

Investigation of energy efficiency improvements in alumina refinery of Seydişehir ETİ Aluminium Plant

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Abstract

Energy is an important issue for all industrial processes. Energy saving not only decreases the production costs but also provides environmental benefits, lowering emissions that contribute to global warming. In alumina production, energy is typically 30 - 50 % of the total production cost, depending on technology, equipment design and capability, process condition, raw material type, production rate, etc. In this study, energy and exergy analyses of the Seydişehir ETİ Aluminium Plant (SEAP) were performed. At SEAP, energy consumption is becoming increasingly challenged by rising operating and production costs, therefore, significant process energy reductions are required. To minimize energy consumptions and exergy destruction points, it is important to understand the energy sinks in its alumina production steps. High energy consumption areas in the SEAP are digestion, evaporation and calcination. Thus, the present study covers the energy and exergy analyses of several units in the SEAP such as boiler house, digestion, evaporation and calcination. The Bayer process in which the cyclic chemical process has been used to produce alumina at the SEAP spends significant amounts of unembodied exergy. Therefore, implementation of the performed analysis will result in distinguishable reduction in energy losses and exergy destruction.

Keywords: Alumina calcination; Bayer process; bauxite digestion; energy saving and efficiency improvement; exergy analysis.

1. Introduction

The importance of the energy efficiency in alumina industry is increasing from both an economic standpoint, with the drive to continually decrease operating costs and also from an environmental perspective, with the greater focus on climate change due to greenhouse gas emissions [1]. On the other hand, energy consumption is the greatest contributor to the operating cost in Seydişehir ETİ Aluminium Plant (SEAP), and the marginal contribution of this component is becoming more pronounced. Thus, one of the main targets is to deliver significant reductions in energy resource usages. Although, it is important to understand the energy sinks in the alumina production to determine how to minimize the energy consumptions. They are mainly digestion, evaporation and calcination units, which are also highly energy consuming steps in several alumina production plants, e.g. SEAP.

In general, the analyses of heat flow diagrams of complex chemical processes only consider the first law of thermodynamics. The amount of the energy input from an external source is considered as an absolute measure of the thermodynamic perfection while all the heat losses are implicitly allocated into a system without any participation in heat transfer and assumed not to produce any useful work. Therefore, heat efficiency is used as the main criterion of the thermodynamic perfection [5]. The first law of thermodynamics is conventionally used for the analyses of plant performances and energy consumptions. However, it is not capable to assess

the quality of energy. For this purpose, exergy analysis is used, which is a consequence of the second law of thermodynamics. It can measure the quality of energy in a process and has been applied for various industries [6]. According to the second law of thermodynamics, any heat process can be characterized by the increase in the entropy of the system. In this case, the augmented entropy can serve as the main criterion of the thermodynamic perfection in the system. Total of the entropy increases shows an energy supply from an external source, e.g., a thermal power station [5]. Exergy analysis of a process contains several steps such as calculation of exergy losses at the productions steps, distribution of the exergy destructions and exergy efficiency. In other words, this enables the analysis of the size and quality of secondary power resources and expediencies of their utilization [5].

This study aims to decrease energy consumptions in SEAP Bayer Process using energy and exergy analyses and is mainly focused on the production units; boiler house, digestion, evaporation and calcination; with the following potential improvements:

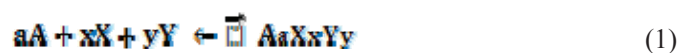
- Using “Indirect Digestion Heating” process in SEAP Bayer digesters (autoclaves) instead of “Direct Steam Injection”, which adds unnecessary dilution that has to be removed by additional evaporation, resulting in increased capital and operating costs and production losses. The new method will enable sending live steam condensate back to the boiler house as the feed water, and the reduction in evaporation discharge liquor caustic concentration due to the elimination of additional dilution in digestion. The new strategy also has the potential to increase the process efficiency and productivity with the provision of a significant amount of energy savings.
- Installation of stationary calciner with high thermal efficiency instead of a conventional rotary kiln, for an energy gain of ~ 1.5 GJ/t Al_2O_3 .

2. Methodology

2.1. Exergy analysis of a chemical process

Balomenos et al. (2011) stated that exergy of a non-isolated system is the maximum work that can be obtained from the system during a process that brings the system into equilibrium with its surroundings [3]. Brodyansky and co-workers (1994) added that by the selection of a surrounding medium for all systems the environment of our planet; exergy, which is measured in energy units, can become a universal size of the quality of matter and energy [4]. Exergy is also defined as the resource consumed by dissipative structures to produce a(n) structure/information and remain in states far from thermodynamic equilibrium with their environment or the resource consumed by decaying structures as they proceed to thermodynamic equilibrium with their environment [7].

The standard chemical exergy (e_x^0) can be calculated from its theoretical reaction of formation at the environmental standard state (T_0, P_0) for several substances except fuel using equations 1 and 2.



according to relationship

$$e_x^0, A_aX_xY_y = \Delta G_f^0, A_aX_xY_y (T_0) + \sum_i v_i e_i^0 \quad (2)$$

where $\Delta G_f^0, A_aX_xY_y (T_0)$ is chemical free energy of formation of the substance, v_i is the stoichiometric coefficient, and e_i^0 is the standard chemical energy of that element. The standard chemical exergy of elements is related to reference substances found more commonly in the

environment and are given in literature [3]. The chemical exergy of a solution containing n chemical species at the environmental state (T_0, P_0) is

$$e_N = \sum_i n_i e_{N,i} = \sum_i n_i e_{N,i}^0 + RT_0 \sum_i n_i \ln \gamma_i x_i \quad (3)$$

The thermomechanical exergy of matter $e_{P,T}$ which is the exergy of matter due only to its differences in pressure and temperature from the environment, is

$$e_{P,T} = h - h_0 - T_0 (s - s_0) = \Delta h - T_0 \Delta s \quad (4)$$

where h, s are the specific enthalpy and entropy of matter at T, P and at T_0, P_0 [3].

Finally the total exergy of a solution at conditions T, P different from the environmental state is

$$e = e_N + e_{P,T} \quad (5)$$

Moreover, chemical exergy allows the definition of a thermodynamic efficiency coefficient for any process, based on a simple exergy balance,

$$E_{in}^{tot} = E_{out}^{tot} + D^{tot} \quad (6)$$

where E_{in}^{tot} , E_{out}^{tot} are the total exergy flows entering and exiting the system (a steady state process is assumed), and D^{tot} is the total exergy losses or exergy consumption or waste heat due to irreversible processes inside the system (internal losses) and between the system and the environment (external losses). According to the Guy-Stolola equation and the second law of thermodynamics

$$D^{tot} = T_0 \Delta S^{tot} \geq 0 \quad (7)$$

where ΔS^{tot} is the total increase in entropy in both system and environment [3].

By dividing the exergy outflow E_{out}^{tot} into products and wastes (e.g., chemical wastes) according to equation

$$E_{out}^{tot} = E_{product}^{tot} + E_{waste}^{tot} \quad (8)$$

The efficiency of the processes can be defined as

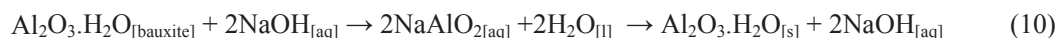
$$\eta_{ex} = \frac{E_{product}^{tot}}{E_{in}^{tot}}, \quad 0 \leq \eta_{ex} \leq 1 \quad (9)$$

3. Exergy analysis of the SEAP Bayer Process

To perform an exergy analysis for the SEAP Bayer Process, it is necessary to calculate the chemical exergy values for all the compounds that are used in the process. The Bayer Process in total is characterized by very low exergy efficiency as large amounts of exergy are spent solely to achieve the chemical separation of alumina from the bauxite "solid-solution" [2]. To understand the reasons for this exergetic inefficiency, a closer look in the process is needed. First of all there is an internal inefficiency in the chemical process itself, as in process of

boehmite extraction which includes bauxite crushing and milling, bauxite digestion, liquor clarification, gibbsite precipitation and evaporation [3].

The SEAP Bayer process is essentially a cyclic process designed to extract the alumina from the boehmitic bauxite ore through high temperature caustic leaching and controlled precipitation, according to the simplified reaction scheme:



The calculated current mass and exergy analysis of the plant is given in tables 1,2,3 and Figures 1,2.

Table 1. Boehmite extraction and gibbsite precipitation

		1 tonne of Al ₂ O ₃ (Current)		1 tonne of Al ₂ O ₃ (Future)	
		Mass (t)	Exergy	Mass (t)	Exergy
INPUT	Bauxite	2.16	0.44 GJ	2.16	0.44 GJ
	NaOH	0.13	0.12 GJ	0.13	0.12 GJ
	Water	6.14	0.96 GJ	6.14	0.96 GJ
	TOTAL INPUT (IN1)	8.44	1.53 GJ	8.44	1.53 GJ
UTILITIES	Coal (for the live steam)	1.29	10.02 GJ	1.11	8.69 GJ
	Electricity		0.73 GJ		0.73 GJ
	TOTAL UTILITIES (IN2)	1.29	10.75 GJ	1.11	9.35 GJ
PRODUCT	Gibbsite	1.53	0.27 GJ	1.53	0.27 GJ
	TOTAL PRODUCT (OUT1)	1.53	0.27 GJ	1.53	0.27 GJ
WASTE	Red Mud	1.03	0.24 GJ	1.03	0.24 GJ
	Water	6.14	0.96 GJ	6.14	0.96 GJ
	CO ₂ from coal burning	0.87	0.39 GJ	0.74	0.34 GJ
	Steam from coal burning	0.19	0.12 GJ	0.16	0.10 GJ
	TOTAL WASTE (OUT2)	8.23	1.71 GJ	8.08	1.64 GJ
WASTE HEAT (IN1-IN2-OUT1-OUT2)			10.30 GJ	8.97 GJ	
Total Energy consumption (Utilities)			10.75 GJ	9.35 GJ	
Total CO₂ emissions		0.87		0.74	
Exergy Efficiency of process			2.16 %	2.44 %	

In the SEAP Bayer process, alumina is extracted from boehmitic bauxite with a sodium hydroxide solution, under a pressure of 4 MPa and at elevated temperature (250 °C), in autoclaves (digestion stage). The produced slurry contains dissolved sodium aluminate and a solid residue (red mud) that is removed in thickeners. The aluminate solution is then seeded with gibbsite (trihydrate alumina) at 60 °C to accelerate the precipitation of gibbsite (precipitation stage).

Finally the precipitate is removed from the solution and is calcined at 1000 °C to produce powdered, smelter and commercial grade metallurgical alumina (calcination stage).

Table 2. Gibbsite calcination (1000 °C)

		1 tonne of Al ₂ O ₃ (Current)		1 tonne of Al ₂ O ₃ (Future)	
		Mass (t)	Exergy	Mass (t)	Exergy
INPUT	Gibbsite	1.53	0.27 GJ	1.53	0.27 GJ
	TOTAL INPUT (IN1)	1.53	0.27 GJ	1.53	0.27 GJ
UTILITIES	Natural Gas	0.28	3.74 GJ	0.24	2.73 GJ
	Electricity		0.09 GJ		0.09 GJ
	TOTAL UTILITIES (IN2)	0.28	3.84 GJ	0.24	2.81 GJ
PRODUCT	Alumina	1.00	0.42 GJ	1.00	0.42 GJ
	TOTAL PRODUCT(OUT1)	1.00	0.42 GJ	1.00	0.42 GJ
WASTE	Steam from gibbsite	0.53	0.33 GJ	0.53	0.33 GJ
	CO ₂ from natural gas	0.67	0.30 GJ	0.56	0.25 GJ
	Steam from natural gas	0.55	0.35 GJ	0.46	0.29 GJ
	TOTAL WASTE (OUT2)	1.76	0.99 GJ	1.55	0.88 GJ
WASTE HEAT (IN1-IN2-OUT1-OUT2)			2.70 GJ	1.79 GJ	
Total Energy consumption (Utilities)			3.84 GJ	2.81 GJ	
Total CO₂ emissions		0.67		0.56	
Exergy Efficiency of process			10.16 %	13.50 %	

Table 3: Total SEAP Bayer Process

	1 tonne of Al ₂ O ₃ (Current)	1 tonne of Al ₂ O ₃ (Future)
Total energy consumption (GJ)	14.59	12.17
Total CO₂ emissions (kg)	1.54	1.31
Exergy efficiency of process (%)	2.59	3.04

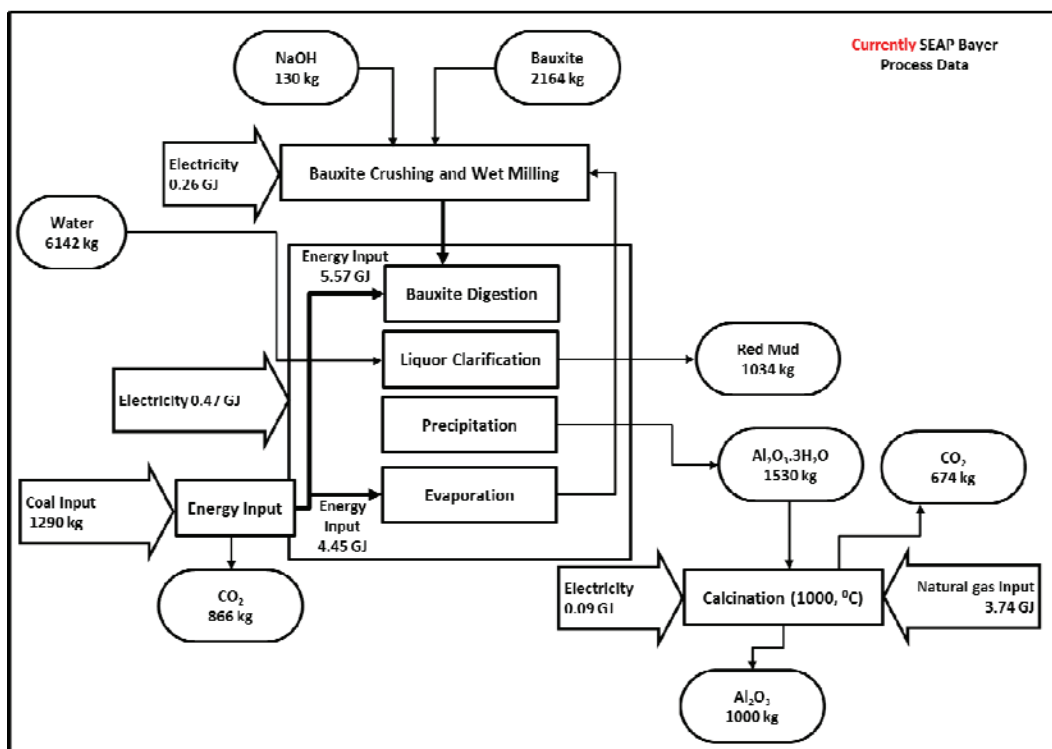


Figure 1. Mass & energy balances in current SEAP Bayer process.

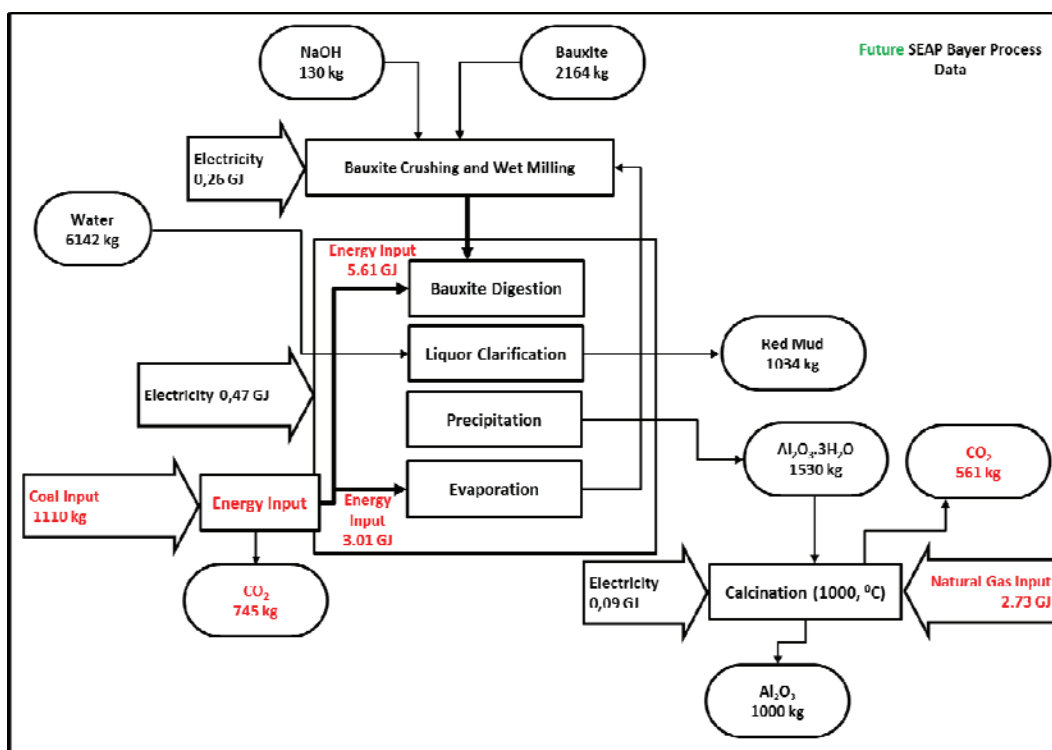


Figure 2. Mass & energy balances for the future SEAP Bayer process

4. Results and Discussions

After implementation of indirect heating in the digestion area, evaporation discharge liquor caustic concentration will be much lower than currently, therefore specific steam consumption for evaporating liquor will be significantly decreased. The current situation and expected future conditions are shown in figure 3. In the SEAP Bayer Process the evaporation area uses steam at 6.5 bar pressure and a temperature of 190 °C, supplied from the boiler house.

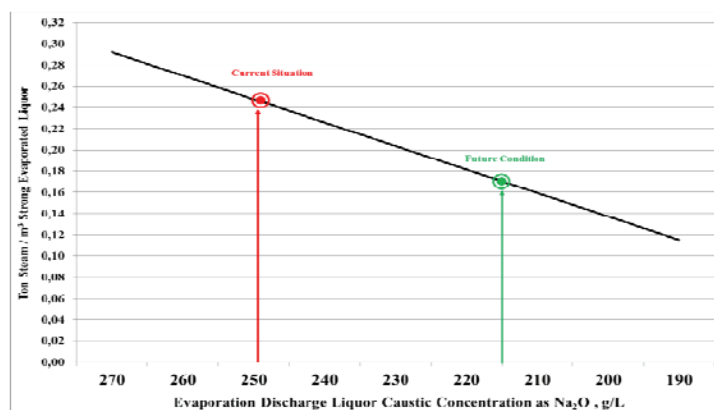


Figure 3. Evaporation discharge liquor caustic concentration vs. specific steam consumption

The SEAP calcination area can be somewhat quantified, with existing rotary kiln technology achieving typically 3.5 – 4.5 GJ/t Al₂O₃, while the more modern stationary calciner achieve 2.8 GJ/t Al₂O₃. That is why SEAP has already determined the need for investment in a new type stationary calciner to replace the high energy consuming rotary kilns. The comparison of energy consumption of rotary kiln and stationary calciner technology is given below:

Table 4. SEAP current and future calcination process heat balance

	Rotary Kiln	Stationary Calciner
ENERGY INPUT	GJ/t Al₂O₃	
Natural Gas Burning (Net)	3.359	2.728
Reaction of Alpha	0.022	0.006
Air Sensible Heat	0.004	0.005
Feed Sensible Heat	0.080	0.080
TOTAL INPUT	3.466	2.82
ENERGY OUTPUT	GJ/t Al₂O₃	
Vaporization of Free Water	0.239	0.239
Reaction of Alumina	1.993	1.995
Cooling Section	-	0.185
Stack Gas Sensible Heat	0.933	0.201
Product Sensible Heat	0.301	0.199
TOTAL OUTPUT	3.466	2.82

5 Conclusions

This study aimed to show energy intensive areas in the SEAP Bayer process and the increment of energy efficiencies with possible improvements for each process step. The contribution of the proposed improvements on energy efficiency for both digestion and calcination processes were evaluated and the total benefits in terms of exergetic efficiencies were determined.

Currently total energy consumption of SEAP is around 14.6 GJ/t Al₂O₃, which is slightly higher compared to other boehmitic bauxite processing alumina refineries. The roadmap for SEAP is to perform major changes in the calcination and digestion units. For this reason, SEAP has initiated the replacement of existing rotary kilns with stationary calciner to bring down energy consumption of its calcination process from 3.8 to 2.8 GJ/t Al₂O₃, which also means nearly a 26 % reduction in specific energy consumption.

In the near future, SEAP will change its direct heating technique with live steam injection in the digestion process to indirect heating system to decrease evaporation energy consumption by about 1.4 GJ/t Al₂O₃, and increase the productivity of boiler house by using less live steam for heating of boiler feed water.

The total gain for SEAP in terms of energy savings will be about 2.5 GJ/t Al₂O₃ and exergy efficiency of the process will be improved nearly 17 %. With its own capability, SEAP produces 1 GJ energy for about 8 US\$, therefore the total savings will be around 20 US\$/t Al₂O₃. Considering the 2.5 GJ/t Al₂O₃ decrease in total energy consumption, SEAP will improve its energy efficiency ranking among the alumina plants in the world at 12 GJ/t Al₂O₃.

6 Acknowledgement

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