Analysis of Equipment Failure in a Production Line of a Coal Fly Ash Plant

Asser Letsatsi Tau, Emmanuel Innocents Edoun, Charles Mbohwa and Anup Pradhan
Faculty of Engineering and the Built Environment,
School of Mechanical Engineering and Industrial Engineering
Department of Quality and Operations Management
University of Johannesburg, 55 Beit St, Doornfontein, Johannesburg, 2028, South Africa
gobetse.t@gmail.com, edounsen@hotmail.com, anupp@uj.ac.za and cmbohwa@yahoo.com

Abstract

Most manufacturers are striving to manage and improve their operations at the perspective of manufacturing costs. Equipment failures and breakdowns should be kept at minimal as possible, thus to increase availability of equipment within a production line. A coal fly ash processing plant experienced continuous equipment breakdowns or failures which resulted in loss of production time. Data was collected on a 31 days period to identify types of failures or breakdown and their frequency of occurrences, and time spent by maintenance personnel to rectify the failures. Cause and effect diagrams were used in order to assess the causes that lead to overall effect of failures. It was identified that pipe conveyor belt failure was as a result of torn metallic structures, belt not fitting fully on idlers, deformed idlers and belt was unfolding at any point on the station while running. Furthermore, pipeline leakages were also identified as contributing factors to failures. Pareto chart was used to analyse the failures and it was identified that 80% of the pipe conveyor belt failure are caused by belt not fitting fully on idlers, torn metallic structure and deformed idlers, meanwhile 20% are caused as a result of belt unfolding at any point while running. Meanwhile in the case of pipeline leakages, 80% of pipeline leakages caused by high coal fly ash operating flow rate and coal fly ash being corrosive which resulted with pipeline being torn, while 20% of the leaks were due to improper sealing on divetor valve. It was concluded that incorrect maintenance procedures lead to the overall continuous failures at the plant and recommendations were made which mainly emphasised the implementation of maintenance program.

Keywords
Fly ash, idlers, pareto chart and program**.**

1. Introduction
1.1. Background
The quest for Fourth Industrial Revolution (4IR) strives for digitalization, machine learning and improvements within existing operations for smart factory design through automation and less human intervention. Critical machine failure within a manufacturing line results with unpredicted downtimes which ultimately which lead to high operational costs and lose in profits within the facility. The unexpected failure of equipment halts the whole production line and it is not cost effective to bring the system of production running while under conditions of emergency conditions which further results with lose in customer' trust (Kotwal et al. 2015; Zasadzień 2013). Maintenance activity within the manufacturing facility has a potential of costing between 15% and 40% of total production cost (Mobley 2002), while it is necessary to implement maintenance strategies for conservation of quality and share of market with product in a production line (Nwadinobi & Ezeaku 2018). Equipment failures follow laws of nature accurately , for instance, if it is loaded above its tensile strength, it breakdown while in the process of reaching the high pressure it does not break. Efficient maintenance of equipment to ensure its available to production lines is an ever-challenging requirement due to continued ever-changing pressure due to time and financial savings needed by a manufacturing facility. The volume of production might change due to seasonal requirements of manufactured products which apply much load on equipment which later increases frequency of equipment failure when operated outside the required conditions (Zasadzień 2013). Figure 1, illustrates the theoretical function of failure intensity λ(t) of equipment.

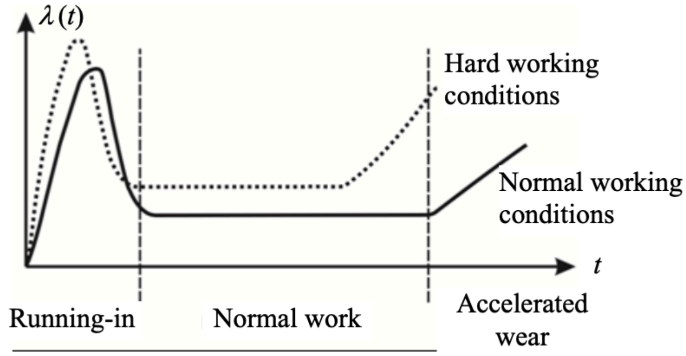

Figure 1. Failure intensity versus working conditions

Source: Zasadzień (2013)

Maintenance that is efficient for ensuring availability of machines and equipment taking part in the production process is not an easy task. This process is complex due to an increase in time pressure and savings in finance required (Zasadzień 2013).

In manufacturing lines, most failures occur on machines as a result of machine undergoing its life cycle due to its use. The failures can occur due to (i) design mistake which is classified as early failure period (ii) operational mistake which is categorised as accidental failure and (iii) end of life due to abrasion failure period. Furthermore, the causes of breakdown can be as a result of motion stress, environmental stress and other reasons such as production errors, repair errors and operation errors (Sulaiman and Ismail 2013). Figure 2 describes the three causes of breakdown.

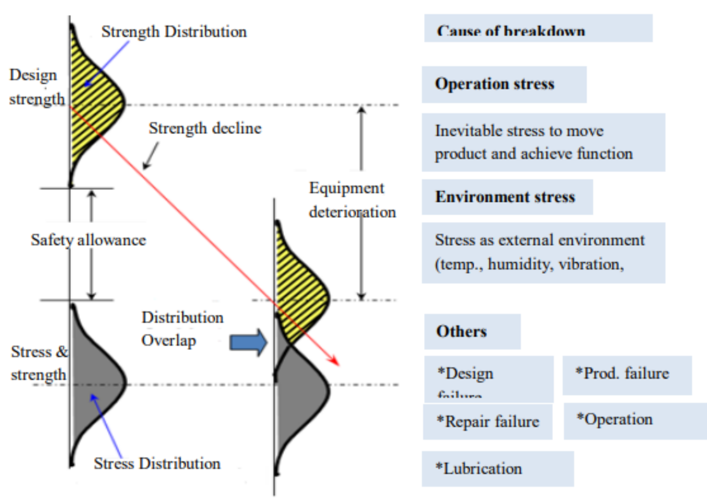

Figure 2. Causes of breakdown on design strength versus stress.

Source: Sulaiman and Ismail (2013)

The breakdown of equipment contributes to cost of production and affects the overall equipment efficiency significantly in production lines that are automated due to downtime unplanned (Oke et al. 2020). This problem takes place through failure in machine along the lines of manufacturing and cause to loss in time of production thus reducing plant productivity (Ab-Samat et al. 2012). Thus equipment in manufacturing lines are always under constant pressure either when being operated or left unattended. Consistent maintenance check and physical strength enhancement assist in ensuring availability of equipment in order to avoid breakdown. When a component fails, it shows that it have completely or partial become ineffective or it has been deteriorated to an extend that is no longer reliable or safe for normal service (Sulaiman and Ismail 2013). Analysis of engineering components' failures are of outmost importance as they aid with the establishment of causes of failures and provides key information for the identification of key areas of that requires improvement in design, operating procedures and utilization of components. Failure analysis might often be complex and frustrating, however, understanding the approach to be deployed and how to interpret the observations thereof provides baselines for the assurance of outcomes which are meaningful (Joule 2002). Thus, failure analysis is a methodology within engineering discipline which determines how and why an equipment or a component has failed in order to identify the root cause to it to avoid reoccurrence of similar failures in future. In addition, it is often necessary to confirm the mode of failure as it is important for determination of factors for explanation of how and why of the event failure. The recognition of root cause of occurrence of failure, how, and why can be assist in clarifying the reason for failure (Sulaiman and Ismail 2013).

A production system's downtime and reliability can be investigated through use of pareto chart, Weibull, and reliability/failure time analysis. The pareto chart further analysis the factors that contributes to approximately eighty per-cent downtime (Oke et al. 2021), while Weibull are models used for description of various observed failures of systems and phenomena (Raju et al. 2018).

The Why-Why analysis entails a build up of why questions that leads to a chain of causes that leads to root cause. The first why entails the direct cause with the logical end leading to the root cause. Using 5Why approach provides method to corrective action and can result with the basis of a broad-based continuous improvement and preventative action plan (Sulaiman & Ismail 2013). Root cause analysis (RCA) is method used to understand the actual reasons behind the any effect that is undesirable in order to address the actual problem from grass root level (Deka and Nath 2015). The methods associated with RCA include cause and effect diagram (Fishbone Diagram), pareto analysis, 5Whys, brainstorming, Failure Mode Effect Analysis (FMEA), and Six Sigma (Susendi et al. 2021)

RCA helps to solve the problems through attempting to identify and correct the root cause of events (Doggett 2004; Jabrouni et al. 2011). RCA entails four steps, namely: data collection, cause charting, root cause identification and recommendation (Kiran et al. 2013). The cause-and-effect diagram is one of the useful tools of quality, which is used to identify potential factors causing an overall effect (Jayswal et al. 2011) and can be used to identify the root cause of breakdowns (Kiran et al. 2013). Also known as Fishbone diagram, it is a graphical technique which is a good tool for finding and significantly analysing the factors affecting work quality output (San et al. 2003) and can assist in arriving at the root cause of either positive or negative symptoms meanwhile combining them with 5 why analysis thereby arriving at the possible solution (Sakdiyah et al. 2022). The cause and effect diagram consist of stages associated with identification of cause by using 4M and 1E categories such as Man associated with user, methods that relates to procedures or systems that are being used, machine which is the equipment being utilised, materials that are used and ultimately the environmental circumstances or conditions that may occur thereof (Liliana 2016).

Bourassa et al. (2016) researched failures and contribution of equipment to industrial incidents and accidents in the industry of manufacturing. The aim was to determine the contribution of failures on commonly used industrial equipment such as machines, tools and equipment material handling to the chain of causality of incidents and accidents. It was noted that in the manufacturing industries, the accidental events can be caused as a results of plenty factors which include methods, insufficient training, equipment design, maintenance and reliability. This was further analysed at a pulp and paper company through analysis of the company's accident database by examination of number, type and gravity of failures that entailed the events and causes thereof. It was concluded that the failures of equipment affected number and intensity of events and causes. Furthermore, it was noted that about 35% of accidental events were linked to failures of equipment , where, about 5% of the 35% accidental events were due to consequences of human.

The root cause analysis of a newsprint waste by making use of pareto chart and matrix of cause and effect has been studied by Varma and Lal (2020) for the purpose of reduction of waste and improvement of environmental conditions. The results obtained showed web breakdown amongst operations and incorrect settings of roller are the reasons for newsprint waste. The improvement that were suggested are associated with reduction of waste by 1303 kg per month which ultimately assist in reduction of waste by 60.43%. Reduction of waste further assist in improving efficiency and reduction of environmental issues. Furthermore, it was concluded that training and awareness of operations to operators with emphasis on management of waste can assist in keeping the newsprint waste at low level which ultimately help with further achievement of waste target ≤ 3.5%.

Pareto analysis and cause and effect diagram has been applied for the examination of stoppage losses in a textile case from Bangladesh by Hossen et al. (2017). The pareto analysis revealed that idling and minor stoppages and breakdown losses were associated with 89.3% of total losses due to stoppage. Cause and effect analysis also revealed that root causes for losses due to stoppages were doffing time which were high, high traveller changing time, end of yarn which was broken as a result of pile generation via the front roller , failures of power and variation in draft change pinion. Corrective actions were recommended for the purpose of reduction of time losses for productivity increase which included total productive maintenance implementation, cause and effect analysis integration which has multi criteria tools for making decisions and statistical process control implementations.

Meanwhile, Tayal et al. (2020) also investigated computation of overall equipment effectiveness in a small-scale industry with the introduction of a novel approach for detection of bottlenecks for the purpose of improvement of the overall equipment effectiveness. This helped the small medium enterprises for example, in the automotive industry to analyse performance of their operations in a way that is better. Three levels of pareto analysis which were followed by fishbone diagram for mitigation of losses were used. The study exposed that Pareto analysis uncovered the losses on a principle of 80/20 rule and the fishbone diagram assisted with exploration of the main losses and solutions were concluded at the shop floor for improvement. Thus the results thereof revealed that availability, performance, quality, overall equipment effectiveness, asset utilization and total effective equipment performance improved by per-centages of 4.6, 8.06, 6.66, 16.23, 4.16, and 14.58 respectively. These further gave an insight into indicators of losses in production, performances, and productivity in the industry of manufacturing in this case.

Based on the successful use of pareto analysis and cause-effect analysis as tools to find root cause to breakdowns in manufacturing facilities and providing recommended solutions thereof, these tools can be used to assess and find solutions to industrial equipment operational challenges in other circumstances.

1.2. Manufacturing process description

Pulverized coal fly ash from power stations operations in South Africa and worldwide has been beneficiated for use in various industries such as in construction sector. In a fly ash processing plant, raw fly ash is extracted from power station electrostatic precipitators/bagging system, pumped into a temporary storage silo, then being fed in a Separator. In the separator, the raw fly ash is separated into fine and course fly ash, where the fine fly ash needs to comply to SANS50450 for use a product and coarse fly ash is transferred to dumping sites for further handling by making use of pipe conveyor belt. Figure 3 depicts the flow diagram of the process.

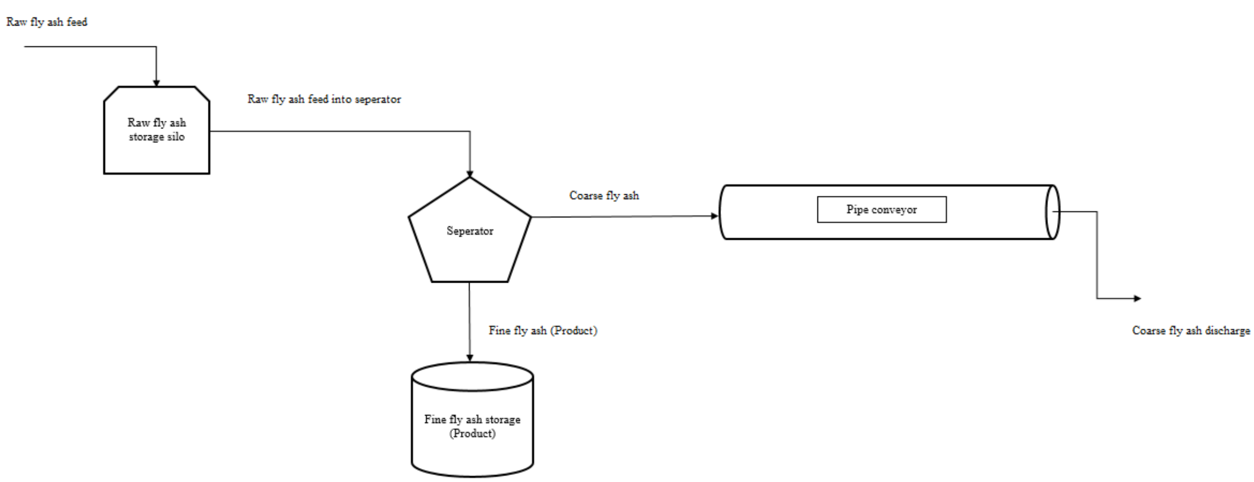

Figure 3. Coal fly ash processing description

The operation of the pipe conveyor belt is that it has 500m length, 200mm diameter and 780mm thickness. As the pipe receives the coarse fly ash from the discharge side of a separator, the pipe unfolds to receive the materials, then closes as soon as it is being fed then runs to discharge the coarse ash where it unfolds again on its discharge side. Then the cycle of the pipe conveyor continues as production take place. The pipe runs on a station that has idlers of different sizes, Figure 4 shows pipe conveyor belt on its running station.

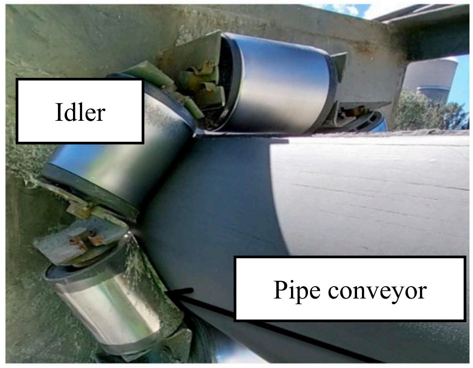

Figure 4. Pipe conveyor belt on station

1.3. Problem statement

A coal fly ash processing plant of a manufacturer has continuous downtimes on one equipment within a production line which ultimately affects product availability within South Africa's building material industry. There is no much construction and infrastructural development projects taking place in South Africa. Every manufacturer is exploring possible ways to minimize breakdowns or failures to optimize plant availabilities which assist in cost reduction. Analysis of the equipment failure is of great importance to avoid recurrence of the breakdown which results with revenue losses for the operations. The modern industries make use of high level of automation on complex equipment in order maximize the uptime and achievement of higher production rates.

1.3 Objective

The main objective of the study was to investigate, analyse and recommend solutions to the causes of equipment failures or breakdowns on a production line in a coal fly ash processing plant.

2. Methods

The manufacturing process of coal fly ash processing plant was studied in order understand raw material together with equipment usage.

Cause-effect diagrams were used to identify the factors causing an overall effect that leads to equipment failures or breakdowns. The results then lead to Root cause analysis in order to prevent recurrence. Data of failures or breakdowns were collected over a period of 31 days through physical observation and from shift logbook of the plant operations. Pareto charts were used in order to identify the split between causes that results with 80% and 20% of the failures. Figure 5 depicts the methodology that was followed.

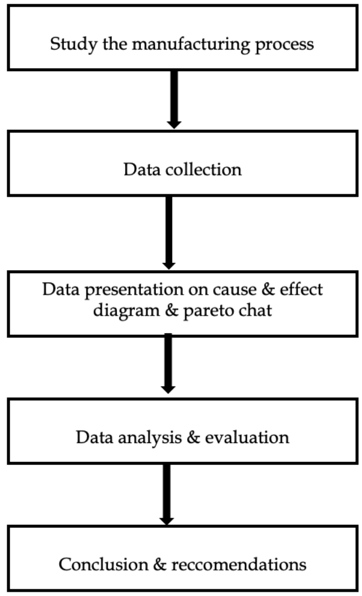

Figure 5. Methodology flow diagram

3. Results and Discussion

3.1. Root cause analysis

Table 1. Breakdown occurred and frequencies over 31 days

Breakdown occurred	Frequency
Pipe conveyor breakdown/stoppage	48
Pipeline leak	27
Unavailability of raw material	16
No enough air for raw material conveyance due to compressor	19

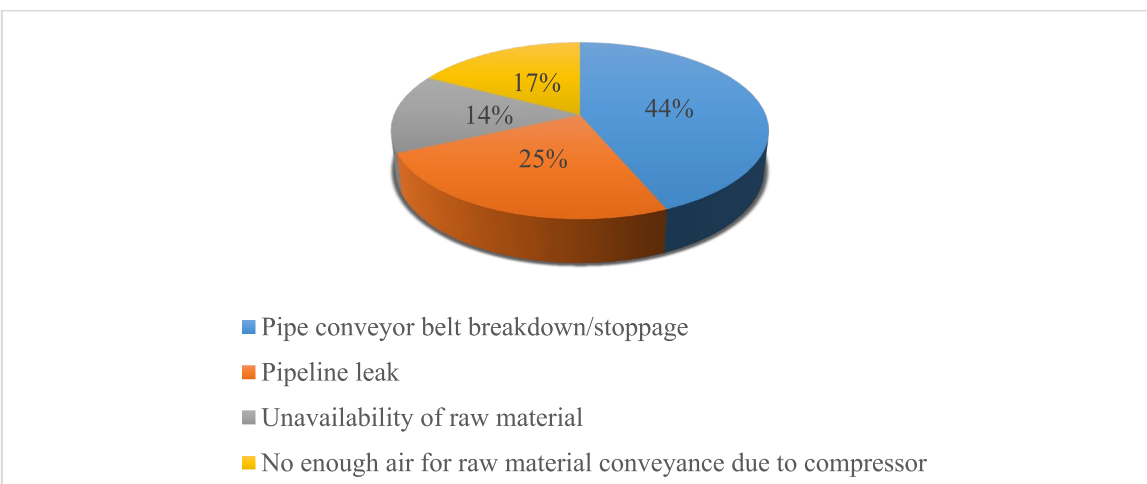

Figure 6. Breakdowns leading to production stoppages

Table 1 and Figure 6 indicated that the frequency of breakdown on pipe conveyor belt was higher than the other breakdowns encountered, followed by unavailability of raw fly ash for processing, compressor breakdown thus not supplying enough air to plant for raw fly ash conveyance into separator and leakages across the pipeline in which coal fly ash flows in (Table 2).

Table 2. Average time spent by maintenance personnel to fix the breakdown.

Breakdown occurred	Average time spent to rectify breakdown (hr)
Pipe conveyor breakdown/stoppage	192.00
Pipeline leak	28.00
Unavailability of raw material	24.00
No enough air for raw material conveyance due to compressor	15.83

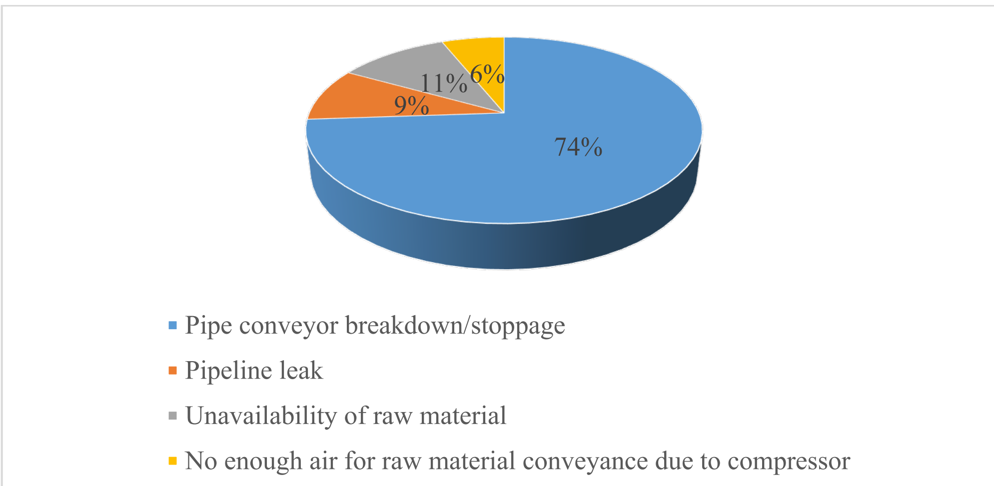

Figure 7. Percentage average time spent by maintenance personnel to fix the breakdown

Figure 7 further indicates that about 74% of breakdown time was spent on attending to breakdown due to pipe conveyor belt. The downtimes result with production losses where supply less demand thus resulting with frustrated customers.

The frequency of breakdowns and time spent to return an equipment to availability from breakdown so production resumes, it was identified that pipe conveyor belt followed by pipeline leakage was the major source of reduced production uptime and plant availability. Root cause analysis was conducted to identify the causes of pipe conveyor belt and pipeline leakages breakdown.

3.1.1. Root cause identification of pipe conveyor belt breakdown

The pipe conveyor belt is used to transport coarse fly ash post processing of raw fly ash to produce fine coal fly ash complying to SANS50450 as product. The pipe conveyor belt ran on station of 120 idlers which are made up of 5 small idlers and 1 bigger idle on top side of the station. The same idle arrangement exists on bottom side of the station. Figure 8 shows the cause-and-effect diagram for pipe conveyor breakdown and Figure 8 depicts some of the actual pipe conveyor belt causes of breakdown.

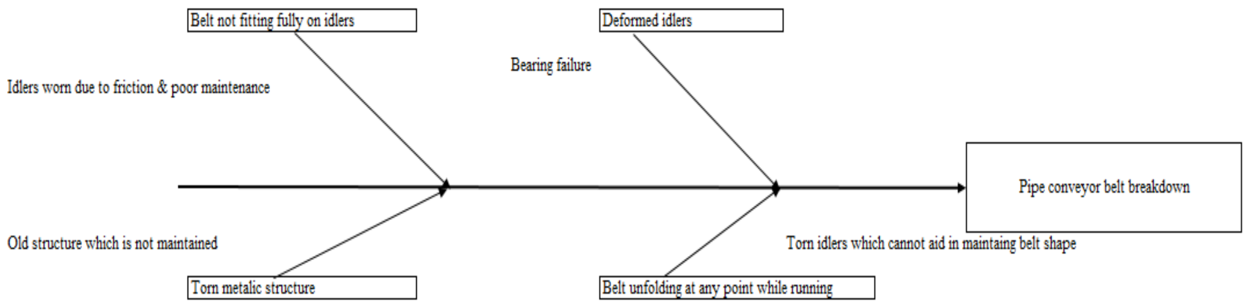

Figure 8. Cause and effect diagram of pipe conveyor breakdown

A pareto chart on Figure 9 indicated that 80% of the pipe conveyor belt failure are caused by belt not fitting fully on idlers, torn metallic structure and deformed idlers, meanwhile 20% are caused because of belt unfolding at any point while running.

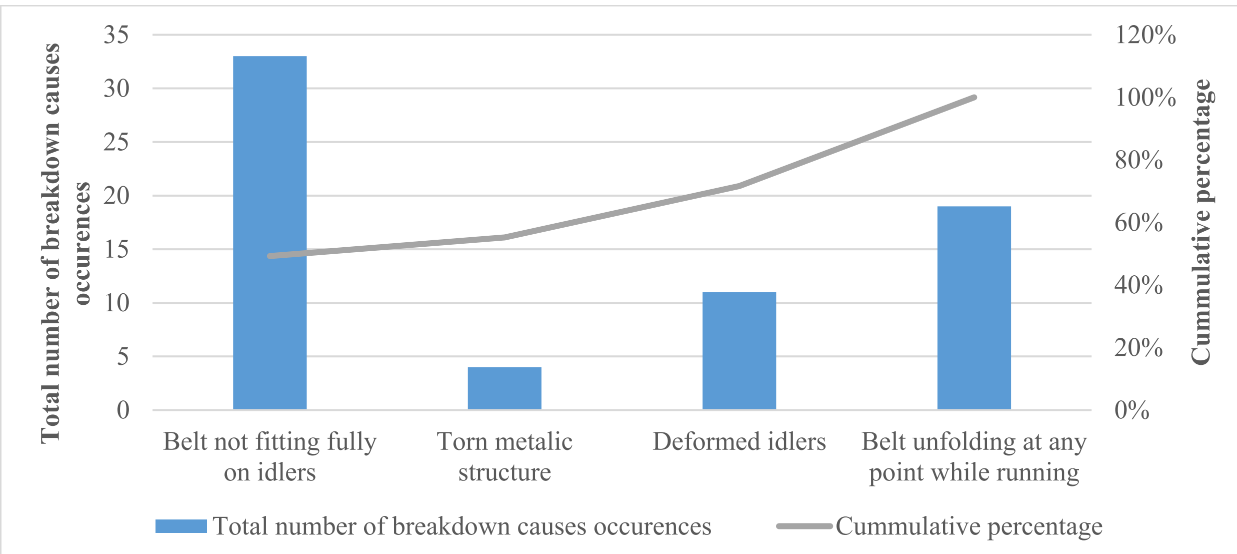

Figure 9. Pareto chart of pipe conveyor belt breakdown

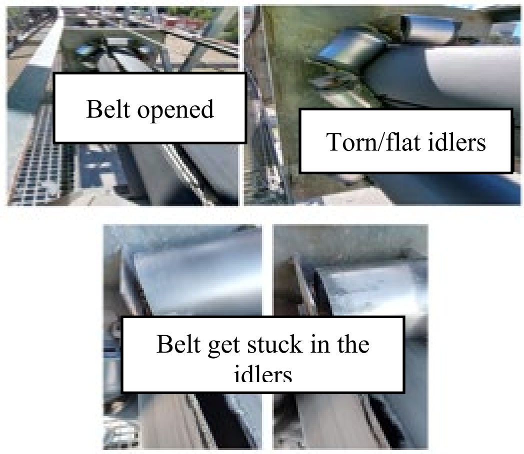

Figure 10. Pipe conveyor belt unfolded as it ran

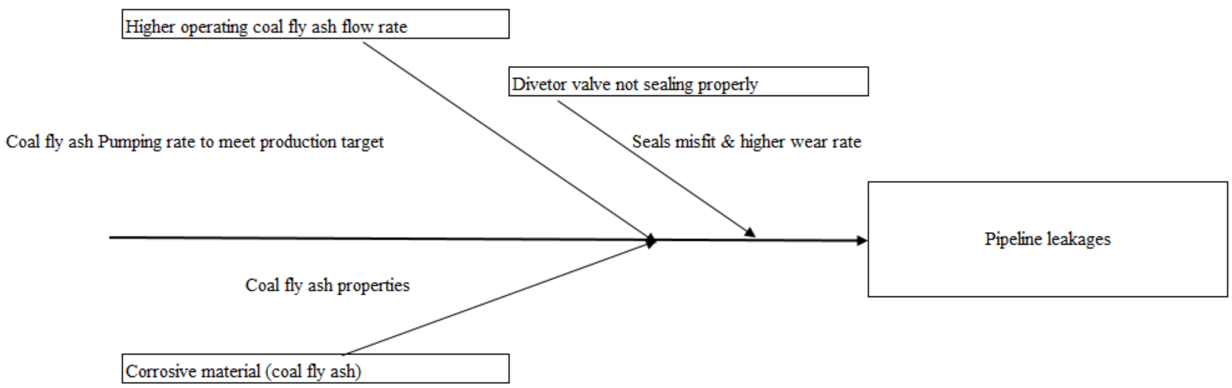

Figure 11. Causes of pipeline leakage

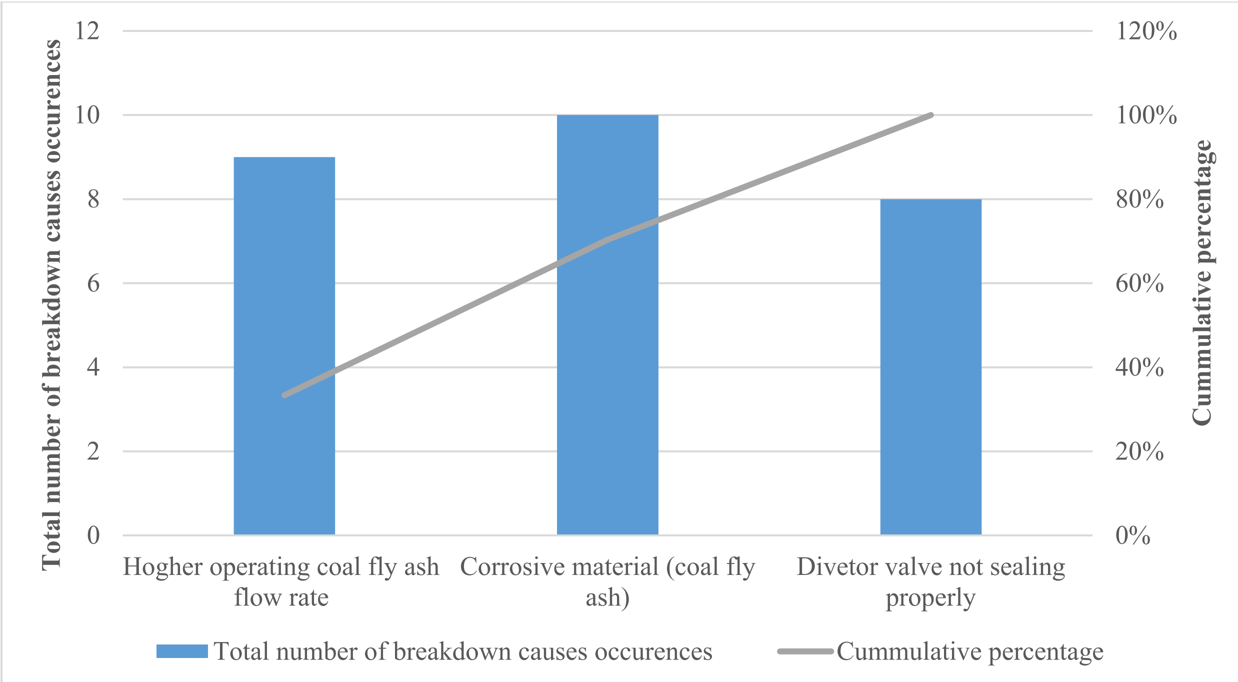

Figure 12. Pareto chart of pipeline leakages

Figure 8 showed that the cause of pipe conveyor breakdown was due to mechanical bearing failure which caused applied stress on the idlers resulting with wear and tear fast of the idlers. Also, as the belt ran on the idlers as a function of time, there was a friction created which caused reduction in thickness of the belt. Due to the infrastructure of the belt station, the torn steel based material contributed to tearing the belt which reduced its lifespan. Figure 13 indicates the belt running on a sharp edge of the infrastructure thus cutting the belt. Belt also was not fitting fully on the circular idles to maintain piping shape as its running from one end to another. Figure 10 shows structure cuts where the belt was rubbing on and other places which have resulted to edge cut resulting with reduction of belt thickness from 780mm to 700mm. The pareto chart as shown by Figure 12 indicated 80% of pipeline leakages caused by high coal fly ash operating flow rate and coal fly ash being corrosive which resulted with pipeline being torn, while 20% of the leaks were due to improper sealing on divetor valve.

Figure 13. Belt running on sharp edge structure.

The pipeline leakages were identified to be caused by higher operating flow rate of raw coal fly ash as a requirement to meet the daily production target. Coal fly ash has corrosive properties due to its chemical composition, and this results with conduct between steel and coal fly ash which causes the corrosion as a function of time as the coal fly ash is running through the pipe. These causes perforation of the pipeline, particularly at the bents of the pipe, resulting with leaks that needs to be repaired constantly which reduces production time as equipment must be stopped. Figure 14 shows the pipeline whole because of corrosion which resulted with leaks and after repair.

Figure 14. Whole on pipeline and repair

4. Conclusion

Based on the failures being identified and analysed through cause and effect diagram, pareto chart, it is clear that 80% of the pipe conveyor belt failures or breakdowns is due to operational challenges that are linked to maintenance of plant equipment in general. In the case of pipeline leakages, the failures were related to requirements of improving the productivity of equipment by operating at higher flow rates with coal fly ash being corrosive and this affecting the lifespan of the pipeline based on its material of construction which were prone to corrosion.

5. Recommendations

Inspect and replace all torn idlers on the pipe conveyor belt station in order to minimise the rate of wear and tear due of the belt. Installation of additional idlers at the back of the idler station to assist the belt to fold and keep the piping structure/shape as is running. Welding of the structure groves to minimize belt damage as its running. The counter weigh needs to be at the required design for the belt to ran properly.

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Biographies

Asser L. Tau is currently a Doctor of Philosophy (PhD) candidate in Operations Management at Department of Quality and Operations management within the Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa. He earned a Bachelor of Technology (B.Tech) Degree in Chemical Engineering; Advanced Diploma and Postgraduate Diploma in Operations Management with all these qualifications obtained from Vaal University of Technology, South Africa. He also earned a Master's Degree in Operations Management (Cum laude) from University of Johannesburg and Postgraduate Diploma in Business Administration from Wits Business School. He further obtained a Master of Engineerinng in Chemical Engineering from Tshwane University, South Africa. He has over 8 years working experience in the Building and Construction materials industry with specific experience in Research & Development, process engineering, and technical sales. He is a registered Candidate Professional Engineering Technologist (Pr Tech Eng) with Engineering Council of South Africa (ECSA). He is also a member for South African Coal Ash Association (SACAA). His research interests include continuous improvement, simulation modeling, energy power generation, industrial solids and liquid waste beneficiation, Life-Cycle Analysis, digitalization for smart factory design, wastewater treatment and process & environmental engineering.

Edoun E.I is an academic, he holds a PhD from the University of Witwatersrand in Johannesburg South Africa. He has travelled widely between different countries in Africa while interacting with academic institutions, policy makers, policy implementers and community members. He is industrious and has good conceptual and organizational skills. He has consulted and spearheaded projects at the African Union, NEPAD , the Pan African Parliament ; AFRODAD. I have been involved as an academic at various University is South Africa and abroad. He has supervised more than

20 PhD Students, 30 full master's and 100 MBAs students . He has attended many conferences, locally and abroad, and has published many articles in the International accredited Journals.

Charles Mbohwa Professor Charles Mbohwa is a Senior Research Associate at the University of Johannesburg. He was, previously the University of Zimbabwe Pro-Vice Chancellor responsible for Strategic Partnerships and Industrialisation from 1st July 2019 up to 30th June 2022. Before that he was a professor of sustainability engineering in the Faculty of Engineering and the Built Environment at the University of Johannesburg. He was a mechanical engineer in the National Railways of Zimbabwe from 1986 to 1991, and lecturer and senior lecturer at the University of Zimbabwe. He was Senior Lecturer, Associate Professor and Full Professor at the University of Johannesburg. He was Chairman and Head of Department of Mechanical Engineering at the University of Zimbabwe from 1994 to 1997; Vice-Dean of Postgraduate Studies Research and Innovation in the Faculty of Engineering and the Built Environment at the University of Johannesburg from July 2014 to June 2017 and Acting Executive Dean in the Faculty of Engineering and the Built Environment from November 2017 to July 2018. He has published very widely. He holds a BSc Honours in Mechanical Engineering from the University of Zimbabwe in 1986; Master of Science in Operations Management and Manufacturing Systems from University of Nottingham; and a Doctor of Engineering from the Tokyo Metropolitan Institute of Technology.

Anup Pradhan is an Associate Professor in the Department of Quality and Operations Management at the University of Johannesburg, South Africa. He received BSc in Agricultural Engineering from Bangladesh Agricultural University, Bangladesh, ME in Agricultural Engineering and Systems from Asian Institute of Technology, Thailand, and PhD in Biological and Agricultural Engineering from University of Idaho, USA. His research interests include life cycle assessment, renewable energy, farm mechanization, smart factory, smart grid management, applied research and optimization, organizational productivity, knowledge management. He has published several journal and conference papers. He is a NRF rated researcher in South Africa and a registered engineer with Nepal Engineering Council (NEC). He is a member of American Society of Agricultural and Biological Engineers (ASABE), Engineering Council of South Africa (ECSA), Nepal Engineer's Association (NEA), Gamma Sigma Delta, Golden Key International Honor Society.