Exhaust to Energy: Waste Heat Recovery in Alumina Digesters

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Abstract

Waste heat recovery is a crucial aspect of sustainable industrial processes, offering both environmental and economic benefits. This study investigates the potential to recover energy from waste/ low quality heat that is released to exhaust in an alumina refinery. Alumina refining process involves digestion of bauxite ore at high temperatures and pressure. After digestion, pressure is released using a series of flash vessels and the evaporative flash steam is optimally used for regenerative heating of caustic liquor. The blow-off slurry still possess temperature of about 104 °C, i.e., above boiling point. Thereby, produces flash steam which is generally unutilized for its relative low energy content and vent through the relief tanks. In alumina refineries, steam is the major source of energy used in digestion (46 %) and any efforts to recover waste heat and utilize for other applications will be of great scope to reduce steam consumption.

Utkal Alumina International Ltd. (UAIL) Refinery being a modern alumina plant operates with 3 low temperature digestion circuits to support overall production requirement. The digestion circuit consumes steam at a rate of 75 t/h. Blow off slurry remains at ~104 °C approximately 6 t/h per train of vapor (waste heat) is being released to relief tank at atmospheric pressure and about 100 °C. Venturi condenser technology was applied to assess its feasibility and effectiveness for waste heat recovery. With this system, it is demonstrated to recover 1.24 MJ/day of waste heat that can be able to reduce 15 t/h of low-pressure (LP) steam from wash water heating in mud wash circuit ultimately saves 430 m^3/day of water from vaporization. Waste heat recovery emerges as a viable and sustainable solution for improving energy efficiency and reducing environmental impact in alumina refining processes.

Keywords: Energy efficiency, Waste heat recovery, Venturi condenser.

1. List of Abbreviations

SNL	Supernatant Liquor
BOT	Blow Off Tank
WHR	Waste heat recovery
PFD	Process Flow Diagram
PID	Piping and Instrumentation Diagram
BOP	Blow Off Pump
CP	Effluent/Caustic Pond
Lv	Latent Heat of Vaporization
Cp	Specific Heat at Constant pressure
Kpa	Kilopascal
RMP	Red Mud Pond
t/h	Tonnes per hour
M	Mass Flow Rate
MOL	Milk Of Lime (Lime Plant)

CFD	Computational Fluid Dynamics
LTD	Low Temperature Digestion
CCL	Caustic Cleaning Liquor
ID	Induced Draft

2. Introduction

The alumina digestion process is a pivotal stage in the production of aluminum, where the transformation of raw bauxite ore into valuable alumina occurs. Aluminum manufacturing itself is an energy consuming process, where 27 % of the energy [1] is being consumed in alumina refining process. and out of 27 % in the refinery the energy consumption pattern seems 46 % (Figure 1) of the total steam energy is consumed in Digestion area and 36 % is used in Evaporation area while 12 % of the miscellaneous steam is being utilized in other areas like lime plant (MOL), mud wash, caustic cleaning liquor (CCL) heating etc. The major challenge is to reduce the miscellaneous steam consumption and waste heat recovery could be a possible alternative.

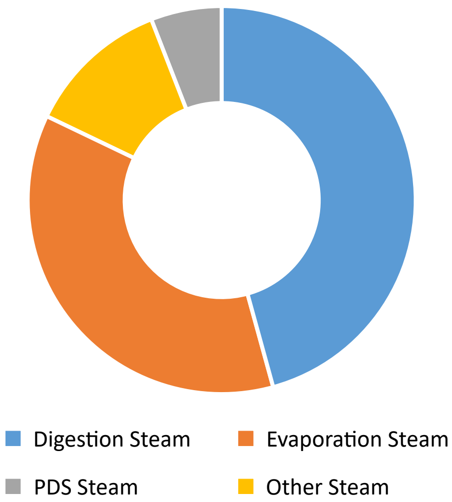

Figure 1. Typical steam consumption in a low-temperature alumina refinery.

In the digestion process the mixture of ground bauxite and sodium hydroxide solution is fed into the digesters, where it undergoes high-temperature and high-pressure digestion. Typically, the digestion process occurs at temperatures ranging from 140 °C to 280 °C and pressures ranging from 172 to 345 kPa (25 to 50 psi). The elevated temperature and pressure enhance the dissolution of gibbsite/boehmite present in the bauxite into the sodium hydroxide solution, forming sodium aluminate.

The dissolution reaction is an endothermic reaction [2] that consumes major steam energy in the refining process. Utkal Alumina International Limited (Utkal) being a modern alumina plant operates with 3 low temperature (LT) digestion trains to produce 2.47 million tonnes of alumina per annum. The digestion circuit consumes 225 tonnes of steam per hour. The blow off slurry remains at the temperature of 104 °C produces flash steam (Figure 2) which used to vent through the relief tanks.

Waste heat recovery is a crucial aspect of sustainable industrial processes, offering both environmental and economic benefits. This process demonstrates and investigates the potential for waste heat recovery in alumina refinery digestion process through the implementation of a venturi condensing system. The parameters such as heat transfer efficiency, energy savings, and environmental impacts are evaluated, alongside economic considerations. The findings highlight the potential of venturi condenser-based waste heat recovery to optimize specific steam consumption to improve profitability of alumina refining operations.

The lessons learned from this project can serve as a blueprint for other alumina refineries across any alumina refinery for sustainable future initiatives aimed at maximizing energy efficiency and minimizing environmental impact across the industrial landscape and can lead to a sustainable business of "Greener, Stronger, Smarter".

7. Appendix

1) The net heat energy loss from the slurry can be calculated as:

Net Heat loss = Q = Inlet energy – Outlet Energy [6]
= M × Cp × (Ti – To) with Cp = 2.071 kJ/kg
= 13 668 kJ
Mass of vapor generated = Mv = Heat Loss/ Enthalpy of steam)
= 6 tph Per Train

2) Amount of heat lost (Ql) = Amount of heat gained (Qg)

(Ql) = Mass of vapor × Enthalpy of steam + Mass of liquid × Enthalpy of liquid
= 20 046 kJ

Considering 5 % energy losses through non-condensable, the net energy is 19 043 kJ

Enthalpy of the vapor at this temperature = 2 676 kJ/kg·°C [Steam Table]

Enthalpy of liquid at this temperature = 419.1 kJ/kg·°C

As per energy balance, if we can heat up the SNL of ~ 42 °C (T1) then the energy balance can be written as:

Heat gain by SNL = Heat loss by vapor

The final temperature of the hot SNL after heating can be calculated as:

M × Cp × (T1-T2) = 19 043 kJ
T2 = 70 °C

[The nominal calculations are shown based on 100 m^3/h cold stream, SNL flow]

3) Condensate Efficiency = $= \frac{T2-T1}{T3-T1} \times 100$ [7]

Or

$$\eta = \frac{M_{out}}{M_{in}} \times 100$$

Where:

T1 = Cooling Water Inlet Temperature
T2 = Hot water temperature from venturi
T3 = Temperature with respect to vacuum inside condenser
M_{in} = The mass of steam input to the condenser.
M_{out} = The mass of steam condensed.

8. References

1. Katerina Kermeli et al., Energy efficiency improvement and GHG abatement in the global production of primary aluminium, *Energy Efficiency*, Springer Netherlands, Vol. 8 issue 4, 2015, 629–666.
2. Gary Gerard & P. T. Stroup, *Volume 1, Alumina; Chapter 1, Discussion of Heat Balance in the Digestion Process of Bauxite*, JW & Sons Publication, pp.73-75, 77.

3. Herman Charles Krannert; *A Digest of the Rules for the Design of Condensers and Air Pumps*, 1912, Chapter 2, Cooling Water for Jet Condensers, pp.5-6.
4. P. J. Marto, *Handbook of Heat Transfer, 3rd Edition*, 1998, Chapter-14, Condensation, pp.14.33, 14.42, 14.43.
5. Bernard Massey, Revised by John Ward-Smith, The Principle Governing Fluids in Motion, *Mechanics of Fluid, Eighth Edition,* 2005; Chapter 3, p. 95.
6. Warren McCabe, Julian Smith and Peter Harriott, Unit Operations of Chemical Engineering, Chapter 11, *Enthalpy Balance in Heat Exchangers*, pp. 319-320, McGraw-Hill.
7. K. Shruthi et al., Increasing the Efficiency of Surface Condenser under Various Load Climatic Conditions by Reducing Subcooling, *International Research Journal of Engineering and Technology (IRJET)*, Volume: 07 Issue: 06 | June 2020, p.3/4069.