Optimization of the Product Recovery Rate in an Air Separation Plant

Nicole M. Méndez Suárez
Master in Engineering Management
Dr. Héctor J. Cruzado
Graduate School
Polytechnic University of Puerto Rico

Abstract *— Process optimization is an area of opportunity for any organization given the recent rise in costs associated with the manufacture of products from local perspective. As part of the productivity initiatives, the decrease in the Argon recovery rate in an air separation plant was identified as opportunity, due to its direct implications on the business. The DMAIC methodology was implemented through its different phase's application, identifying as root causes deficiencies in the mechanical integrity of the main air compressor. Successful improvements implementation was completed considering the integration of control measurements resulting in sustainable changes. Daily production showed increase per preliminary evaluation indicating a positive trend towards production target objective.*

Key Terms*—Argon, Continuous Improvement, DMAIC Methodology, Inlet Guide Vanes.*

INTRODUCTION

LIN is a leading global company in the industrial gases business dedicated to developing application technologies while supplying high-quality products to its customers. The company provides a wide selection of industrial products in the gas market, some of which are Oxygen, Nitrogen, Argon, Carbon Dioxide, Hydrogen and rare gases [1].

Problem Statement

The recent rise in production costs in the country related to manufacturing has been the main contributor in the search for process optimization elements to reduce costs and increase the efficiency through different parts of the business. To contribute with the ongoing effort, a continuous improvement initiative was started to evaluate critical business areas. A decrease in the recovery rate of Argon within reported production was identified within the production process that supplies thousands of cubic feet per month to different industries at the local perspective. Table 1 presents relevant information related to Air stream composition and its direct relation to Argon production. The importance of this product lies in the current added value in the market given its scarcity, especially considering its low percentage within the composition of the air.

Table 1
Air Stream Composition

Components in Air	Percent by Volume	Contaminants in Air	Percent by Volume
Nitrogen	78.10%	Water	0.10 to 2.80%
Oxygen	20.96%	Carbon Dioxide	350 to 500 PPM
Argon	0.94%	Hydrocarbons	1 to 6 PPM

Source: National Geographic [2]

The progressive decrease in the monthly recovery rate has had repercussions in different aspects of the business, directly impacting the metrics and key performance indicators (KPI's) of the plant at the production level. The problem has forced the management to adopt drastic business measures by incurring in additional expenses associated with the importation of product to satisfy the local demand of the clients, which is estimated to be approximately 1400 kscf (standard cubic feet).

Project Objective

The objective of this project is to achieve an increase in the Argon recovery rate that allows production to be matched at a minimum with the estimate of local demand based on customer consumption. It is intended with the fulfillment of this objective to make the separation process more robust and positively impact the performance indicators of this plant in the long term.

Literature Review

Process optimization is an area that involves the identification of relevant opportunities at the production level that directly impact business metrics. DMAIC methodology is a tool that has been used in different industries for many years as part of Six Sigma initiative to contribute towards the implementation of value-added activities in a company and overall process improvement [3]. The tool is developed to improve the processes and to align them to pursued business metrics where the level of production is identified as one source of performance and opportunity to reach competitive advantage.

Within the industrial gas production sector, Argon is considered a critical product with direct effect in the business metrics. From the economical perspective, the wide range of applications for Argon worldwide has positioned it as a dynamic product market with significant demand over the years. Currently the market for this product is valued at approximately 357.75 million with a promising forecast related to the compound annual growth rate (CAGR) of 3.9% for the coming years. [4].

Argon recovery is mainly completed within an air separation process, consisting in five (5) basic stages:

- Air Compression
- Air Cooling
- Contaminant Removal
- Separation and Liquefaction
- Production

Figure 1 presents the basic air separation process. Crude Argon column produces a Crude Argon stream of approximately 90% Argon, and 10% Oxygen to be further refined in a subsequent separation system called Argon Refinery. During this stage, Argon feed goes into a deeper purification in the high ratio column obtaining a final product within quality standards specifications for delivery either as bulk product or compressed gas [5].

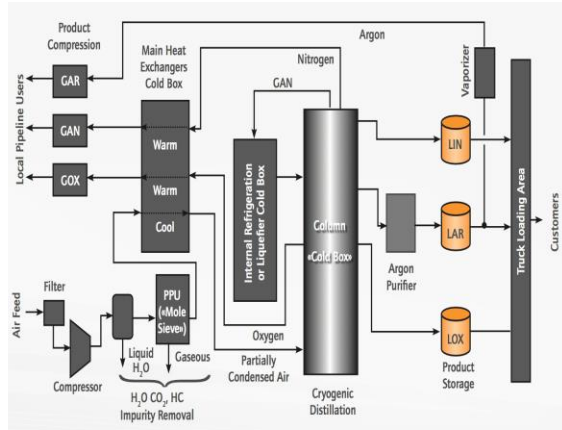

Figure 1
Air Separation Process Diagram [6]

The recovery of this product can be affected by different factors within the process such as oxygen removal by DEOXO, Argon feed pressure drop, waste nitrogen, and gaseous oxygen purity that may have severe connotations during recovery process [7]. Adsorption and pre-purification processes are also critical parts of Argon recovery process.

Methodology

The research methodology implemented for the development of this project was DMAIC. This methodology is based on the Six Sigma tool with a focus on continuous optimization to guarantee quality within processes. Its application consisted of five phases, per Figure 2 that made up a complete study of the existing problem, through the analysis of collected data, identification of root causes and determination of sustainable solutions from the business perspective.

Figure 2
DMAIC Methodology Cycle [8]

Table 2 summarizes the application of DMAIC methodology approach pursued for the purpose of the selected project:

Table 2
DMAIC Standard Methodology Application

Definition Phase	Opportunity Identification: Decrease in Argon recovery rate
Measurement Phase	Data collection plan strategy related to Argon production rate
Analysis Phase	Current situation assessment verification. Identification of trends, variations, elements impacting production
Improvement Phase	Corrective actions proposal for resolution/ improvement
Control Phase	Monitoring strategy development for sustainable results

Results and Discussion

The team key players from different functional areas (operations, engineering, reliability, and productivity) agreed upon the application strategy through the completion of the different phases that constitutes the DMAIC methodology for project resolution related to Argon recovery in the plant operation.

Define Phase

The definition phase purpose was to establish the problem statement with the appropriate objective for the project development. In the context of this investigation, the decrease experienced in the recovery rate of Argon product was identified as the main element of opportunity within the plant operation. The situation was escalating causing business impact related to absorption of costs for product importation to satisfy local demand and decrease in production KPI's related to this product. Considering previously stated elements, the objective defined was to increase in the Argon recovery rate in this plant for optimization purposes.

Measure Phase

Further situation assessment was completed during the measurement phase where the main situation was quantified through valid data collection pertaining process. The data collection strategy consisted in the compilation of variable process data regarding Argon production rates in a monthly basis obtained through the iHistorian system. The time frame selected for data gathering was 18 through 20 with the purpose of being able to establish a better comparative basis of the data per year in the subsequent phase. The range used for investigation was from May 2021 through November 2022. Figure 3 summarizes the data compilation related to Argon production.

The following points were considered of main interest:

- July 2021
- January 2022
- July 2022

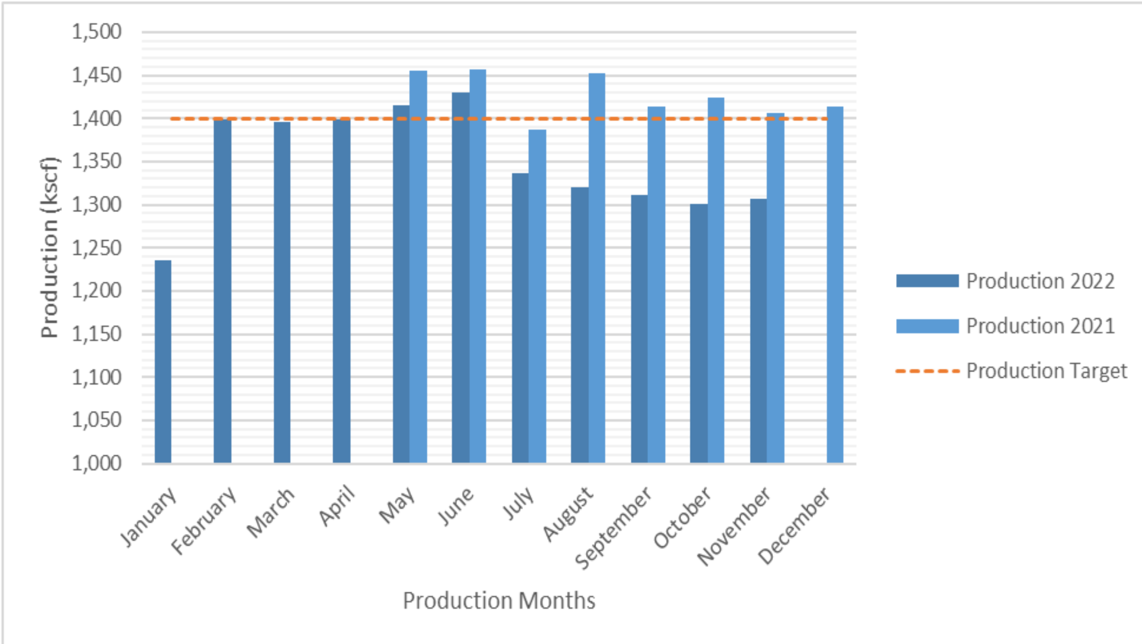

Figure 3
Argon Production Profile

After further verification of plant records with average run time for the periods of interest, a production downward trend in July 2022 was confirmed. The downward trend based on the data collected coincided with the plant's peak production season due to high customer consumption in preparation for the hurricane season. This data was considered as the input for the analysis phase.

Analyze Phase

During the analysis phase, the efforts were directed towards the identification of trends, patterns of variation in the process, and elements impacting Argon production to assign them a specific reason of occurrence. The strategy followed by the team during this stage was mainly focused on the evaluation of three areas of interest being equipment performance, maintenance, and operational process performance subjects of attention. The areas of interest were verified accordingly to determine root cause for the production downward trend observed from data collected (refer to Figure 3). Figure 4 summarizes the initial brainstorming developed by team members for the observed condition. The cause-and-effect diagram (also known as fishbone diagram) was assessed for further investigation in relation with the previously defined areas of interest.

The equipment performance verification consisted mainly of a capacity analysis of critical equipment to produce Argon in the plant. The selection of this equipment was based on the technical aspect of the operation together with the consideration of critical operating parameters (COP's) and wear susceptibility experienced in similar plants locations. The equipment selected as critical elements for the operation were the main air compressor, Argon compressor, pre-purifiers, dryers and DEOXO. The capacity verification was conducted using as input the design capacities of the equipment in comparison with the flows that they were currently processing, obtained from real-time production. Equipment manuals, design specifications and performance curves, among others, were assessed by the operations and reliability team obtaining incongruences related to main compression cycle (refer to Figure 5).

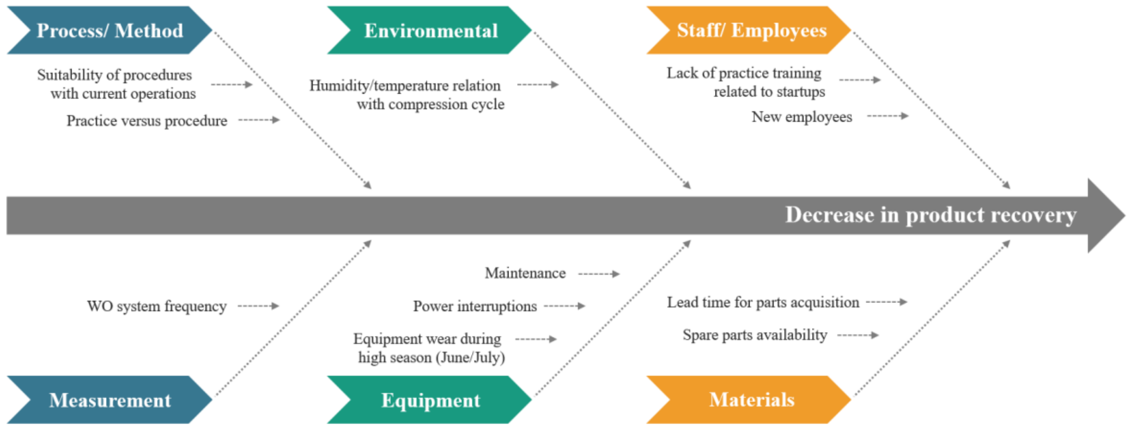

Figure 4
Cause and Effect Diagram (Fishbone)

Further investigation captured an air leakage related to this equipment specifically in the second stage of the centrifugal compressor. The air leakage was produced due to the deterioration of a gasket located in the second stage of the compression cycle near intercooler section. Leakage was confirmed by reliability experts and technicians with the aid of an ultrasonic leak detector equipment.

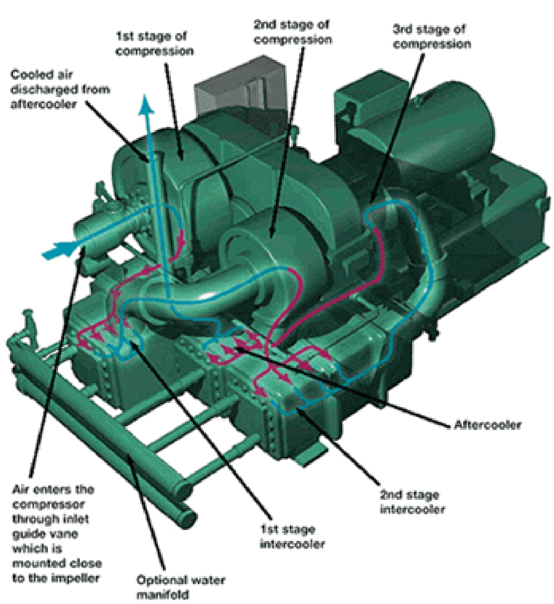

Figure 5
Centrifugal Compressor Diagram [9]

It was also found during the investigation a malfunction with the inlet guide vanes (IGV) located in the first stage of the cycle. Guide vanes are an integral part within the anatomy and structure of the compression cycle since the throughput of the compressor is controlled by them. behavior in relation to air flow increment. Theoretically, as more flow enters at the compressor suction, more power is required to drive compression process [9]. However, investigation concluded limited compressor loading through the verification of power indicating control (JIC2500) which showed a non-proportional behavior in relation to air flow increment.

The maintenance schedule for the critical equipment was also evaluated as part of project analysis with special attention to work orders (WO) related to main air compressor. EAM maintenance system showed that three WO were not completed within the established time frame:

- Oil sample analysis
- Motor bearings lubrication route
- Main drive coupling inspection

None of the pending WO were directly related to the identified compressor malfunctions, in fact, the verification pointed out that the intercooler gasket was changed within the predefined frequency per maintenance procedure requirement.

Operational process performance verification was completed with focus on personnel training related to plant operation and startup procedures. The standard operating procedure SOP-109 associated with plant startup was revised to identify gaps with current process conditions and parameters. As part of this verification, it was also evaluated the training requirements completion for both new and experienced personnel to identify accordance with completion schedule and appropriateness of study material. Verification results indicated that SOP-109 does not include instructions related to power control verification (JIC2500) during compressor startup operation and does not specify flow and power relationship during this stage nor physical visual inspection during this process. Personnel training verification was found to be within compliance with existent training matrix for plant operation, however, opportunities in terms of operators practical training were suggested within an established frequency.

After the completion of analysis phase related to Argon production decrease the following root causes were identified:

- Leakage in the main air compressor
- Guide vanes malfunction

Both elements were associated with the same equipment directly affecting the process flow that subsequently will be separated downstream into Argon product.

Improve Phase

Process improvement constitutes a critical part of this project emphasizing in the proposal of solutions that will eradicate root causes identified as part of project analysis. The proposed improvements were defined within the investigation team upon agreement of implementation. The following solutions aim to correct deficiencies with a sustainable approach to guarantee results:

- Intercooler gasket replacement in second stage of the compression cycle
- IGV actuator replacement
- Development of a preventive maintenance strategy integrating IGV inspection and intercoolers gasket replacement in the EAM system.
- Revision of main air compressor maintenance procedure to include new PM strategy.
- Revision of plant startup procedure to include power control verification instruction and guide vanes inspection.
- Training matrix update to include a practical plant startup refresher training within a year frequency.

After mechanical improvements implementation, plant operation flowrates were balanced obtaining an inlet flowrate that matched the compressor capacity. Preliminary evaluation showed that the Argon production rate was improved per day in a four-day base period. Forecast indicates that if production trend continues with the average recovery rate obtained, the production target of 1,400 kscf will be accomplished at the end of the month. Further data will be evaluated during the month for trend assurance.

Control Phase

Controls measures were defined for improvements implementation sustainability in the production scenery. As part of the monitoring strategy the agreement was that the operations department will be responsible of the generation of a monthly report related to Argon production that will be submitted to the productivity department for further analysis related to production costs. It was also determined the implementation of an Argon production dashboard that will be available at the plant with the purpose having the information accessible while integrating employee towards metric commitment. Monthly meetings will be scheduled within plant members, management, and productivity to discuss production results and align efforts within plant personnel.

CONCLUSION

The proposed investigation successfully identified the root causes associated to the decrease of Argon recovery in the plant. The DMAIC methodology application addressed deficiencies related to the main compressor guide vanes and air leakage that were negatively impacting production KPI's. Improvement proposal focused on correcting equipment mechanical integrity while integrating changes assurance through supporting actions in the operations scenery. Preliminary results indicated that the implementation positively impacted production rate in a daily basis, thus obtaining a promising forecast that will allow production target to be accomplished per defined objectives.

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