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Modeling and evaluating mill plant production using AggFlow software: Case study in the South of Jordan

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Abstract

Purpose. This paper aims to investigate the process of modeling and simulating the mill plant operations with a specific emphasis on the use of AggFlow software. The main purpose is to highlight the importance of modern approaches in to mill plant operation, with a focus on the crucial role of simulation in improving production processes, reducing inefficiencies and optimizing resource use.

Methods. The AggFlow software is used to model current operations at a mill plant in Jordan with a specific emphasis on the limestone production in different size fractions. The accuracy of the simulation is verified by carefully comparing it with actual operational data, confirming the AggFlow effectiveness in predictive modeling to enhance mill plant performance.

Findings. This study has systematically increased the production rates of mill plant products through thorough analysis while ensuring that the supplying conditions remain consistent. The aim was to increase production efficiency while guaranteeing the marketability of the finished products. The findings provided useful insights into effective operational modifications and strategies for enhancing production rates while maintaining product quality.

Originality. This research provides novel insights by integrating actual mill plant operations with sophisticated simulation utilizing AggFlow software. The study confirms the reliability of AggFlow as a tool for predicting models and offers new insights into enhancing production efficiency in mill plant environments.

Practical implications. The research results are directly applicable to mill plant operators, providing a realistic method for improving operational efficiency through the use of AggFlow simulation. The research provides practical methods that can be implemented to optimize production rates and maintain consistent product quality in mill plant operations.

Keywords: *AggFlow, mill plant operations, quarry, production optimization, crusher*

1. Introduction

The crushing process is one of the most important mining operations, which are considered as an important step to crush the rock and facilitate the next process or other purposes such as building roads, houses and dams [1]-[4]. The crushing plant has different operations depending on its location in the quarry; there is a primary, secondary and tertiary crusher [1], [5]. In general, quarries use simulation to predict plant performance such as capacity, quality and productivity using a flow process [6]. There are many software packages used to evaluate the plant performance in steady-state simulation, such as PlantDesigner, JKSimMet, AggFlow and USIM PAC [6]-[9].

The efficiency of mill plant operation depends on several aspects, encompassing the effectiveness of machinery, the quality of raw materials, and adherence to product specifications [10], [11]. Simulation and design are crucial for optimizing these activities, as they provide numerous advantages. Simulation enables mill operators to predict and evaluate the operational outcomes of their facilities under different scenarios. It provides valuable insights into the influence of several aspects, including equipment settings, material quality and processing sequences, on overall performance. Simulation allows operators to conduct experiments to test various process configurations and parameters [6], [7], [9].

The utilization of an iterative strategy facilitates the identification of the optimal and economically viable method of achieving the target level of output and quality. Through the process of simulating and developing mill plant operations, the optimization of resource utilization can be achieved. This includes optimizing the distribution of labor, energy, and equipment to achieve maximum productivity while minimizing both waste and operating expenses. The process of designing and modeling the mill plant processes provides the means to ensure accurate and thorough control over the final output quality [10]. The implementation of this process ensures that the ultimate outcome aligns with the intended requirements, hence mitigating the potential for deviations and subsequent customer dissatisfaction. The utilization of efficient design and simulation techniques helps to identify possible bottlenecks and operational inefficiencies. By effectively tackling these concerns, operators of milling facilities can decrease instances of unscheduled operational halts and enhance the overall accessibility and reliability of the plant. Simulation and design technologies offer a platform for doing cost analysis. Mill

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operators have the opportunity to investigate solutions aimed at reducing costs, optimizing machine utilization, and minimizing material waste. These efforts can ultimately lead to improved financial performance of the operation.

The design and optimization of mill plants are essential factors in attaining efficiency, productivity, and cost-effectiveness across a variety of industries. AggFlow takes a central position in facilitating this endeavor [12]-[14]. The platform offers a comprehensive solution for the design and optimization of mill plant operations. During the design phase, engineers have the capability to generate a virtual prototype of a mill plant via AggFlow. This allows them to experiment with various layouts, equipment configurations, and process sequences before starting any tangible building activities. The software facilitates the entry of comprehensive specifications pertaining to raw materials and equipment, thus allowing for simulations pertaining to material flow, equipment interaction and physical layout. AggFlow also optimizes pre-existing mill plants, enabling engineers to detect inefficiencies, adjust equipment configurations, and improve processes to increase overall performance. This system facilitates the implementation of quality control protocols, management of material properties, and optimization of production capacity by ensuring efficient usage of equipment and making necessary process adjustments. Moreover, AggFlow plays a crucial role in conducting cost analysis, enhancing resource efficiency, and attaining financial performance objectives. Consequently, it serves as an indispensable instrument for the design and optimization of mill plants in many industries [12]-[16].

The implementation of AggFlow in mill plant operations provides numerous benefits that are crucial for improving performance and productivity. This software provides operators with the ability to efficiently design and optimize mill plants, allowing them to virtually prototype and experiment with layouts, equipment configurations, and process sequences. As a result, it helps to minimize the expenses involved in physical construction. The real-time modeling capabilities and resource allocation insights provided by AggFlow enable the optimization of material flows and equipment usage, resulting in increased efficiency, reduced downtime, improved product quality, and compliance with environmental and regulatory standards. The software's ability to facilitate long-term strategic planning and adapt to dynamic market conditions promotes sustainability and enhances competitiveness. Through the adoption of data-driven decision-making, AggFlow effectively contributes to the financial success of mill plant operations by reducing operating expenses and optimizing output capacity [13]-[17].

Jordan has long been known for its rich mineral resources, and the mining industry has played an important role in the country's economy. Phosphate, limestone, copper, and oil shale are the important minerals extracted in Jordan, and they are economically significant [18]-[21]. Due to its abundant phosphate reserves, Jordan has played a crucial role in the worldwide phosphate industry. Jordan is a significant supplier of phosphate rock, which is a crucial mineral used in the production of fertilizers [22]-[24]. The nation's phosphate reserves have significant strategic value, serving as a crucial resource for both domestic agricultural requirements and global trade. Limestone is a crucial mineral resource that is extensively mined in Jordan. The nation is renowned for its abundant reserves of superior-grade limestone, which finds extensive application in several sectors. Limestone is an essential primary material in industries such as construction, cement and lime production [18], [20]. The limestone mined in Jordan is often distinguished by its advantageous chemical composition, rendering it appropriate for many industrial purposes [20].

Recently, there have been efforts to investigate and exploit fresh mineral reserves in Jordan. The government has been promoting exploratory endeavors to discover supplementary resources and broaden the mining industry. For example, copper exploration and prospecting endeavors in Jordan encompass the identification of possible deposits, evaluation of their economic feasibility, and conducting feasibility studies [21], [25], [26]. These endeavors are commonly undertaken by both governmental entities and private enterprises with a vested interest in investing in the mining industry. Implementing copper concentration projects in Jordan has the potential to make a substantial contribution to the nation's economy. Copper, being a commodity sold worldwide, has the potential to provide higher exports and money for the country if mining activities are successful [25], [26].

This paper has contributed to the field of mill plant operations by demonstrating the practical application of AggFlow for modeling and evaluating production processes. The presented case study not only validates the accuracy of the simulation results, but also provides a framework for strategically enhancing production rates in mineral processing industries. The findings offer valuable guidance for industry professionals seeking to optimize mill plant operations to improve productivity and profitability.

2. Methods

2.1. Field survey and data collecting

A field survey was conducted at a mill plant of limestone located in southern Jordan. The mill plant is designed to produce four main products derived from different size fractions of limestone: (-6" +4", -4" +1", and -1" +0") and the rejected oversize fraction (-24" +20"). The three main products are used in road construction and sometimes in cement production. The reason for choosing this mill plant is its layout, which encompasses crushers, mills, and conveyors intricately connected to produce various size fractions to meet the software features. The data collected during the field survey provide an important benchmark for validating the AggFlow model and refining assumptions to ensure accuracy in the simulation results. The survey collected valuable information on various parameters such as feed material characteristics, equipment specifications, operational settings and production rates, providing a comprehensive foundation for building the AggFlow model. The data collected during the field survey is comprehensively presented in Table 1, which encompasses various crucial aspects such as unit operations, number of trucks, bulk and solid densities of limestone, feed fraction size, etc.

2.2. Data investigations

The mill plant produces products by hauling and dumping the material into single-deck vibrating scalper with 20" cut size. The oversize fraction is stockpiled as a waste product, which is used later if there is a failure in hauling system, while the underflow fractions goes to the primary jaw crusher.

Table 1. Mill plant survey data

Feed weight (ton)	~35 ton	
Number of trucks per hour	4 truck/hour	
Feed	Bulk density	100.0 lbs./ft^3
	Solid densities	165.32 lbs./ft^3
	Solid SG	2.65
	Maximum size fraction	24 inches
	Minimum size fraction	#4
	P_{80}	14.7 inches
Single-deck vibrating scalper	Deck cut size	20 inches
Jaw crusher	Crusher model	Universal 2436
	Manufacturer limits for maximum feed	21.6 inches
	Manufacturer limits for maximum rate	110-175 ton/hour
	Cut size setting	3 inches
Screen	Screen model	2 decks inclined screen 6×8
	1st deck cut size	4 inches
	2nd deck cut size	1 inch
Average production rate stph	Rejected oversize	~12
	-6” +4”	~18
	-4” +1”	~75
	-1”	~35

A 3” cut size universal jaw crusher was set up to crush the feed and then classify it into three main products using double-deck inclined screen.

According to the valuable insights from the mill plant operation department, and the feed size distribution is assumed to range within -24” and #4, with a P_{80} value of 14.7 inches, as clearly depicted in Figure 1.

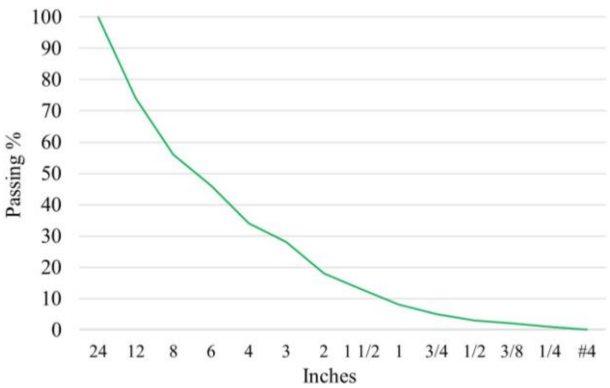

Figure 1. Limestone size distribution

In addition, several samples were collected from the screen feeds, production lines and oversized waste area to calculate the efficiency of the screen and single-deck vibrating scalper. The samples were sieved using a laboratory sieve shaker machine in the Tafila Technical University laboratories. The efficiency was then calculated based on the oversize and undersize fractions from the screen using these Equations:

$$E(o) = \frac{Q_{ms}(o)\cdot(1 - M_u(o))}{Q_{ms}(f)\cdot(1 - M_u(f))}; \tag{1}$$

$$E(u) = \frac{Q_{ms}(u)\cdot(1 - M_u(u))}{Q_{ms}(f)\cdot(1 - M_u(f))}. \tag{2}$$

Overall screen efficiency was then calculated by multiplying these two efficiencies together.

$$E = E(u)\cdot E(o), \tag{3}$$

where:

$Q_{ms}(o)$ – is the mass flow rate in the screen of oversize;
$Q_{ms}(f)$ – is the mass flow rate of feed;
$Q_{ms}(u)$ – is the mass flow rate in the screen of undersize;
$M_u(o)$ – is the mass undersize fraction in the oversize;
$M_u(f)$ – is the mass undersize fraction in the feed;
$M_u(u)$ – is the mass undersize fraction in the undersize;
$E(u)$ – is the efficiency based on the undersize;
$E(o)$ – is the efficiency based on the oversize.

The dry density of samples was determined using caliper method according to ISRM standards. The results show that the dry sample ranged from 158.5 to 168.5 lbs./ft^3. The uniaxial compressive and tensile strengths of samples were also assessed. Dry samples have an average tensile strength of 6.2 MPa and uniaxial compressive strength of 55.5 MPa.

3. Results and discussion

The current mill plant, designed using AggFlow (Fig. 2) based on surveyed field data, demonstrated more than 95% accuracy in its flowchart, as verified by comparing actual production rates (APR) with simulated production rates (SPR). Notably, main product averages, such as 37, 72, and 20 stph in APR are closely related to 35, 75 and 18 stph in SPR. Verification also involved calculating the product P_{80} and comparing it with sieve analysis samples. Table 2 shows the comparison of surveyed field data with simulated data for main mill plant products. for instance, the particle size distribution and P_{80} for -6”+4” product was 5.67” (sample) vs. 5.425” (simulated) and for -1” product, 0.787” (sample) vs. 0.786” (simulated). These results affirm the high screen efficacy of the system.

Based on the field survey, the rejected oversize product is typically torn to pieces and utilized as feed for the primary crusher in the event of a hauling failure in the quarry, as shown in Figure 2. Consequently, the created layout was used to assess the production rates under a new scenario. The scenario of changing some specifications of two main units in the mill plant to meet the production requirements, namely single-deck vibrating scalper and jaw crusher, is depicted in Figure 3.

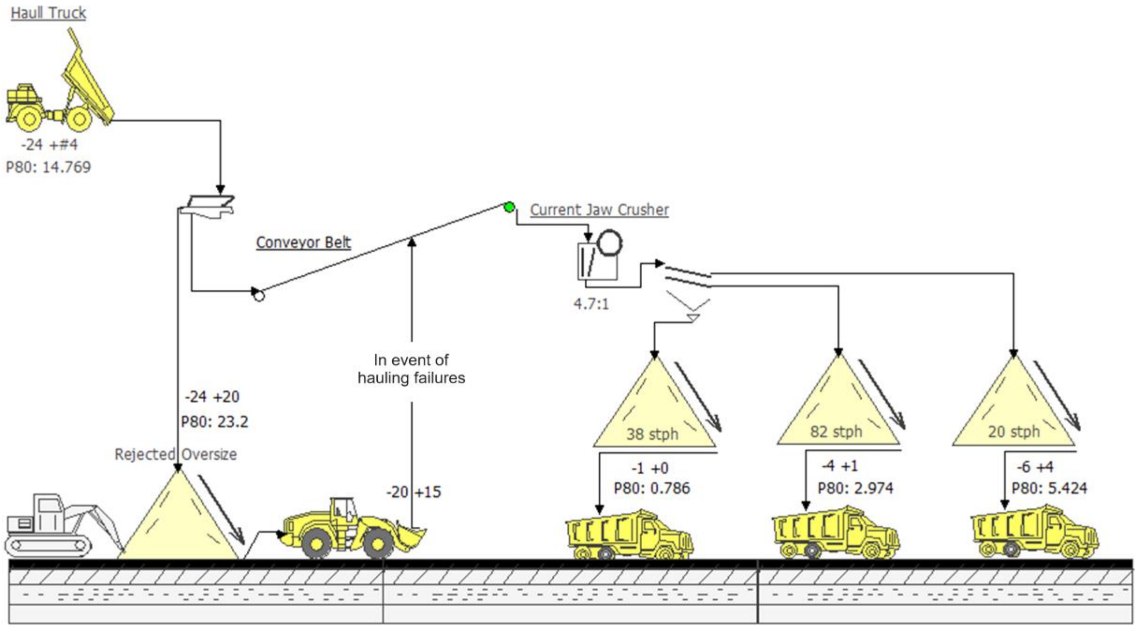

Figure 2. Current operational process design using AggFlow (current scenario)

Table 2. Comparison of field survey data with simulation data for main mill plant products

	Particle size fractions (P_{80})		Production rate (tph)	
	Surveyed field data	Simulated data	Surveyed field data	Simulated data
Product 1 (+6”-4”)	5.67”	5.424”	18	20*
Product 2 (-4”+1”)	2.824”	2.974”	75	82*
Product 3 (-1”)	0.787”	0.786”	35	38*
Rejected oversize	23.2”	23.2”	~12	~12**

*The total tph when the oversize re-crushed again
**In event of hauling failures this oversize will be fed into the crusher

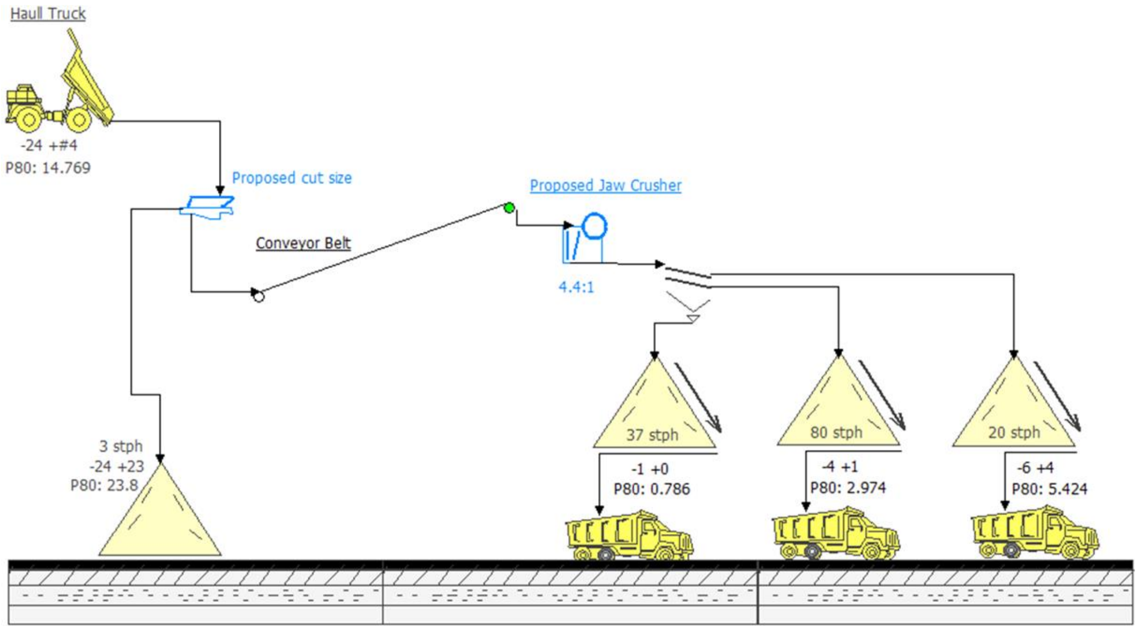

Figure 3. Layout utilization for assessing production rates – scenario of modification of specifications in the single-deck vibrating scalper and jaw crusher to meet production requirements (proposed scenario)

After numerous simulation trials, it was ascertained that the crusher’s feed size can be increased to 23.5”, with a capacity range of 155-230 tph. To enable the movement of this fraction size to the crusher, the cut size of the single-deck vibrating scalper was adjusted to 23”. As a result, undersized materials will be sent to the crusher, while oversized fractions over 23” will be sent to the rejected oversized stockpile. It is important to note that the capacity specifications of the conveyor belt will not be surpassed by undersized material. Table 3 illustrates a comparison of the current and proposed scenarios, demonstrating that modifying the operation units (crusher size and screen size) results in producing the uniform size specifications and reducing the quantity of rejected oversize material. This adjustment eliminates the need for a ripper and loader.

Table 3. Comparative analysis of current and proposed scenarios using AggFlow

	Particle size fractions (P_{80})		Production rate (tph)	
	Current scenario	Proposed scenario	Current scenario	Proposed scenario
Product 1 (+6”-4”)	5.67”	5.424”	20	20
Product 2 (-4”+1”)	2.824”	2.974”	82	80
Product 3 (-1”)	0.787”	0.786”	38	37
Rejected oversize	23.2”	23.2”	12	3

Future research will further investigate the operational aspects of the mill plant, with a specific emphasis on identifying areas that can be optimized and improved. The main objective is to perform comprehensive evaluations of process efficiency, equipment performance and product quality in order to identify potential areas for improvement. In addition, researchers are striving to investigate sophisticated modeling techniques and cutting-edge technologies in order to improve simulation models and more accurately predict plant behavior. This research is crucial as it allows for the formulation of tactics to increase productivity, reduce expenses, and mitigate environmental impacts in the mill plant and other similar industrial environments. Ultimately, these advances play a role in promoting sustainable and efficient operations in the mining and processing industry.

Verification of the AggFlow model accuracy was a paramount aspect of this case study. Numerous verification methods were employed, including a rigorous comparison of simulated production rates (SPR) with actual production rates (APR). Remarkably, the AggFlow model achieved over 95% accuracy in reflecting the real-world production rates of the main products, thus confirming the reliability and robustness of the simulation, which has already been assessed accurately by other researchers [5], [14], [15], [17]. Furthermore, particle size distribution analysis and comparison of P_{80} values validated the model accuracy in determining key performance metrics, particularly screen efficacy.

4. Conclusions

In conclusion, this project embarked on a comprehensive endeavor to model and evaluate the production process of a limestone mill plant using the powerful AggFlow simulation tool. Through careful field survey and data collection, crucial insights were gained on feed material characteristics, equipment specifications, operational settings, and production rates. These data formed the cornerstone for the development of an accurate and representative AggFlow model, which successfully simulated the existing mill plant operation process.

Building upon this foundation, the case study delved into scenario analysis to explore process optimization opportunities. The ingenious repurposing of rejected oversize material as feed for the primary crusher in the event of hauling failures has demonstrated a sustainable and resource-efficient approach. By adjusting specifications of pivotal units within the mill plant, specifically the single-deck vibrating scalper and jaw crusher, the case study unveiled a new operational scenario. Through extensive simulation trials, it was determined that an increased crusher feed size of 23.5” and an adjusted capacity range could be achieved, bolstered by a harmonious adjustment of the scalper cut size to 23”.

Ultimately, this case study has significant implications for the quarry operations. The thorough modeling, validation, and scenario analysis conducted herein have unveiled pathways to enhance both operational efficiency and resource utilization. By harnessing the power of AggFlow, the mill plant can confidently explore and implement changes that align with real-world performance, thereby optimizing production processes and maximizing the utilization of available resources. As a result, the case study outcomes stand to bolster the quarry productivity, reduce waste, and contribute to a more sustainable and efficient operation in general.

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Conflicts of interests

The author declares no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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Моделювання та оцінка виробничого процесу дробарної установки із використанням програми AggFlow: тематичне дослідження на півдні Йорданії

А. Альсафасфех

Мета. Дослідження процесу моделювання та симуляції виробничого процесу дробарної установки з особливим акцентом на використанні програми AggFlow для вдосконалення виробничих процесів, підвищенні ефективності та оптимізації використання ресурсів.

Методика. Програмне забезпечення AggFlow використовується для моделювання поточних операцій на дробарній установці в Йорданії з особливим упором на виробництво вапняку різних фракцій. Точність моделювання перевіряється шляхом ретельного порівняння його з фактичними експлуатаційними даними, що підтверджує ефективність AggFlow у прогнозному моделюванні для підвищення продуктивності роботи дробарної установки.

Результати. Продемонстровано стійкий та ресурсозберігаючий підхід на основі винахідливого перепрофілювання відбракованого негабаритного матеріалу як сировини для первинної дробарки у разі збоїв при транспортуванні. Розкрито новий сценарій експлуатації шляхом коригування характеристик основних агрегатів млина, зокрема, однодекового вібраційного скальпера та щокової дробарки. Встановлено на основі комплексу симуляційних випробувань, що можна досягти збільшення розміру завантаження дробарки до 23.5 дюймів та скоригованого діапазону продуктивності, яка підкріплюється гармонійним регулюванням розміру скальпера до 23 дюймів.

Наукова новизна. Отримано нові знання завдяки інтеграції реальних операцій дробарної установки і складного моделювання із використанням програмного забезпечення AggFlow. Дослідження підтверджує надійність AggFlow як інструменту для прогнозування моделей та пропонує нове розуміння підвищення ефективності виробництва в умовах застосування дробарної установки.

Практична значимість. Результати дослідження безпосередньо застосовуються операторами дробарних установок, надаючи реалістичний метод підвищення ефективності роботи за рахунок використання моделювання AggFlow. Дослідження пропонує практичні методи, які можна застосувати для оптимізації темпів виробництва та підтримки стабільної якості продукції, виготовленої на дробарній установці.

Ключові слова: *програмне забезпечення AggFlow, робота дробарної установки, кар'єр, оптимізація виробництва, дробарка*

Publisher's note