# Reduction of Auxiliary Energy Consumption in an Aluminium Smelter

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**Abstract**

In today's global landscape, where Environment, Social and Governance (ESG) considerations wield increasing influence over corporate decision-making, the aluminum industry is undergoing a profound transformation. Embracing the imperative of sustainability, Vedanta Aluminium Limited has embarked on a journey towards producing environmentally friendly aluminum while prioritizing energy efficiency and social responsibility.

This paper underscores Vedanta's commitment to ESG principles through the implementation of energy-efficient measures in its smelting operations, with cell technology provided by GAMI, China. Traditional aluminum production involves electrolytic cells powered by direct current (DC), alongside auxiliary energy consumption for other processes. Vedanta aims to reduce this auxiliary energy consumption in its electrolytic reduction processes, thereby advancing sustainable development while safeguarding the environment and benefiting society.

Key initiatives outlined include the installation of a pot cooling system, hydro jetting of secondary alumina conveying pipes in the Fume Treatment Plant (FTP), and the adoption of belt conveyors to replace pressure vessel systems for alumina transport. Additionally, process enhancements such as fume flow balancing and compressed air optimization are highlighted, demonstrating Vedanta's commitment to minimizing auxiliary energy consumption in aluminum smelting. This paper underscores the pivotal role of environmental stewardship and social responsibility in fostering sustainable innovation and operational excellence in the aluminum industry.

**Keywords:** Environment, Social and Governance (ESG), Smelter auxiliary energy consumption, GAMI cell technology, Sustainable practices, social responsibility.

## 1. Introduction

The Hall-Héroult process to produce primary aluminum consists of electrolysis of aluminium oxide dissolved in molten cryolite. Direct current (DC) is used as the energy source for electrolysis process. This method is currently the key industrial process to produce aluminium, independently developed by Charles Martin Hall in USA and Paul Héroult in France in the late 19th century. The primary reaction involved in the Hall-Héroult process is stated below (1):

$$2Al_2O_3 + 3C \rightarrow 4Al + 3CO_2 \tag{1}$$

Here, the overall energy required for the electrolytic reduction of aluminium is calculated in terms of energy required to produce one metric tonne of aluminium which is known as Specific Energy Consumption (SEC). Specific Power Consumption (SEC) comprises of specific DC energy consumption which is the DC energy used for electrolysis and specific auxiliary energy consumption that accounts for the energy consumed by other auxiliary equipment. This paper outlines some of the energy saving initiatives and process enhancements at Vedanta Limited, Jharsuguda towards the journey in the reduction of specific auxiliary energy consumption from 407 kWh/t Al to 386 kWh/t Al. The reduction in specific energy consumption not only poses a financial benefit, but also plays a major role in reduction of greenhouse gas (GHG) emissions and environmental sustainability.

## 2. Specific Auxiliary Energy Consumption

The Vedanta Aluminium Limited located at Jharsuguda consists of two smelters that jointly has an annual production capacity of 1.75 Mt/a (million tonnes per annum) of aluminium. The utilised by auxiliary equipment to produce one tonne of hot metal of aluminium is known as specific auxiliary energy consumption of potline. The major contributors of auxiliary energy consumption in potline consists of induced draft fans in FTP, fans and blowers of FTP, rectifier, rectifier pump house, compressor house and other miscellaneous equipment. The specific auxiliary energy consumption is calculated by the formula (2),

$$Aux. Energy = \frac{Total\ MCC\ Energy + Rectifier\ energy + 60\ \% \times Utility\ energy}{Gross\ metal\ Production} \quad (2)$$

where:

| | |
|---|---|
| *Aux. Energy* | Specific Auxiliary Energy Consumption, kWh/t Al |
| *Total MCC Energy* | Energy consumed by ID fan and other auxiliaries of potline, kWh |
| *Rectifier energy* | Energy consumed by rectifier, kWh |
| *Utility energy* | Total energy consumed by utility, kWh |
| *Metal Production* | Total metal produced for a given period, t |

### 2.1 Journey of Vedanta in Auxiliary Energy Reduction

The Vedanta Aluminium Limited marked its journey in the reduction of auxiliary energy consumption with the implementation of various energy saving initiatives since the full phase plant production in 2011. The Figure 1 shows the yearly auxiliary energy consumption to produce hot metal of aluminium in the potlines of Vedanta Aluminium Limited. The Figure 1 also demonstrates the Vedanta's commitment in producing environmentally friendly aluminum while prioritizing energy efficiency and social responsibility.

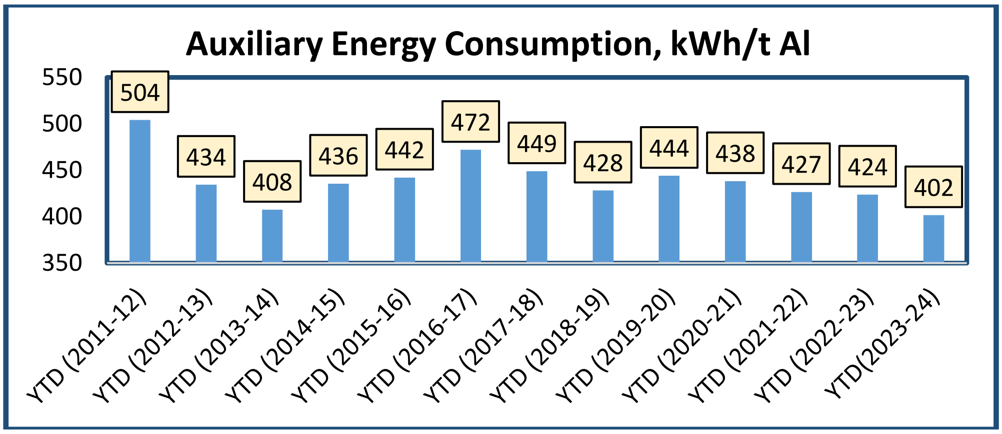


**Figure 1. Specific auxiliary energy consumption over the years.**

This paper briefly summarizes the various energy efficient initiatives and process enhancements showcasing the journey from annual auxiliary energy consumption from 424 kWh/t Al to 402 kWh/t Al in the financial year 2023–24.

## 2.2 Strategy of Auxiliary Energy Reduction

The specific auxiliary energy to produce one metric tonne of hot metal comprises of total auxiliary energy consumption in potline, energy consumption in rectifier and 60 % of energy consumed in compressor house. To identify the improvement areas in energy saving, a methodology called energy review is followed as per the recommendation in ISO 50001. In this process, all the energy streams used in potline is analysed and all the data related to energy use and energy consumption of each equipment is collected. Then significant energy use and significant equipment has been identified by the application of pareto rule (80 % of equipment consuming 20 % energy and 20 % of (equipment consuming 80 % of energy). Therefore, after the energy review process, the major improvement areas identified are Induced Draft installed in Fume Treatment plant, Fans and blowers used for alumina conveying process. Also, optimization of compressed air usage is considered as one of the major improvement initiatives since compressors contribute for more than 25 % of overall auxiliary energy consumption. The Figure 2. shows the overall breakup of auxiliary energy consumption.

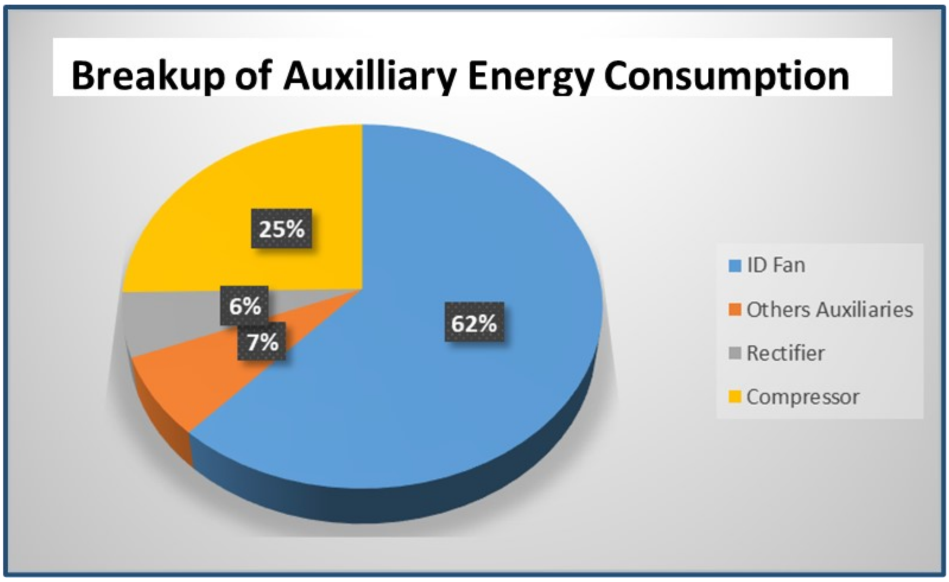


**Figure 2. Breakup of auxiliary energy consumption.**

## 3. Energy Saving Projects for the Reduction of Auxiliary Energy Consumption.

After the identification of significant energy use and significant energy consuming equipment, some high energy consuming problems were listed out and projects were taken for the resolving the problems that in turn provides a potential saving in energy consumption. Two major initiatives taken in Smelter 2 of Vedanta Aluminium Limited in the journey of auxiliary power reduction is listed below:

- Replacement of pressure vessel systems with belt conveyors in alumina handling systems
- Hydro-jetting of enriched alumina conveying pipes.

### 3.1 Replacement of Pressure Vessel Systems with Belt Conveyors in Alumina Handling Systems

The project of replacing pressure vessel systems with belt conveyors in alumina handling system of Smelter 2 is considered as one of the major steps that underscores the journey of Vedanta Limited in the reduction of auxiliary energy consumption. In Smelter 2, alumina handling system is equipped to handle alumina received from BTAP and bulker. The alumina handling system was initially provided with four storage silos of capacity 16 000 t. Later, for the reduction of alumina unloading time and to enhance the alumina handling capacity, three intermediate silos of capacity 1 500 t were installed. These intermediate silos are used only during the time of alumina unloading. After the process of unloading, the alumina that is unloaded in the intermediate silos were transferred to storage silos with capacity 16 000 t. Pressure vessel system was used for conveying the alumina from the intermediate silo to the storage silos. The pressure vessel system is powered with compressed air of pressure 200 kPa (2 bar). Compressed air required for conveying was supplied by five LP compressors. The operation of LP compressor for alumina conveying from intermediate silo to storage accounts for about 6.5 kWh/t Al in the overall specific auxiliary energy consumption.

#### 3.1.1 Belt Conveyor – An Ultimate Energy Saving Solution for Alumina Conveying

The alumina from the storage silos is transferred to potline fume treatment plant by means of belt conveyors for the process of dry scrubbing. After the dry scrubbing process, the fluoride enriched alumina is fed to the pot cells for aluminium production. By taking the mechanical conveying of alumina by using belt conveyors from the alumina unloading station to potline as a reference, the idea of implementation of belt conveyors for alumina conveying from intermediate silo was proposed. As per the proposed idea, belt conveyors were installed for conveying alumina from the intermediate silo to the existing belt conveyors of the respective line directly as shown in Figure 3.

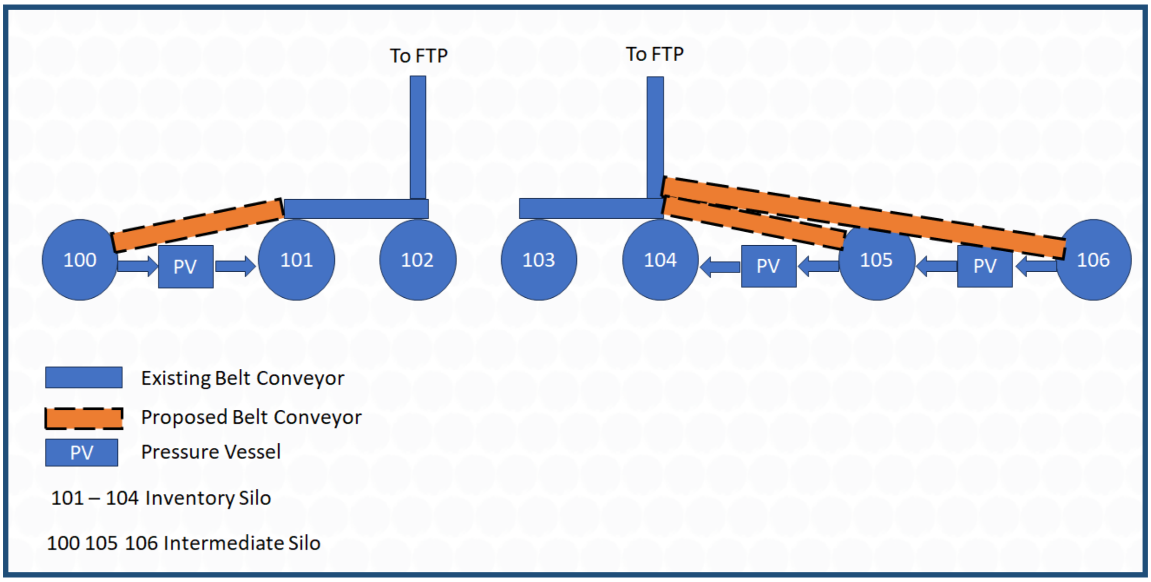


**Figure 3. Proposed layout of belt conveyor in intermediate silo.**

The installation of belt conveyors replacing the pressure vessel system has potentially reduced the LP compressor operating duration by 15 h/day. The reduction in LP compressor operation is impacted a gain of around 5.6 kWh/t Al in the overall auxiliary energy consumption. Also, the elimination of pneumatic conveying has led to the reduction alumina attrition below 2 % which has an impact in the reduction of pot voltage and DC energy consumption. Also, the project poses benefit in BTAP (Alumina Rake) turnaround time that paves the way for eliminating the road transportation of alumina by 11.5 kt/month.

### 3.2 Hydro-Jetting of Enriched Alumina Conveying Pipe

In Aluminium smelters, the alumina ($Al_2O_3$) which is the prime raw material in the production of aluminium is also used in dry scrubbing process in its FTP before electrolysis. Alumina which is known for its large surface area, high mechanical properties and good resistivity to thermal degradation is considered as an efficient adsorbent in dry scrubbers for effective removal of hydrogen fluoride before emitting the pot outlet gas from the stack to atmosphere. The fluoride enriched alumina from the outlet of FTP is stored in enriched alumina silo of capacity 3 000 t which is then fed to the electrolytic cells to produce aluminium. The enriched alumina from FTP is transported to 3 000 t enriched silo through airlift system. Airlift works on the principle of lean phase conveying which is one of the techniques used for conveying powder material in vertical pipes.

#### 3.2.1 Problem Statement

The Smelter 2 of Vedanta Aluminium Limited consists of eight fume treatment plant, each FTP is designed to handle 168 electrolytic cells or pots in potline. The fume treatment plant not only collects and treats the hydrogen fluoride from the pots, but also serves the purpose of supplying fluoride enriched alumina to the pots. The enriched alumina is conveyed to the silo by means of airlift system through set of roots blower of 55 kW. Each FTP consists of two root blowers for airlift system, one for continuous operation and one for standby purpose. In the long run, the conveying capacity of the airlift system is reduced due to the formation of hard grey scales on the inner surface of the alumina conveying line as shown in Figure 4. Hard grey scales are hard slate like material that accumulates on the inner surface of the conveying line that results in the reduction of cross-sectional area available for alumina conveying. The reduction of conveying area has led to the reduction of alumina flow, which in turn leads to the drop in enriched alumina silo level creating back pressure in the alumina feeding circuit. Therefore, to meet the alumina supply requirements and to avoid the risk of drop in alumina silo level and development of back pressure, it was decided to run both roots blower for maintaining alumina feed rate to the enriched alumina silo. So, for meeting the alumina feed rate requirements, two roots blower were in continuous operation which has increased the energy consumption.

**Figure 4. Hard grey scale formation in conveying line.**

### 3.2.2 Hydro-Jetting: A Novel Approach in an Aluminium Smelter

To mitigate the challenges faced due to hard grey scale formation in the alumina conveying pipe, multiple solutions were proposed and some of them were implemented as well. But none of the solutions implemented had given the desired results. Even, in one of the FTP, the entire conveying line is replaced. Since the process of conveying line replacement is time consuming and not cost effective, it was not feasible. Therefore, an idea of hydro-jetting for cleaning the enriched alumina conveying line was proposed which was done for the first time in an Indian Smelter. Hydro-jetting is a process of using high pressure water jets for cleaning process to remove scale, debris, and other buildups in conveying pipes, storage tanks etc. In large scale industries, hydro-jetting is mainly used to remove deposits and scale formations in heat exchanger tubes. Here, the technique of hydro-jetting was used to clean the hard grey scale formations inside the enriched alumina conveying system.

In this process, a water jet of around 10 000 $m^3$ with pressure 70 MPa (700 bar) was used throughout the length of the conveying line for the effective removal of hard grey scale formations on the inner surface of the pipe. Since there are two conveying lines present in each FTP, Hydro-jetting process was carried out by taking the isolation of the conveying line one by one in such a way that the hydro-jetting process will not affect the normal operation of FTP. The entire process takes around 4 to 6 hours for completion of one conveying line. To avoid hindrance to normal operation of FTP, the standby conveying line was isolated for the hydro-jetting process. After the completion of the process, the moisture in the conveying line is dried out by blowing fluidization air for one hour. Then the conveying line is taken into operation and the other which was in operation gets isolated for the hydro-jetting process. Almost 1 t of hard grey scales were recovered from each conveying line in the process of hydro-jetting as shown in Figure 5.

**Figure 5. Hard grey scales recovered after hydro-jetting.**

The removal of hard grey scale had increased the effective area of conveying which in turn had regained the conveying capacity of the system**.** Figure 6 shows the % load on the airlift blower before and after the process of hydro-jetting in one of the FTP. Before hydro-jetting, both airlift blowers were in operation to manage the alumina conveying process, whereas after hydro-jetting activity, the alumina conveying process is managed smoothly with one airlift blower operation.

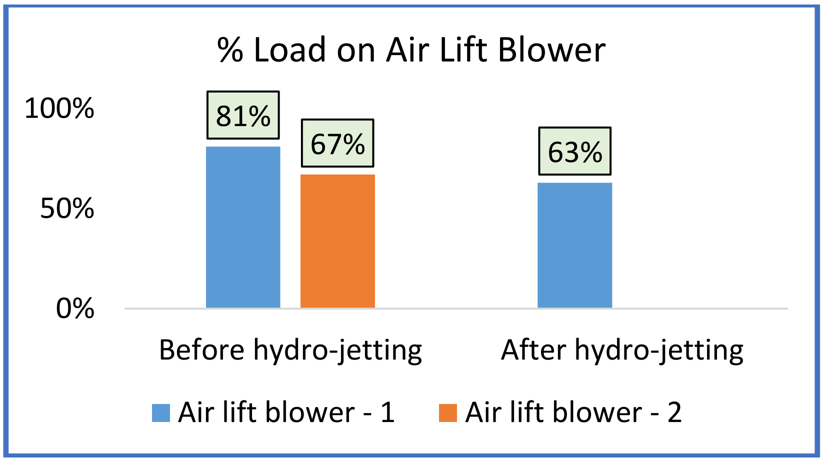


**Figure 6. % Load on airlift blower before and after hydro-jetting.**

The increase in conveying capacity had led to the operation of one air lift roots blower for the process of conveying of enriched alumina. The shutdown of one roots-type blower has provided the overall gain of reduction in auxiliary energy consumption. Therefore, the process of hydro-jetting poses a benefit of around 2.7 kWh/t Al in the overall auxiliary energy consumption. Table 1 shows the calculation of potential saving in auxiliary energy consumption by the process of hydro-jetting in enriched alumina conveying line.

**Table 1. Energy saving calculation of hydro-jetting in enriched alumina conveying line.**

| Energy savings calculation - Hydro-jetting | | | |
|---|---|---|---|
| **Sl No** | **Description** | **Value** | **Unit** |
| 1 | Air lift Blower motor rating | 55 | kW |
| 2 | Average load on Air lift blower (ALB 1) in 8 FTP's | 81 | % |
| 3 | Average load on Air lift blower (ALB 2) in 8 FTP's | 67 | % |
| 4 | Total power consumption of Air lift blower in one FTP before hydro-jetting | 1954 | kWh/day |
| 5 | Power consumption of air lift blower in one FTP after hydro-jetting | 832 | kWh/day |
| 6 | Total Energy saving in 8 FTP's per day | 8976 | kWh/day |
| 7 | Average metal production per day | 3360 | t |
| 8 | **Average saving in Auxiliary power consumption** | **2.7** | **kWh/t** |

## 4. Process Enhancements in Auxiliary Energy Reduction.

Other than the energy saving projects, some of the process enhancements were done to eliminate the causes for high auxiliary energy consumption. The process enhancements were done in optimization of both ID fan and compressor energy consumption. These process enhancements include:

- Application of Computational Fluid Dynamics (CFD) in fume flow balancing,
- Optimization of compressed air consumption in potline.

### 4.1 Application of Computational Fluid Dynamics in Gas Flow Balancing

A potline to produce hot metal of aluminium consists of FTP for the treating the exhaust hydrogen fluoride gas formed during the electrolysis process. The reaction of primary hydrogen fluoride formation in the pot cell is given in Equation (3):

$$3H_2O + 2AlF_3 \rightarrow 6HF + Al_2O_3 \quad (3)$$

In the above reaction, the aluminium fluoride added in the pot for maintaining bath chemistry reacts with the percentage of loss of ignition present in the alumina to form hydrogen fluoride gas. For the collection of the exhaust gas, each fume treatment plant is provided with ducting system connected to each pot cell of a potline. Damper system is provided in the duct at each pot outlet for the purpose of adjusting the fume flow of each pot as per requirement or design fume flow. The process of flow measurement at each pot duct and adjusting the damper accordingly to maintain uniform flow across each pot is known as pot gas flow balancing. The general layout of ducting system of fume treatment plant is shown in the Figure 7.

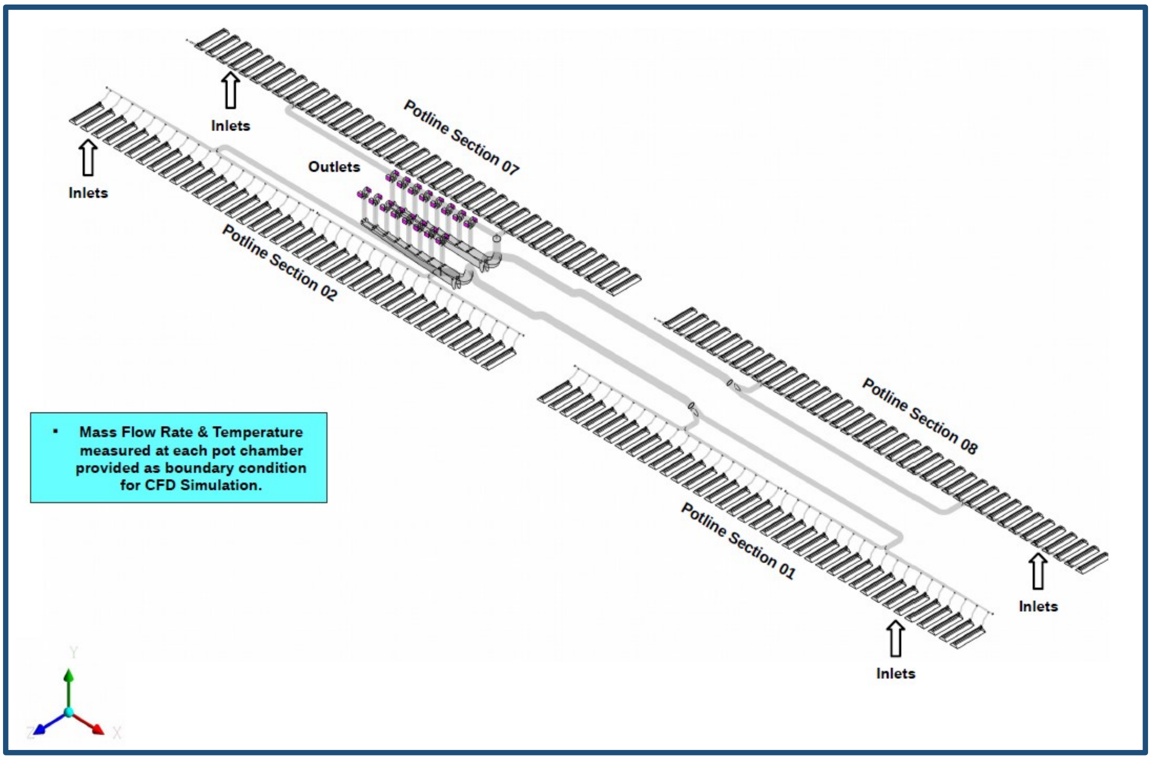


**Figure 7. General layout of ducting system.**

#### 4.1.1 Problem Statement

In Smelter 1 of Vedanta aluminium limited, each section consists of four parts in the ducting system. Since each section duct consists of four pots, finding the right opening combination of individual pot cell damper for maintaining uniform flow across each pot cell is difficult. Hence, even after the trial of various damper opening combinations, it was observed that some pot cells had higher flow and some pot cells had flow lower than the recommended flow. This pattern of higher on one side and lower flow on the other side has led to the formation of stagnation zone on one side. This stagnation not only causes suction loss at the end pot cells and high fugitive emission, but also it causes high turbulence inside the ducting system that increases the load on ID fan and ultimately increases the overall energy consumption of the ID fan.

#### 4.1.2 Introduction to CFD

CFD is a part of fluid mechanics which applies numerical analysis and data structures to solve and analyze problems that involve fluid flows. It consists of specialized software packages that can simulate the behavior of fluids, predict fluid flow pattern, and analyze the performance of fluid systems. Some of the specialized software packages used for performing CFD simulations are OpenFOAM, ANSYS Fluent, COMSOL Multiphysics, STAR-CCM+. By understanding the fundamental principles and its application in real world problems, CFD can improve the process design and improve the efficiency of specific processes.

#### 4.1.3 CFD to Study the Flow Patterns in the Ducting System

The initial step to create a CFD model is to do manual measurements across the system to set the boundary condition and the various assumptions according to the system. Here, CFD analysis was carried out in one of the FTP of Smelter 1. The flow measurements were done across the outlet fume duct of each pot cell, common duct at the inlet of fume treatment plant, across individual reactor and at the inlet and outlet of each ID fan. From the initial flow measurement, the boundary condition and the system assumptions were made to study the fume flow pattern in the ducting system and accordingly the CFD model of the system was created. Pressure and velocity contour in the ducting system is shown in the Figure 8.

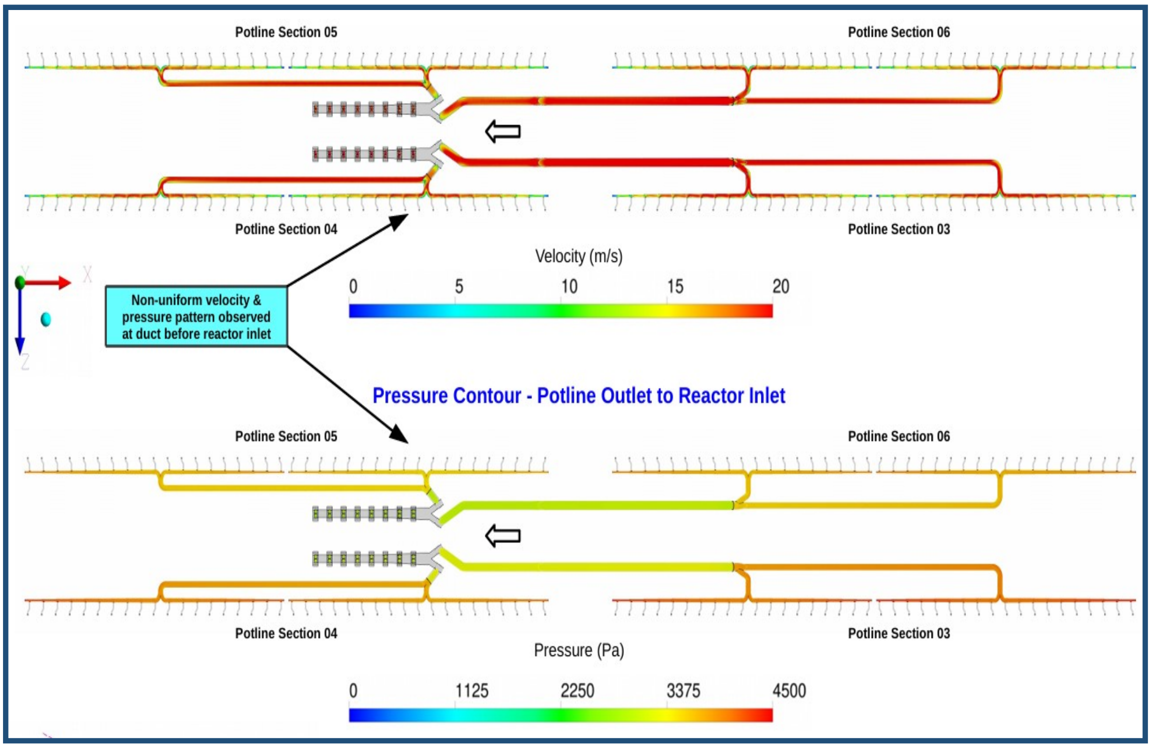


**Figure 8. Pressure and velocity contour in the ducting system.**

The CFD model was used to identify the high turbulent zones that causes suction loses and the areas of stagnation. By using the CFD model, numerous pot cell damper opening combination were tried to identify the right combination that provides uniform suction to each pot cell. After the identification of right combination of pot cell damper opening that has minimum turbulence in the system, same opening combination is implemented physically in the system and the manual measurements were done for validation. The uniform flow across each pot cell and the turbulence reduction in the system have ensured the subsequent reduction load on the ID fan which has a potential benefit of 1.7 kWh/t Al in the auxiliary energy consumption. The idea of CFD implementation not only helps in the reduction of energy consumption, but also helps in reduction of fugitive fluoride emission.

### 4.2 Optimization of Compressed Air Consumption

The energy consumption of compressor is one of the major contributors in the overall specific auxiliary energy consumption. It accounts for more than 25 % in the auxiliary energy consumption of potline. Therefore, optimization of compressed air usage will play major role in reduction of compressed air energy consumption. Also, the pressure loss in the compressed air also needs to be optimized for further reduction in compressed air consumption.

#### 4.2.1 Reduction of Pressure Loss in Compressed Air Line Circuit

In potline, based on the air usage, the compressed air supply with minimum pressure of 500 kPa (5 bar) is to be maintained during normal operation. Prior to the project, for maintaining the compressed air pressure, 7 HP compressors were operated continuously. The figure shows that the ring header circuit of compressed air system in potline of Smelter 1. The compressed air line header consists of manually operated control valves at both the duct end and tap end side of the potline. It was identified that all the control valves were found in full open condition that significantly caused turbulence and pressure loss in the compressed airline header. Therefore, trial was taken in potline– 1 to throttle the control valves on the duct end side. After throttling the control valves, it was found that the line pressure of that potline was increased to 6 bar with 7 HP compressors. Since the pressure requirement is only 500 kPa (5 bar), the valve throttling activity has provided the opportunity to operate only 6 HP compressors instead of 7 HP compressors. The shutdown of one HP compressor has a potential saving of 9.6 kWh /t Al in the auxiliary energy consumption.

## 5. Pot Cooling System: First of Its Kind in GAMI Potline

In the ever–evolving landscape of industrial progress, Vedanta Limited Jharsuguda proudly introduces installation of pot cooling fan in GAMI Potline for pot side shell and collector bar cooling. Currently, an external compressed air supply is provided at each pot cell that can be utilized for the purpose of cooling during the occurrence of high collector bar and side shell temperature in abnormal pot cells to avoid tap out of molten metal which is considered as a major business risk in aluminium industry. The usage of compressed air for the purpose of cooling side shell and collector bar has increased the overall compressed air consumption, thereby causing issue of pressure drop in plant air which has affected normal plant operation and caused deviation in various process parameters. Therefore, for maintaining the pressure of plant air, standby compressor was also operated that has ultimately led to the increase in overall auxiliary energy consumption.

### 5.1 Pilot Implementation of Pot Cooling system

The idea of pot cooling consists of a high-capacity cooling fan and ducting system connected across the potline for serving the purpose of cooling the side shell and collector bar of abnormal pot cells. A pilot pot cooling system is installed in one section of Potline 4. In this pilot system, a high-capacity fan is installed in the courtyard of fume treatment plant and the ducting system is arranged in a such a way that there will be air source at each pot cell and can be used during abnormal situations. The layout of pot cooling system for one section of potline is shown in Figure 9.

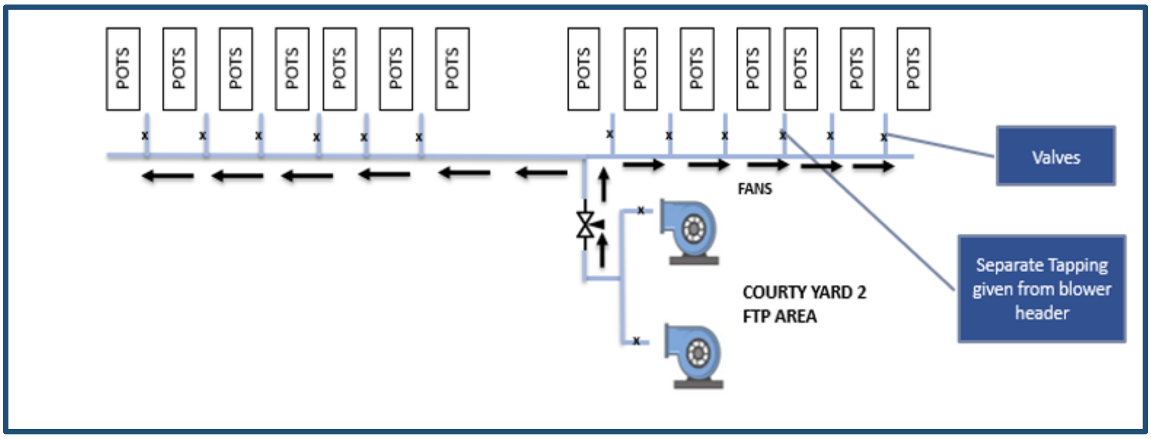


**Figure 9. General layout of pot cooling system.**

The trail phase installation of pot cooling system in one section has reduced the energy consumption of one HP compressor by 27 %, that accounts for about 1.4 kWh/t Al in the auxiliary energy consumption. In the way forward, on implementing the same throughout the smelter will have a potential saving of 25 to 30 kWh/t Al in the overall auxiliary energy consumption. This project is a major step in Vedanta that underscores the environment and social responsibility fostering operational excellence in GAMI potline.

## 6. Conclusions

In conclusion, this paper focused on the reduction of auxiliary energy consumption through various energy saving initiatives and process enhancements with the integration of Environmental, Social and Governance (ESG) principles has demonstrated significant progress and impactful results. This paper also underscores the importance of incorporating ESG principles into our operations, resulting in cost savings, enhanced operational efficiency and a stronger reputation among stakeholders. Our commitment to ESG principles will remain a cornerstone of our strategy, driving us towards a more sustainable and responsible future.

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