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# Investigation on life cycle assessment of lead and zinc production

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**Abstract**
Lead and zinc production is one of the main predisposing factors of excessive greenhouse gases emissions, air pollution and water consumption. In this paper, the environmental problems of lead and zinc production in Calcimin plant are expressed and life cycle assessment of this plant is assessed. The data regarding the amount of induced global warming and pollution, acidification, and depletion of water resources were collected and discussed. It was concluded that depletion of water resources affected the environment and this was the main issue of the lead and zinc production of this plant. According to the results, in the global warming's impact category, the proportion of carbon dioxide is more than that of methane. The results also showed that in the acidification's impact category, the nitrogen oxide proportion is greater compared to that of the sulfur dioxide.

**Keywords:** *acidification, depletion of water resources, environmental impact, global warming, life cycle assessment.*

## 1. Introduction
Life cycle assessment (LCA) is an analytical tool that has been referred to as "cradle to grave" analysis. LCA is used for quantifying environmental impact and the resource consumption associated with a product, process or activity during its entire life cycle. Two main parts of LCA in mining industry are: (1) mining industry can use LCA for evaluating of mining activity environmental impacts, and (2) the mining industry can provide data for evaluating environmental impact assessments of downstream activities. [1-6]. The environmental impact assessment for the mining sectors involves analysis of the mining reserves; description of quality of metals and the site selection; plans for construction and site preparation; broad analysis of land use for mining activity purposes; description of the maintenance and operation phase; identification of

environmental impacts and plan for environmental prevention and mitigation [7].

Examples of mining LCA studies were established from 2000 to 2015. The aims of these LCA are evaluating the life cycle environmental impacts of different grades of coal mined with different mining methods [8], using of LCA to compare sulfide tailing management options [3], environmental impact assessment of mine haulage options in surface mines [9], studying of LCA methodology for copper and nickel production to estimate the life cycle emissions of greenhouse and acid rain gases for these metals [5], studying of the Mexican mining industry from technological development, historical and economic perspectives [7], the current application of LCA in the mining industry [1], LCA analysis for comparison of various mineral carbonation processing routes [10] and estimating land-use equivalency factors, identifying high impact processes during mining, treating and marketing of bauxite and copper waste [11].

In this paper, first, the environmental problems of lead and zinc in Calcimin company are investigated, then the amount of global warming, acidification which is caused by pollution, and also, depletion of water resources are evaluated. The purpose of this study is to determine the life cycle emission during the production of lead and zinc, as well as the proportion of three impact categories which damage the environment.

## 2. Materials and Methods

### 2.1. LCA methodology

The basic objective of the most studies of life cycle is to determine the design option that minimizes the life cycle impact of the process. This way is including assessment of the inputs and outputs and environmental impacts. The life cycle assessment can:

- propose a systematic assessment of the environmental consequences.
- estimate the amount of emission to the water, air and soil environment in each cycle of the product or process.
- measure ecological effects of substances on the local, regional and global environment.
- contrast health and ecological effects of the same product or process in order to select the optimum process [2-6].

The LCA has four separate stages:

- The goal definition stage. The goals of the suggested study are described and agreed upon with reference to the intended application;
- The inventory stage (LCI). The material and energy inputs and outputs to and from the system are expressed;
- The life cycle impact assessment stage. The results of the previous stage are explained in terms of the potential impacts that they have on the environment;
- The interpretation stage. This stage of an LCA is consist of analyzing the results.

Some of the environmental impacts are: global warming potential (GWP), acidification potential (AP), depletion of water resource, depletion of fossil resource, human toxicity, smog, corrosion and other impacts. In this paper, the following impacts were investigated:

- global warming potential, measured relative to the effect of 1 kg of $CO_2$.
- acidification potential, measured relative to the effect of 1 kg of $SO_2$.
- depletion of water resources, measured relative to world reserves.

These impacts related to human and ecological health [2, 3].

### 2.2. Region considered for the study

The region considered for this study is Dandi factory (lead and zinc production). This factory is located in Zanjan city- Iran. Supplying by Anguran mine, feed of Dandi factory is divided to two types of high and low grades, based on zinc grade. High grade feed has about 30% zinc and 10% lead. This feed enters flotation path. Low grade feed has 21.5% zinc and 7.5% lead. This feed is not used in cold seasons because of moisture and cohesion. Table 1 shows the characteristics of the feed used in the factory:

**Table 1. Feed used in the factory**

| Feed type | Zn (%) | Pb (%) | Major mineral | Density (Kg/m$^3$) | Moisture (%) |
|---|---|---|---|---|---|
| High grade feed | 34-36 | 8-10 | $ZnCO_3$ $PbCO_3$ | 2600 | 5-8 |
| Low grade feed | 20-21.5 | 7-7.5 | $ZnCO_3$ $PbCO_3$ | 2500 | 8-9 |

## 3. The environmental problem of Calcimine company

The Calcimine lead and zinc factory produces lead and zinc concentrates. The factory is started as zinc smelter (with a production capacity of 7000 tons per year) since 1997. The raw material of the factory extracts from Angoran mine. The most important environmental problems in the lead and zinc mine can be noted in the protected area where the mine are. The adverse effects including destruction of vegetation and pasture area for mineral exploration, development of residential townships near the mine in a protected area, existing the cord conveyor control stations in protected areas, roads and traffic and etc., also the effect on regional climate and ecosystems. Environmental problems within the factory are as follows:

- Location of factory in a protected area;
- Distribution of mineral dust particles in the area of grinding and screening area;
- The industrial wastewater in the flotation unit that is the most important pollution of the plant;
- Low grade ore fines which are discharged on the tailing dam crest and back of them, and the strong wind disperse the particles in the surface water, villages and downstream farms. These particles contain heavy metals.

The environmental problems in the zinc smelter unit include:

- The presence of acid vapors in the areas of leaching, purification and electrolysis that are the major environmental issues within the workshop that is caused the pollution of the water, soil and loss of green space.
- The solid waste which is filter press cake of the leaching and purification units. Filter press cake of the leaching unit depot in the open area. This cake has no valuable materials.

## 4. Stages of the life cycle in the plant

### 4.1. Aim

The first step in the life cycle assessment method is to determine the reference unit. The reference unit connects inputs and outputs of the product and provides a reference for comparison [2-5, 12]. The aim of this study is to evaluate the environmental effects of depletion of water resources, global warming and acidification in the processing sector in Anguran lead and zinc mine and reference unit is production of lead ingots and zinc sheets of mine.

### 4.2. Determination of the inputs and outputs of the system

In this section, all the resources and values needed to be studied in production, as well as the amount of pollutants released into the environment are calculated based on the reference unit [2-4, 12].

**Table 2. Inputs and outputs of system**

| Input | ⟹ | System boundary | ⟹ | Output |
|---|---|---|---|---|
| Natural resource | | Mining | | Environmental consequences |
| Fossils fuel | | Production | | Air pollution |
| Minerals | | Usage | | Water pollution |
| Water | | Recycling | | Soil pollution |
| Land | | | | Noise pollution |

***- Inputs of system***

Gas and diesel fuel are used in the factory and data about their pollution are given in the outputs of the system. The most important greenhouse gases are $CO_2$, $NO_2$, and $CH_4$ which are produced from the combustion of diesel fuel. There is no information about the amount of fuel consumption; therefore, it's not mentioned here. In addition, the amount of consumed water per unit and factory's water recovery are given in Table 3.

The total amount of water consumption in the factory with considering the recovery of water and using the data in Table 3 is 12.5 $m^3$/hr. The total amount of recovery water to factory is 240 $m^3$/hr. Some of the water is wasted into the surface water. So, the surface waters of lead and zinc factory in Zanjan contains heavy metals (e.g. zinc, lead, cadmium and arsenic). These waters are directed through a channel to Zanjan roud. These surface waters are arising from washing the factories' surfaces waters and roads.

***- Outputs of system***

Various compounds in the life cycle assessment of mineral processing are considered for emissions estimate. Accurate measurement of these emissions with considering financial and time matters also differences in results, not practical and will not be appropriate for the purposes of life cycle assessment. The amount of emissions depends on soil, climate and management system of mine. So, instead of measurements, structural methods are applied for average emission rates which are used in this paper. The amounts of emissions are given in Table 4. Table 5 shows fuel consumption and its emissions.

**Table 3. The amount of water consumption in Anguran lead and zinc factory**

| Water | Q(lit/s) | Q($m^3$/hr) | The total monthly consumption ($m^3$/h)* |
|---|---|---|---|
| Industrial water consumption for factory | 3.47 | 12.5 | - |
| Industrial water consumption in flotation unit | 34 | 122.4 | 88128 |
| Industrial water consumption in mill unit | 6.63 | 23.86 | 17179.2 |
| Industrial water consumption in the zinc factory | 5.5 | 20 | 14400 |
| The total amount of recovery industrial water to factory | 66.66 | 240 | 172800 |
| Consumption of other units such as ovens, filtration | 26 | 93.74 | 67492.8 |

* The values in the table is the rate of changes in water consumption per hour in duration of one month. These values are measured in different months and average measurements have been reported

**Table 4.The amount of air pollution in the factory**

| The amount of air pollution in the factory | ppm |
|---|---|
| Produced carbon monoxide/ the mean CO | 4.8 |
| The amount of the Eker safety limit per hour CO | 35 |
| The mean nitrogen monoxide ( NO) | 0.05 |
| The mean amount of nitrogen dioxide ($NO_2$) | 0.018 |
| Permitted limit of $NO_2$ | 0.05 |
| The mean amount of ozone photochemical oxide ($O_3$) | 0.013 |
| Permitted limit of $O_3$ | 0.08 |
| The mean amount of sulfur dioxide ($SO_2$) | <0.4 |
| Permitted Limit of $SO_2$ | 0.5 |
| The mean 10-micron particles (micrograms per cubic meter) | 46.3 |

**Table 5. Fuels and pollution (Device: Testo 350)**

| The place of sampling | Factors evaluated and results | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $O_2$ % | $CO_2$ % | CO ppm | $NO_2$ ppm | NO ppm | $NO_x$ ppm | $H_2S$ ppm | SO2 ppm | $C_xH_y$ ppm | $H_2$ ppm | E- air % | Effg % | Ta °C | Tg °C | Fuel |
| The chimney of the factory diesel unit | 16.5 | 3.79 | 55 | 6.2 | 70 | 78 | 1.5 | 148 | 90 | 19 | 330.9 | 72.68 | 28.8 | 160.4 | Gasoil |
| The chimney of the factory boiler unit- No.1 | 13.04 | 6.87 | 74 | 3.6 | 75 | 80 | 0.4 | 1 | 83 | 20 | 153 | 80.7 | 28.4 | 155.2 | Gas |
| The chimney of the factory boiler unit- No.2 | 15.6 | 4.72 | 69 | 2.5 | 88 | 92 | 0.3 | 2 | 85 | 22 | 265.1 | 76.35 | 28.1 | 253.3 | Gas |
| The chimney of the factory Electro furnace- No.1 | 13.2 | 6.89 | 54 | 0.7 | 90 | 92 | 1.2 | 2 | 110 | 27 | 159.1 | 76.71 | 27.8 | 203.4 | Gas |

## 4.3. Impact assessment

The purpose of impact assessment is interpretation of the inputs and outputs of lead and zinc which has three categories, normalization and weighting [2-5, 12, 13].

***- Characterization***

This stage in the life cycle assessment is necessary. At this stage, each of the values obtained from part two i.e. the consumption of fossil resources, the amount of emissions to the environment, and water consumption are related to the environmental impacts. In Table 6, with considering the water resources depletion's effect groups, global warming's effect groups and acidification's effect groups show the connection of fuel and water consumption and also emission of the atmosphere to produce lead and zinc. In this table, efficiency or characterization factor of any combination in its creation is given. By multiplying the amount of each pollutant or source to its efficiency and summing them, for each of impact category is obtained a characterization index.

**Normalization**

This stage in the life cycle assessment is optional. In this stage, the contribution of the environmental impact of the system on the environmental impact of a region is determined because the characterization stage cannot apply the values. In other words, in the normalization stage, the results obtained in the previous step divide across the region, so, the characterization index of each effect divided to a normalization factor. Thus, the data can be without unit and are ready to step weighting.

**Weighting**

This is an optional step in the life cycle assessment, too. In this part, each environmental impact on base the performance of harm to the environment is given a weight and each effect groups that having a greater performance of harms to the environment, has greater amount allocated to it. Normalized index for each effect groups multiplied in the weighting factor and final index for each environmental impact achieved. In Table 7 normalization and weighting factors are expressed.

**Table 6. Characterization factor [13-15]**

| Impact category (unit) | compounds | Potential of compounds |
|---|---|---|
| Global warming (kg $CO_2$ eq) | $CH_4$, $CO_2$, $N_2O$ | $CO_2$=1, $CH_4$=21, $N_2O$=310 |
| Acidification (kg $SO_2$ eq) | $NH_3$, $SO_2$, $NO_x$ | $SO_2$=1.2, $NO_x$=0.5, $NH_3$=1.6 |
| Depletion of water resources ($m^3$) | Water consumption | 1 |

**Table 7. Normalization and weighting factors [16]**

| Impact category | Normalization factor (unit) | Weighting factor |
|---|---|---|
| Global warming | 7000 (kg CO2 eq) | 0.12 |
| Acidification | 450(kg $SO_2$ eq) | 0.14 |
| Depletion of water resources | 677 ($m^3$) | 0.21 |

The total equation for three stages of assessment is shown in the following equation:

$$FI = \sum_i \left( \frac{\sum_j \left(E_j or R_j\right) \times CF_{i,j}}{NF_i} WF_i \right) \qquad (1)$$

In this equation, $E_j$ or $R_j$ is combination emission of j or source consumption of j on any single of reference; $CF_{i,j}$ is characterization factor for combination of j or source of j involved in the impact category of i; $NF_i$ is normalization factor for impact category i; $WF_i$ is weighting factor for impact category of i; and FI is final index for impact category of i.

## 5. Results and Discussion

The amount of water consumption to produce lead and zinc is 12.5 ($m^3$/h). The outputs of systems are given in Table 8. The results of impact assessment of three phases are expressed in Table 9. According to the final environmental indexes in the production of lead and zinc for global warming, acidification and depletion of water resources, demonstrated depletion of water resources compared to other impacts has more environmental harmful performance (Fig. 1).

This study showed that the share of emission compounds in the lead and zinc production to environment are in the two impact category i.e. global warming, acidification. Results has been demonstrated that the proportion of carbon dioxide in global warming impact category is more than that of methane and also in the acidification impact category, the nitrogen oxide proportion is greater in comparison to that of the sulfur dioxide (Figs. 2 and 3).

**Table 8. Lead and zinc production inputs (Emission sources: Gas and Diesel)**

| Emission contents (ppm) | Emission compounds |
|---|---|
| $5.5675 \times 10^4$ | $CO_2$ |
| 3.25 | $NO_2$ |
| 85.5 | $NO_x$ |
| 1.62 | $SO_2$ |
| 92 | $CH_4$ |
| 63 | CO |
| 80.75 | NO |

**Table 9. Results of impact assessment**

| Impact category | Characterization index | Normalization index | Final index |
|---|---|---|---|
| Global warming | $5.7883 \times 10^{-2}$ | $3.1542 \times 10^{-7}$ | $3.78514 \times 10^{-6}$ |
| acidification | $4.5174 \times 10^{-5}$ | $1.0038 \times 10^{-7}$ | $1.40532 \times 10^{-8}$ |
| Depletion of water resources | 12.5 | $1.8463 \times 10^{-2}$ | $3.8774 \times 10^{-3}$ |

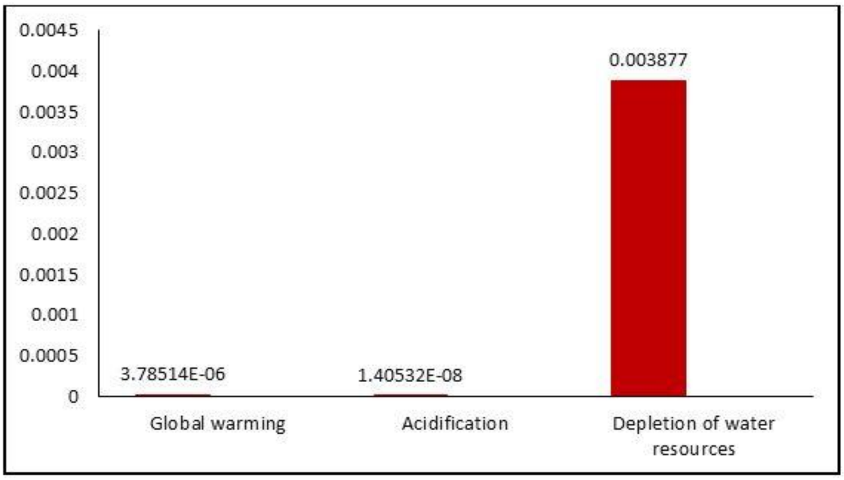


**Fig. 1. Effect of impact categories on the environment**

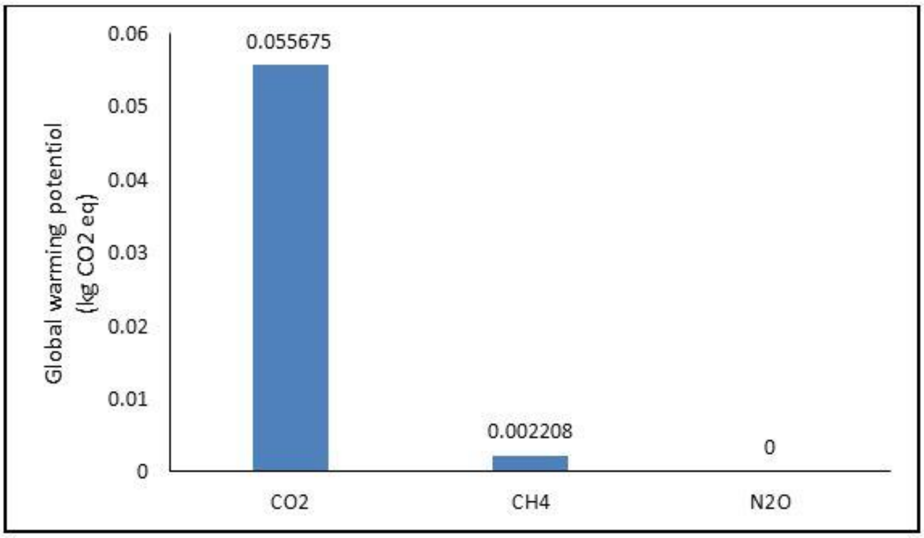


**Fig. 2. Greenhouse gases share in global warming impact category**

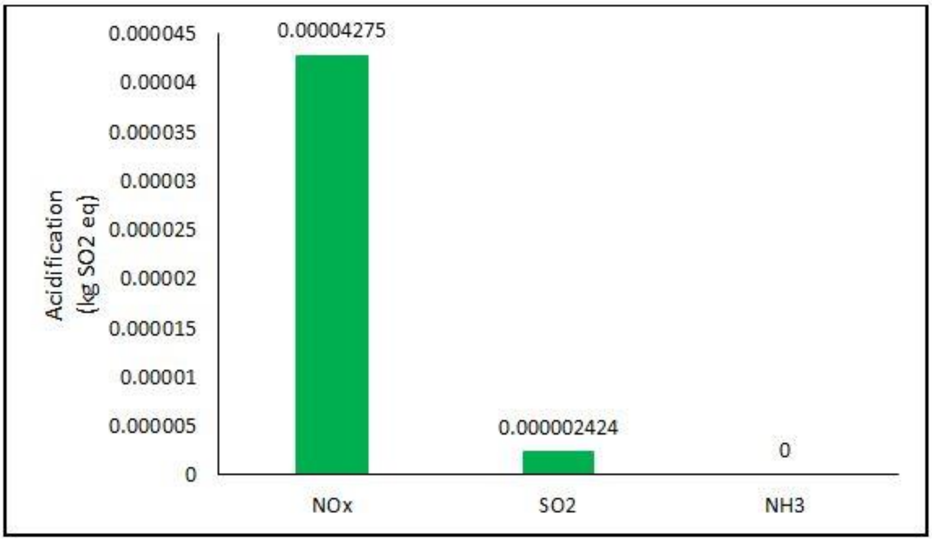


**Fig. 3. Nitrogen and sulfide Compounds share in acidification impact category**

## 6. Conclusion

The use of life cycle assessment made it possible the investigation of processes and all of the environmental impact resulting from extraction of raw materials and energy consumption to production via consumption estimate and waste; also analysis of the environmental impacts and methods to its protect in the entire life cycle of a product or process are calculated. This process can do the range of analysis in scale of local, regional and global. The life cycle assessment indicates the approach to environmental protection and plans for reducing environmental impact, even at every stage of the production process or service. In this study, we investigated the effect of depletion of water resources, global warming and acidification in the Anguran lead and zinc mine in the mineral processing part. The studies show that the depletion of water resources more than others impact categories is harmful to the environment. According to the results, share of carbon dioxide in the global warming impact category is more than methane, and also in the acidification impact category, share of nitrogen oxides is greater than sulfur dioxide. Thus, the appropriate management strategies should be adopted.

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