Mathematical Model for Estimation of Thermal Energy Consumption in an Alumina Refinery

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Abstract

The Bayer Process to produce alumina trihydrate (ATH) from bauxite ore involves caustic digestion at elevated temperature and pressure, efficient solid liquid separation, soda recovery from bauxite residue at atmospheric conditions and seeded precipitation of ATH through natural and forced cooling of Bayer liquor, rich in alumina content. Since water is added to the circuit to wash bauxite residue, maintaining water balance in the closed circuit system through evaporation becomes essential. All of these steps consume thermal energy in the form of steam at appropriate conditions. The total energy consumed in the process depends on the process / plant design which in turn is based on the quality of bauxite that is processed. In general, thermal energy requirements are more than 90% of the total energy. Steady state heat and mass balance models (like S-Flo, Aspen, SysCAD, etc.) are available in the market, for use by engineers. These are extensively used, especially for the process / plant design purpose. Use of these models need some specialized training and hence, are typically limited to a select few in refineries. Hence, an idea was floated to develop a simplified computer model to estimate thermal energy requirements in various sections of a Bayer plant, so that many engineers in the refinery can use it on a more frequent basis and decide on the areas of concern / improvement. This paper presents the concept behind the development of the mathematical model and also a case study of applying this model in one of the alumina refineries in India.

Keywords: Bayer, consumption, energy, model, thermal.

1 Introduction

The Bayer process to produce alumina trihydrate (ATH) from bauxite is an energy intensive process. The dissolution of gibbsitic and boehmitic alumina phases in bauxite require elevated temperatures and pressures, mainly due to the nature of the dissolution reaction, which is endothermic. The efficiency of operation of an alumina refinery is determined largely by the specific energy consumption. The total energy consumption in the Bayer process is a combination of thermal and electrical energy requirements.

The total energy consumed in the process depends on the process- /- plant design which in turn is based on the quality of the bauxite that is processed. In general, the thermal energy requirement is more than 90% of the total energy [1].

Electrical energy is required mainly for crushing and grinding of bauxite to the required size and for the operation of

- various pumps, which are used to transfer liquid and slurry from one section to another and to generate required pressure and
- various agitators to keep the slurry in suspension at various points.

Energy estimation in refineries is being done through complex models which are unique to the selected refinery and cannot be used for some other operations. With the advent of steady-state heat and mass balance software models (like S-Flo, Aspen, SysCAD, etc.) in the market, the energy estimation process has been simplified.

These are extensively used, especially for the process- /-plant design purposes. However, use of these models need some specialized training and hence, are typically limited to a select few in refineries.

Hence, an idea was floated to develop a simplified computer model in order to estimate thermal energy requirements in various sections of a Bayer plant, so that many engineers in the plant can use it on a more frequent basis and decide on the areas of concern- /- improvement.

Accordingly, an MS: Excel® based model was developed. This paper presents the concept behind the development of the mathematical model and also a case study of demonstrating application of this model in one of the alumina refineries in India.

2 Conceptual Approach

Energy consumption in Bayer process is mainly used for dissolution of bauxite in caustic at elevated temperature. Monohydrate / trihydrate alumina dissolution is an endothermic reaction. Hence, heat needs to be supplied to achieve higher extraction efficiencies. Usually, the heat is supplied from steam, generated using coal- /- furnace oil- /- natural gas as fuels. This supplied heat is utilized for increasing the temperature of liquor for achieving the target digestion temperature. In addition to digestion temperature, liquor concentration is another important parameter for achieving target digestion efficiency. In the Bayer process, liquor concentration is maintained by evaporation of spent liquor as well as addition of fresh caustic for maintaining steady plant volume. The tradeoff between the addition of thick liquor as well as fresh caustic for maintaining liquor concentration, in turn, has an effect on the overall plant specific thermal energy consumption. The model development methodology [2] is presented in Figure 1.

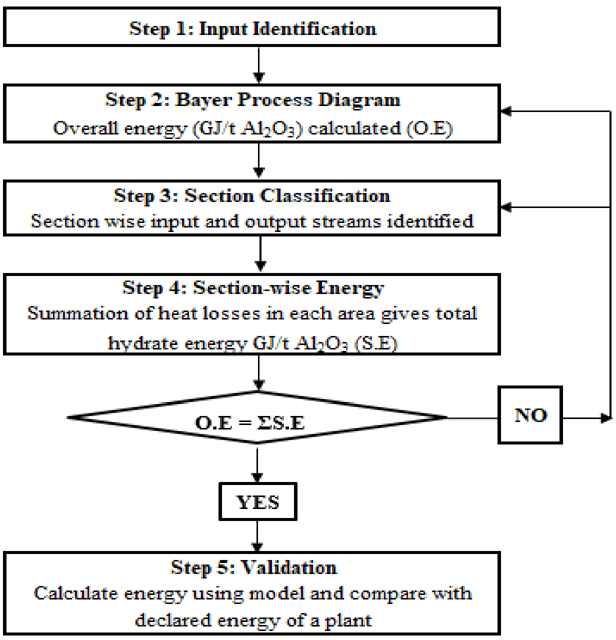

Figure 1. Conceptual flow diagram for the development of a model for Bayer process thermal energy consumption.

- Section-wise heat input and heat output streams were identified along with the physical properties, flow and consumption parameters.

- Heat losses were estimated by carrying out section-wise mass and energy balance and the total hydrate energy (S.E) in GJ/t Al_2O_3 was calculated.
- The plant is divided into the following major sections as:
  a. Section 1: Grinding + Predesilication + Digestion + Flashing
  b. Section 2: Live Steam Heater
  c. Section 3: Decanter + Filter
  d. Section 4: Wash Train + Dry Mud Stacking
  e. Section 5: Flash + Precipitation + Classification + Hydrate Wash
  f. Section 6: Evaporation
  g. Section 7: Test Tanks
  h. Section 8: Steam Plant
  i. Section 9: Cooling Tower
  j. Section 10: Steam Pipes
- For each of these major sections, input and output streams are determined and heat losses are estimated. The summation of the heat losses gives the total Bayer process thermal energy in GJ/t of Al_2O_3.
- The model developed is a closed loop model, wherein the main convergence variable as explained earlier in the flow diagram is based on the equivalence of total thermal energy generated from fuel to the summation of section wise thermal energy consumption.

3 Model Highlights

The model developed in MS: Excel® for the Bayer process thermal energy consumption analysis consists of the following sheets.

3.1 Introduction

The points to be considered for using the model and for arriving at the results based on a set of inputs is presented in this sheet as shown in Figure 2.

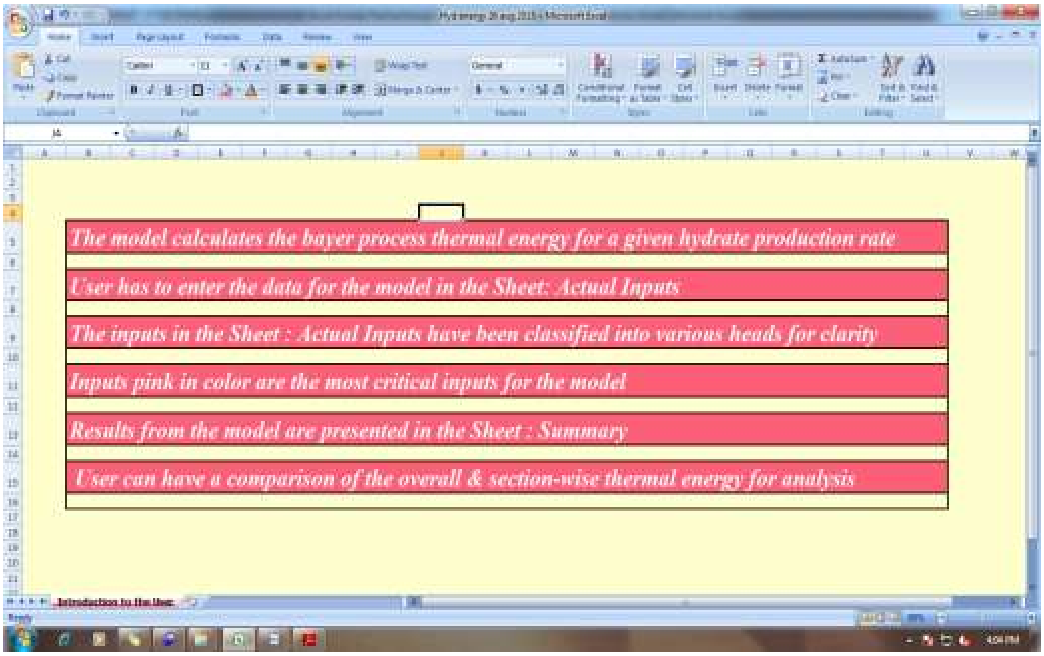

Figure 2. Introduction to the model.

3.2 Actual Inputs

The calculation of thermal energy consumption using the model requires various process inputs, to be given by the user. The input data has been classified into the various sections for clarity. Some of the major inputs have been presented in Figure 3.

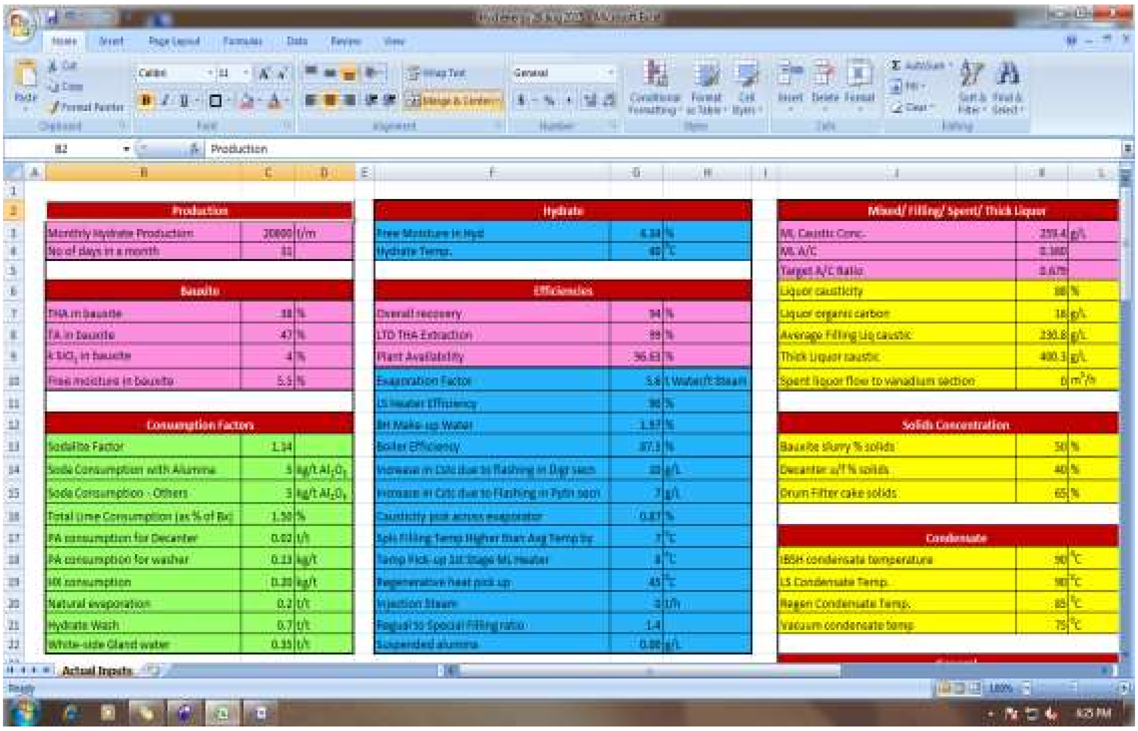

Figure 3. Actual Inputs to Model.

The physical properties of liquors & solids viz. density, specific heat, gibbsite and boehmite dissolution at 25 °C etc., generated at each stage of the Bayer Process was calculated based on empirical formulae available from Vadreuil data handbook and the same was used for the various calculations.

a. Production

Data on target hydrate production has to be entered here, which forms the basis for the calculation.

b. Bauxite

Data on bauxite quality viz. Trihydrate and Total Alumina Content (THA & TA), k.SiO_2 (Reactive Silica) content and the moisture in bauxite.

c. Consumption Factor

Data on consumption factors such as flocculent, soda and water

d. Efficiencies

Data on efficiencies such as overall recovery, plant availability, THA Extraction

e. Mixed / Filling / Spent / Thick Liquor

Data on mixed liquor caustic, A/C and target A/C

4 Summary

The results from the model are presented in the following sheet. Users can compare the overall heat input through fuel, against section–wise thermal energy distribution, as shown in Figure 4.

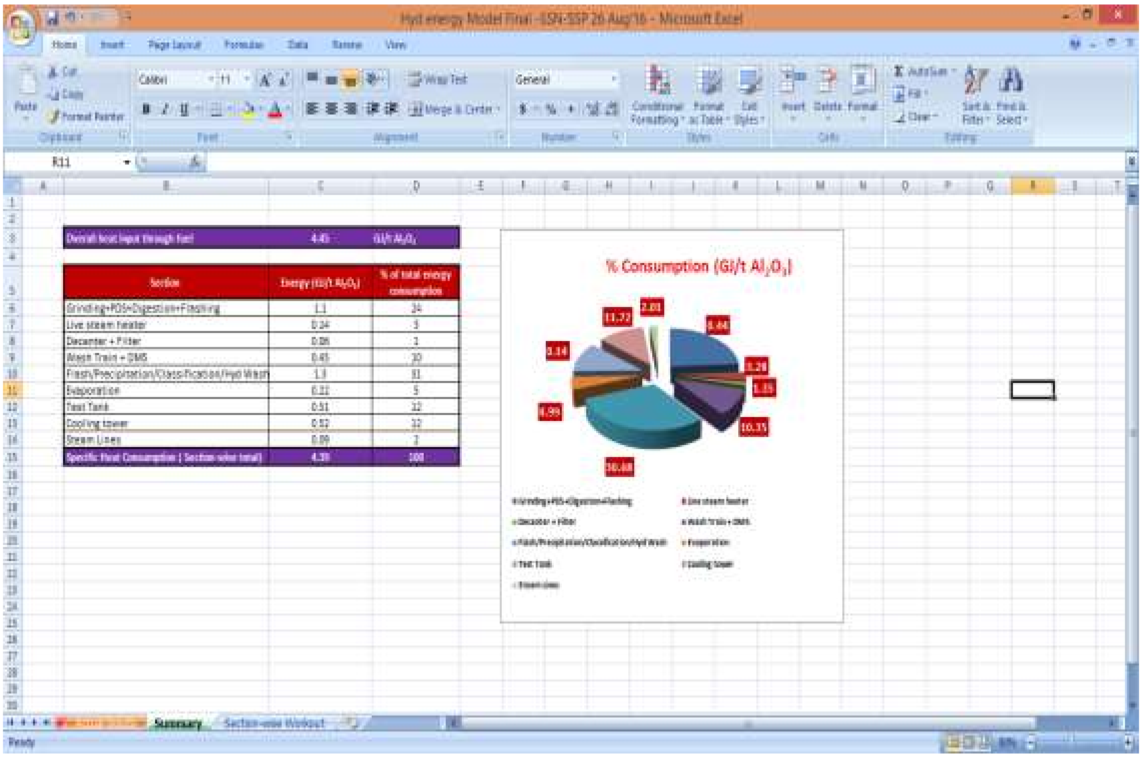

Figure 4. Summary of results.

In order to validate the results from the model, the data from one of the alumina refineries in India was used. Overall and section-wise hydrate energy was calculated and was matched with the actual energy consumption reported by the refinery for a specific period. The comparison of the results is presented below in Table 1.

Table 1. Validation of model.

Parameter	Unit	Actual	Model
Hydrate Energy (w/o power)	GJ/t Al_2O_3	5.25	5.25
Furnace Oil consumption	kg /t Al_2O_3	118.4	118.1
Digester steam consumption	t/t Al_2O_3	1.27	1.27
Evaporator steam	t/t Al_2O_3	0.33	0.33
Total mixed liquor flow	m^3/h	410	413

The above table clearly shows that the results from the model are fairly matching with the results from the model.

5 Case Study - Alumina Refinery

In order to investigate the viability of this model, a case study, on the effect of reduction in bauxite silica on thermal energy distribution was studied for one of the refineries in India, whose details are as follows;

5.1 Present Plant Conditions

The thermal energy distribution for an operating refinery of Karnataka (India) was calculated based on the following major inputs, as presented in Tables 2 – 3.

Table 2. Inputs - present plant conditions.

Monthly Hydrate Production	20600	t/month
THA in Bauxite	38	%
k.SiO_2 in Bauxite	4	%
Overall Recovery	94	%
Plant Availability	96.6	%
Digestion Liquor Caustic	259.4	g/L
Digestion Liquor A/C	0.360	
Target A/C	0.679	

Table 3. Summary of results – present plant conditions.

Overall Heat Input Through Fuel	**4.45**	**GJ/t Al_2O_3**
Section	**Energy (GJ/t Al_2O_3)**	**% of Total Energy Consumption**
Grinding+PDS+Digestion+Flashing	1.1	24
Live steam heater	0.14	3
Decanter + Filter	0.06	1
Wash Train + DMS	0.45	10
Flash+ Precipitation+ Classification + Hydrate Wash	1.3	31
Evaporation	0.22	5
Test Tank	0.51	12
Cooling tower	0.52	12
Steam Lines	0.09	2
Specific Heat Consumption (Section-wise Total)	**4.39**	**100**

5.2. Reduced Silica Content in Bauxite

The major inputs are kept constant, while only k.SiO_2 content in bauxite is reduced from 4 % to 2 %. The results of the model are presented in Table 4.

Table 4. Summary of results – with reduced silica in bauxite.

Overall Heat Input Through Fuel	4.50	GJ/t Al_2O_3
Section	**Energy (GJ/t Al_2O_3)**	**% of Total Energy Consumption**
Grinding+PDS+Digestion+Flashing	1.0	22
Live steam heater	0.14	3
Decanter + Filter	0.06	1
Wash Train + DMS	0.45	10
Flash + Precipitation + Classification + Hydrate Wash	1.3	29
Evaporation	0.27	6
Test Tank	0.71	16
Cooling tower	0.50	11
Steam Lines	0.09	2
Specific Heat Consumption (Section-wise Total)	**4.55**	**100**

Comparison of the results shows that with a reduction in k.SiO_2 content in bauxite, the thermal energy consumption has gone up by ~0.16 GJ/t Al_2O_3 and the increase is observed in the Evaporation & Test Tank Sections. The reason for this can be explained on the basis of the tradeoff between the raw caustic addition versus the evaporator product liquor for maintaining the liquor caustic concentration to digestion.

With the reduction in k.SiO_2 content in bauxite, there is a reduction in the chemical caustic loss. Since in any alumina refinery, the raw caustic addition should be equivalent to the chemical caustic loss in general considering that the loss with residue and alumina is minimal. The digestion liquor caustic concentration is maintained by sufficing the extra caustic requirement through addition of evaporator product liquor. Hence the higher requirement of evaporator product liquor results in higher energy consumption in the evaporation section as shown in the findings from the model. This is one of the ways of using the model for estimating the change in process conditions on section-wise thermal energy consumption and it perfectly matches with the actual plant results.

6 Discussion

An attempt has been made in this paper to understand the section-wise thermal energy distribution in Bayer process through a steady state model. Through this model, section-wise heat consumption can be determined and thus the total thermal energy in GJ/t Al_2O_3 can be calculated. The model involves simple mass and heat balance calculations using some input values for various streams, which is a very simple application technique.

It is expected to be very useful to plant personnel for estimating the high energy consuming sections, under the present operating conditions and thus the reasons for higher energy consumption can be ascertained.

This will also be useful to determine the changes required when major input conditions are modified, in order to achieve an optimum process conditions.

7 Reference

1. T. Mach, "Energy Consumption in the Bayer Process" , *Proceedings of the 9th Alumina Quality Workshop*,2012, p. 375-378.
2. Sagar S. Pandit and S. Sankaranarayanan, Development of MS: Excel-based model for Bayer process thermal energy consumption analysis - case 1 - Belgaum alumina refinery, *Hindalco Industries Limited, Hindalco Innovation Centre - Alumina, Technical Report No. HICA-2015/21,* 31 August 2015.