preventive strategy: depends on time-base maintenance. It is based on scheduled maintenance and requires inspection calibration, adjustment and cleaning actives.

- Predictive strategy: depends on measure of performance before a failure happened, and requires inspection and monitoring.

Considering the above strategies, the following maintenance systems are required for the project:

#### 5.7.2. Maintenance Facilities for Machinery

Maintenance shop, including haul trucks and other machinery in the Aynak copper mine is designed based on width and height of haul truck. The maintenance shop is designed in steel frame structure with internal brick wall. The area covering a maintenance or repair shop is depended on mine size and daily production. Therefore, in ACD the maintenance facilities may cover an area of approximately 1500 m<sup>2</sup> on the west side of the pit.

Maintenance of Machinery need to be scheduled based on pre-planned, estimated operating time, and based on manufacturer and regular inspection of machinery [59]. While a maintenance planning, it is important to register the equipment and mark each item need to be maintenance.

It is important that maintenance workshops effectively work. The effective hours of workshop will obtain by controlling the workshop control data. Workshop control data is used to report the progress in workshop by the following three forms.

1. Number of Completed order
2. Number of progress order
3. Number of new order

#### 5.7.3. Roadway Maintenance

The goal of roadway maintenance is to secure safety transportation and to provide a suitable surface. The following road maintenance is required for the project.

- I. Grading profile: water plays a critical role in degradation of road, to maintain cross slop regular grading is required for the project.

- II. Compaction: due to heavy truck system uses the haul road, a regular compaction is required.
- III. Drainage: cleaning drainage is a regular task of road maintenance.

#### 5.7.4. Electrical Power Maintenance

Electric power is supplied through diesel generators. The power is distributed by network feeders to substations for each auxiliary operation. The following points are required in maintenance of electric power:

- I. The most common damage occurs in power cable by heavy equipment, therefore, monitoring and maintenance of such power cable is applied before any failure occurs.
- II. Transformers, regular monitoring of transformers is required to achieve good performance.
- III. Water pumps used to supply water for the project and dewatering of the pit will be equipped with sensing devices to prevent water losses in reservoirs. These devices will check periodically to achieve proper function.

#### 5.7.5. Warehouse

As Aynak project is located in remote area and the supply of goods takes time for transportation to the mine site, Thus, a moderate warehouse with the size of 40 m × 30 m on west side of the pit is required to store the machineries, metallic materials, nonmetallic materials and electrical equipment. The warehouse building will be equipped with crane lifting in order to facilitate the displacement of heavy goods.

The warehouse will be designed in such a manner, that facilitates not only store of the goods but also the easy handling and accessibility of goods. Moreover, while construction of warehouse It should be particularly considered, that toxic material should be stored within proper ventilation system. In addition, it is under strongly consideration that, solid, liquid and gas agents will be warehousing separately from each other. The solid material will be



stored in containers, boxes and bags. The liquid material will be stored in containers and plastic bags while the gas agents will be stored in under pressure in gauge cylinders [52].

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## 5.8. Accommodation

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Aynak copper deposit will be the first and biggest open pit mine in Afghanistan, therefore the following welfare facilities are in consideration for the project

- A. Office buildings, meeting room and guesthouses
- B. Concentrator buildings, workshop and warehouse building
- C. Workers dormitory, canteens, shower rooms and other facilities
- D. Emergency center and recreation rooms
- E. Supermarket, hotel, canteens, and outdoor activities

It is assumed that 500 people are in charge in the project, from which 250 workers are from local and nearby cities and the remaining 250 technical staffs are permanent employees. Therefore, the accommodation is considered for 250 workers.

Workers dormitory is designed based on 5-person share room including kitchen and toilet in 5-floor building each floor with 10 rooms. In addition, those staff who have technical responsibility are allowed to have site offices near plant [52].

### 5.8.1. Amenities

Amenities including canteens, medical center, employee shop and other required facilities, which are necessary for the project, will be located in a central area, to achieve the minimal traveling to and from such facilities. Therefore, amenity areas for Aynak copper mine will be sited near to the main administration buildings.

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## 5.9. Laboratories

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Site laboratory is used "to provide an analytical service both for routine and special samples of raw material and products" [52]. For Aynak copper mine, a central laboratory is in

consideration. In order to maintain the range of service and minimize the transportation of personal and materials.

The central laboratory may contain toxic and other hazardous materials, therefore the risk of fire and chemical reaction must be studied in order to prevent hazards associated with laboratory activities.

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### 5.10. Labor

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Following labor are considered for the project

The following factors are considered while calculating the required workforce. 1. Labor directly related with equipment and 2. Labor associated with function of the task.

- ✓ Shift per day
- ✓ Working days per week
- ✓ Availability of personal
- ✓ Availability of equipment

The number of personal requires for mineral processing is estimated from the following equation [60]

$$Nml = 5.90 \times t^{0.3} \quad (5.10-1)$$

$$Nml = 5.90 \times 35000^{0.3} = 117$$

Where, T is the ton of ore crushed and milled/day.

The total number of workforce for Aynak copper deposit is assumed 500 staff. From which 150 people are technical staff. While, 100 other are skilled person and 250 others are helper for the project.

## Chapter 6. Cost Analysis

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The factors, which effects on costs in mining projects are the mine size, daily ore production and ore treatment in the processing plant. The estimated capital and operating cost for processing plant and auxiliary operation in Aynak copper mine is calculated based on estimated cost from real operations. The equations used for cost calculation is taken from open pit mine planning and design by Hustrulid (2006), [60]. In addition, the transportation cost from pit to port is calculated for truck within roadway system.

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### 6.1. Capital Cost

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The capital cost refers to investment requirement for the project. The capital cost for mineral processing and other auxiliary operation for Aynak copper mine is calculated based on production rate (t/d) in U.S. dolor. The calculation process is the following formulas [60].

#### 6.1.1. Investment Cost for Mineral Processing

Site cleaning and foundation preparation cost for processing plant is obtained as below.

1. The processing plant area in  $m^2$

The area required for the processing plant, including crushing plant, grinding and flotation is obtained using Equation (6.1-1):

$$Ac = 0.05 t^{0.5}; m^2 \quad (6.1-1)$$
$$Ac = 0.05 t^{0.5} = 9.3 \text{ acres} \cong 36,420 m^2$$

2. Concrete foundation costs

The cost of concrete foundation and reinforcing steel for the processing plant buildings and services including offices warehouse and laboratory is obtained by the following equation(6.1-2):

$$\text{concrete foundation costs} = \$30,000 t^{0.5} \quad (6.1-2)$$
$$\text{concrete foundation costs} = \$30,000 t^{0.5} = \$5.6 \text{ million}$$

### 3. Building costs

Considering that, primary crusher is placed outside pit in processing plant. The cost of processing plant building, offices and laboratory building excluding the cost of equipment is obtained by the following equation(6.1-3):

$$\begin{aligned} \text{cost of building} &= \$27,000t^{0.6} && (6.1-3) \\ \text{cost of building} &= \$27,000t^{0.6} = \$14,381,513 \end{aligned}$$

#### 6.1.1.1. Crushing costs

It is assumed that the cost of primary secondary and tertiary crusher will be roughly \$5 million.

##### 1. Primary crusher

The cost for primary crusher installation, construction of truck dump, feeders and conveyor system under crusher is obtained by the following equation(6.1-4):

$$\begin{aligned} \text{ost of primary crushing plant} &= \$15,000 tc^{0.7} && (6.1-4) \\ \text{cost of primary crushing plant} &= \$15,000 tc^{0.7} = \$22.7 \text{ million} \end{aligned}$$

##### 2. Secondary crusher

The cost of secondary and tertiary crusher installation, construction of the feeders and conveyor system under crusher is obtained from the following equation:(6.1-5)

$$\begin{aligned} \text{cost of fine ore crushing plant} &= \$18,000 t^{0.7} && (6.1-5) \\ \text{cost of fine ore crushing plant} &= \$18,000 t^{0.7} = \$27.2 \text{ million} \end{aligned}$$

#### 6.1.1.2. Grinding costs

The capital cost for milling process varies from site to site. It depends on the quantity of ore, size of ground ore and the hardness and abrasiveness of the ore.

Considering the medium to hard ore that, 85% of the ore is passing through 200 mesh. The cost for installation and construction of grinding plant is assumed by the following equation(6.1-6):

$$\begin{aligned} \text{cost of grinding + bins} &= \$22,500 t^{0.7} && (6.1-6) \\ \text{cost of grinding + bins} &= \$22,500 t^{0.7} \approx \$30 \text{ million} \end{aligned}$$

#### 6.1.1.3. Flotation cost

The cost for flotation, thickening and filtering of concentrator is obtained by the following equation(6.1-7):

$$\begin{aligned} \text{process capital cost} &= \$30,100t^{0.6} && (6.1-7) \\ \text{process capital cost} &= \$30,100t^{0.6} \approx \$16 \text{ million} \end{aligned}$$

#### 6.1.1.4. Tailing storage costs

Tailing storage costs depend on topography of the site, distance from the processing plant, environmental consideration, availability of the tailing construction materials, etc. therefore, the minimum tailing storage cost is obtained from the following equation (6.1-8):

$$\begin{aligned} \text{minimum tailing storage cost} &= \$20,000t^{0.5} && (6.1-8) \\ \text{minimum tailing storage cost} &= \$20,000t^{0.5} \approx \$10 \text{ million} \end{aligned}$$

Table 6.1-1 Investment costs for Processing plant

Investment cost for processing plant (M\$)	
Concrete foundation	5.6
Building	14,38
Crushing	54.9
Grinding + bins	30
Flotation	16
Tailing	10
Total investment cost	130,8

### 6.1.2. Investment Cost for Auxiliary Infrastructure

#### 1. Road construction costs

a. Access road

The estimated cost for construction of one km access road within 9 m width in gravel road is obtained as below:

$$\text{Access road cost} = \$122,500 \text{ per km}$$

$$\text{Access road} = \$122,500 \times 15 \text{ km} = 1,837,500$$

b. Haul road construction

The estimated cost for construction of haul road within 26 m width is roughly estimated \$1,500,000.

c. Light vehicle road

The cost for construction of light vehicles road with the width of 5 m is assumed \$50,000 per km. the estimated cost for 5 km light vehicle road is \$250,000

2. Water supply costs

The cost for water supply through pumping, water storage and reclaim of water is obtained by the following equation(6.1-9):

$$\text{minimum tailing storage cost} = \$20,000t^{0.5} \quad (6.1-9)$$

$$\text{water supply} = 14,000T^{0.6} = \$7,457,081$$

3. Power (energy demand)

It is assumed that, the project requires 50-mw electric power. The average daily power consumption in kw/h calculated by the following equation(6.1-10):

$$\text{peak load (PL)} = 78 T^{0.6} = \$20,000t^{0.5} \quad (6.1-10)$$

$$\text{peak load (PL)} = 78 T^{0.6} = 41,546 \text{ kw/h}$$

- a. The cost for generation electricity through diesel power plant is obtained by the following equation (6.1-11):

$$\begin{aligned} \text{cost of diesel electric plant} &= \$6000 \times (PL)^{0.8} && (6.1-11) \\ \text{cost of diesel electric plant} &= \$6000 \times (PL)^{0.8} \approx \$29.7 \text{ million} \end{aligned}$$

- b. The estimated cost for power generation of one MW electricity through renewable energy in Afghanistan is estimated as following [61]:

Table 6.1-2 Estimated costs for renewable energy

Economic parameters	Wind turbine	PV Solar	Unit
Installation costs	2300	3500	\$/kwh
Operation costs	81	63	\$/kwh
Total	2381	3563	\$/kwh

4. Storage costs

a. Fuel storages costs

Fueling system includes fuel storage and service cost, is obtained by the following equation(6.1-12):

$$\begin{aligned} \text{fueling system cost} &= \$28 \times t^{0.7} && (6.1-12) \\ \text{fueling system cost} &= \$28 \times t^{0.7} = \$42,462.5 \end{aligned}$$

b. Explosive storage

It is assumed that, explosive storage costed \$5 million, two explosive magazines are required for the project with the total cost of \$10 million.

5. Fire protection

It is assumed that \$100,000 is required for fire protection system for the

6. Project maintenance costs

Cost for construction and equipment in maintenance facilities is obtained by the following equation(6.1-13):

$$\begin{aligned} \text{cost of maintenance facilities} &= \$6000 A^{0.6} t^{0.1} && (6.1-13) \\ \text{cost of maintenance facilities} &= \$6000 A^{0.6} t^{0.1} = \$1,374,715 \end{aligned}$$

7. Accommodation cost

The construction cost for staff accommodation in Aynak project is estimated roughly \$1,000,000.

8. Administrative offices

The cost for administrative offices is obtained by the following equation(6.1-14):

$$\text{cost of office} = \$155 A^{0.9} \quad (6.1-14)$$

Where,

A is the office area, and it depends on the number of technical staff requires the offices.

It is assumed, that the number of technical and administrative staffs are 150 persons. The office area within 1500 m<sup>2</sup> is required for administrative offices in Aynak project.

The cost of administrative office is assumed as \$200,000

9. Repair-shop

Considering that, maintenance personal requires 85 ft<sup>2</sup> per person. Assume that, 50 persons working for maintenance and repair shop. The cost of construction and equipment on maintenance shop is obtained by the following equation: (6.1-15)

$$\begin{aligned} \text{ccost of repair shop} &= \$102(85 \times Nsv)^{0.9} & (6.1-15) \\ \text{cost of repair shop} &= \$102(85 \times Nsv)^{0.9} = \$187,996.6 \end{aligned}$$

10. Warehouse

The cost for construction of warehouse that, accommodate all spare part of machinery and vehicles for the project is calculated by the following equation(6.1-16):

$$\begin{aligned} \text{warehouse cost} &= \$5750 T^{0.4} & (6.1-16) \\ \text{warehouse cost} &= \$5750 T^{0.4} = \$377,828.8 \end{aligned}$$



Table 6.1-3 Investments cost for infrastructure and auxiliary facilities

Capital cost for infrastructure and auxiliary facilities (\$M)	
Road construction	3.58
Water supply	7.45
Power supply	29.70
Fuel storage	0.04
Fire protection	1.00
Explosive storage	10.00
Maintenance	1.37
Accommodation	1.00
Offices	0.20
Repair-shop	0.18
Warehouse	0.37
<b>Total investment cost</b>	<b>54.89</b>

## 6.2. Operating Cost

Operating costs refereeing to the cost of operation per ton of ore. Operating cost is very from country to country and from mine to mine. Low operating cost achieves when the deposit is shallow and contains higher-grade ore. Due to that, Aynak copper mine contains high-grade deposit. Therefore, low operating cost is the objective of project planning. Based on Runge (1998), an objective of low operating cost is particularly important for export-oriented mines [62].

Operating cost for Aynak copper project is calculated in yearly bases based on actual cost reported by Hustrulid, (2006) [60].

### 6.2.1. Operational Cost for Mineral Processing

The operating cost for processing plant is obtained as below

#### 1. Operating cost for primary crushing

The primary crushing cost per day is obtained by the following equation:(6.2-1)

$$\text{crushing cost/day} = \$ 7.90t^{0.6} \approx \$4,200 \quad (6.2-1)$$

$$\text{crushing cost/day} = \$ 7.90t^{0.6} \approx \$4,200$$

2. Operating cost for secondary and tertiary crushing.

The secondary and tertiary operating cost per day is obtained from the following equation(6.2-2):

$$\text{fine crushing cost per day} = \$12.6T^{0.6} \approx \$4,200 \quad (6.2-2)$$

$$\text{fine crushing cost per day} = \$12.6T^{0.6} \approx \$6,700$$

The total cost of crushing per day is assumed to be \$11,000.

3. Operating cost for grinding

$$\text{Grinding cost per day} = \$4.9T^{0.8} \approx \$4,200 \quad (6.2-3)$$

$$\text{Grinding cost per day} = \$4.9T^{0.8} \approx \$21,156$$

4. Operating cost for flotation

$$\text{Flotation cost per day} = \$54T^{0.6} \quad (6.2-4)$$

$$\text{Flotation cost per day} = \$54T^{0.6} \approx \$28,763$$

5. Tailing operating cost

$$\text{Tailing cost per day} = \$0.92T^{0.8} \quad (6.2-5)$$

$$\text{Tailing cost per day} = \$0.92T^{0.8} \approx \$3,900$$

6. Maintenance cost for mineral processing per day is obtained from the following equation(6.2-6):

$$\text{maintenance cost} = \$40.80 t^{0.8} \quad (6.2-6)$$

$$\text{maintenance cost} = \$40.80 t^{0.8} \approx \$176,000$$

Table 6.2-1 Operating costs for mineral processing

Operating cost for mineral processing (\$/t)	
Crushing	\$0.35
Grinding + bins	\$0.60
Flotation	\$0.82
Tailing	\$0.11
Maintenance	\$5.0
Total operating cost	\$6.88

### 6.2.2. Operational Cost for Auxiliary Infrastructure

Operating cost is derived from total cost per ton of ore mined. Here the operating cost is calculated on yearly bases

1. Power supply to the project

$$\begin{aligned} \text{Electric power cost} &= \$330 \times 145T^{0.56} && (6.2-7) \\ \text{Electric power cost} &= \$330 \times 145T^{0.56} \approx \$16.5 \text{ million} \end{aligned}$$

2. Maintenance

Maintenance cost for infrastructure around the pit is counted in accordance to the project cost multiplied by repair rate between 2- 5 percent. Is roughly estimated as \$5,6 million.

The estimated operating costs for auxiliary operation is shown in table.

Table 6.2-2 Operating costs for auxiliary operations

operating cost for auxiliary operation (\$/t)	
Power supply	1.42
Water supply	0.5
Maintenance	0.5
Total operating cost	2.42

### 6.2.3. Supply of the Concentrated Ore

Considering that, there is no active railway networks in Afghanistan. Therefore, the transportation of copper concentrate to the port through roadway is roughly calculated as shown in table

Table 6.2-3 Description of the Vehicle

Cost factors	Descriptions	Units
Vehicle type	Truck	1
Fuel costs	1	\$/L
Average delivery	40	t
Fuel consumption	55.5	lit/100 km
travel Distance	480	km
Capital cost of truck	200,000	\$
Capital cost of trailer	80,000	\$
Tire wears	\$750/ tire	\$/tire
Premium rate	25	%
Interest rate	10	%
Loan payment period	5 years	years
Loan amount/year	46,200	\$

It is assumed that in 18,000 km driving the maintenance cost would be \$1500.

Considering the above parameters, the following cost is associated for truck transportation as illustrated in Table 6.2-4:

Table 6.2-4 Cost for transportation

Cost summary	\$/day	\$/month	\$/year	Costs (%)
Fuel cost	250	5,750	69,000	35.0
Finance principle	128	3,850	46,200	17.9
Fixed cost	181	4,166	50,000	25.3
Driver cost	100	2,229	35,474.4	14.0
Tires waring cost	4.5	135	1,620	0.6
Maintenance	30	687	8,244	4.3
Other services	20	458	5,500	2.8
total	713.5	17,275	207,300	100

Fixed cost including insurance, accounting, road tolls and other cost \$50,000/year

Estimate charge/day 713.5

Estimated cost/t \$8.92

Estimated cost/ km \$1.58

The comparison between road and railway is calculated in \$/t-km as below [33].

1. the average capacity for diesel locomotive and truck are shown in Table 6.2-5

Table 6.2-5 Description of truck and locomotive

Freight	Transportation type	Towing capacity(t)	Load capacity (t)
Bulk	Locomotive	600	420
Bulk	Truck	-	50

- The operating cost is calculated considering the following costs factors ( ) excluding the freight handling

Table 6.2-6 Cost comparison for truck and locomotive

Cost factors	Locomotive cost (\$/T-km)	Truck (\$/T-km)
Energy consumption	0.01	0.02
Circulation cost*	0.00004	0.002
Maintenance costs	0.01	0.01
Personal costs	0.002	0.01
Other operational costs	0.01	0.003
Total cost	0.03	0.045

Circulation cost refers to vehicle insurance and rights of way

As shown from the table the transportation cost of copper concentrate by railway is cheaper than transportation by road way [33].

### 6.3. Cost Summary

The estimated operating cost for mineral processing and auxiliary operation for Aynak copper mine is shown in Table 6.3-1

Table 6.3-1 Total operating cost for ACD

Operating cost for Aynak copper mine (\$/t)	
Processing cost \$/ton	6.88
Power supply costs	1.42
Water supply costs	0.5
Maintenance	0.5
Other costs	1.58
Total operating cost	10.8

## Chapter 7. Thesis Summary

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This study focused on feasibility study of Aynak copper deposit considering the infrastructure, logistics, processing and auxiliary operations. In brief the study is summarized as following:

1. In comminution process the ore is crushed, either through mobile or stationary crusher. Considering that the stationary crusher provides the following advantages (a) Suitable for higher capacity, (b) Lower production cost (c), Easy maintenance. Hence, the Stationary crusher is recommended.
2. For ore recovery, the following options are proposed:
  - a. For sulfide ore, pyrometallurgical process is recommended because ACD contains High-grade ore. Moreover, the output through pyro-metallurgical process is higher than hydrometallurgical process. For oxide ore hydrometallurgical process as it is commonly used for oxide, ore concentration is recommended.
  - b. Treatment of blind oxide and sulfide ore via n-octyl hydroxamate collectors (AM28). This option is the most economical treatment of ore. As it is well resulted in Minto Copper mine Canada, where the ore characteristics in Minto copper mine is nearly the same as Aynayk coper deposit.

Both options are possible for ore recovery, but the most feasible option will obtain after the laboratory investigation is carried on for ore treatment.

3. Discussing the transportation of copper concentrate from pit to port: The cost for transportation of copper concentrate by truck is roughly \$1.58/km as it is compared to the cost of transportation in Chile. The cost for transportation in Chile is much lower than Afghanistan. Therefore, the transportation of copper concentrates is not feasible due to the following reasons. (A) Higher transportation cost via truck. (B) Long distance transportation within low-grade concentrate (30-35 %) Cu contains. Therefore, onsite smelter and further processing is required to produce copper cathode.

4. Chapter five, discussed the Infrastructure and auxiliary operations required for the project. Infrastructure within and around pit considered for the project are as roads, power supply water supply and other auxiliary facilities.

(a) Roads:

Three types of roads are proposed for Aynak copper deposit as access road, haul road and light vehicle road. Considering that the project is located in mountains area within stable surface, therefore, sand and gravel-wearing surface is recommended.

(b) Water supply for the project:

Comparing the two options available for water supply to the project (a) Logar River (b) groundwater source. Considering the dry climate of the region, moreover, the river source in Afghanistan is mostly used for agricultural purposes. Therefore, the groundwater sources are recommended

(c) Power supply for the project:

Due to shortage of electricity in Afghanistan, the design for power supply of the project is based on self-power supply system. A diesel power plant is recommended due to the following advantages, easy installation, high thermal efficiency and required less area.

In addition, other auxiliary facilities including fuel storage, explosive storage, fire protection, maintenance and accommodation facilities to support the mining operations and mineral processing is described in detail.

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