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Exploring Waste Heat Recovery: A Case Study of a Batch Centrifugal Machine

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Abstract
Recovering waste heat is crucial for improving energy efficiency in industrial processes. As the demand for sustainable and eco-friendly solutions grows, industries are seeking various methods to reclaim and reuse the heat generated during their operations. The primary objective of this study is to explore the potential for waste heat recovery in batch centrifugal machines by analyzing their current energy consumption and waste heat generation, investigating the feasibility and efficiency of various recovery methods, assessing the potential energy savings and environmental benefits of implementing these systems, and providing practical recommendations for industries to optimize their energy use, thereby demonstrating the significant role of waste heat recovery in enhancing the overall energy efficiency and sustainability of industrial operations. Through an analysis of empirical data collected from the operation of batch centrifugal machines, this study quantifies the magnitude of waste heat generation across different operating conditions. By examining power and current values obtained from the tables, the study identifies opportunities for energy recovery and optimization. Leveraging innovative techniques, the research demonstrates how proactive waste heat management can enhance energy efficiency and sustainability in industrial operations. The findings underscore the importance of integrated approaches to waste heat management, emphasizing its role in reducing environmental impact and improving overall operational performance.

Keywords: Waste energy recovery, Batch centrifugal machine, Energy efficiency, Environmental impact, Industrial practices, Power and current values.

1.Introduction

Waste heat recovery is an essential aspect of enhancing energy efficiency in industrial processes. With the increasing demand for sustainable and eco-friendly solutions, industries are exploring various methods to reclaim and reuse waste heat generated during operations. This study focuses on the potential of waste heat recovery in batch centrifugal machines, which are widely used in various manufacturing sectors for processes such as drying, separation, and crystallization. By analyzing the efficiency and feasibility of capturing waste heat from these machines, this research aims to contribute to the development of more energy-efficient and environmentally friendly industrial practices.

The global imperative for sustainability and resource conservation has sparked heightened the waste energy recovery, specifically examining a case study involving a batch centrifugal machine. The introduction sets the stage for understanding the realms [1-3]. This study focuses on waste energy across various sectors, especially within industrial scope, importance, and significance of interest in energy efficiency and waste reduction research project. The 21st century has underscored the necessity for sustainable practices across industries [4-5]. While energy fuels modern manufacturing and economic growth, inefficiencies in energy usage result in waste, higher operational costs, and adverse environmental impacts [6-7].

The industrial sector, a significant energy consumer, faces particular scrutiny due to its reliance on complex machinery, notably in sectors like food processing, chemicals, and sugar production [8-9]. Waste energy, often referred to as surplus or unused energy; represent a significant untapped resource across various sectors [10]. In the context of industrial processes, waste energy is generated when energy inputs exceed the requirements of a particular task. The potential for waste energy recovery lies in capturing this surplus energy and re-purposing it for other applications, thus enhancing overall energy efficiency [11].

Waste energy recovery offers a solution by identifying opportunities to reclaim and repurpose otherwise lost energy [12-14]. One of the key strategies for waste energy recovery in industrial settings is the utilization of waste heat recovery

Figure 1 Battery of centrifugal Machine

technologies [13]. These technologies are designed to capture heat energy produced as a byproduct of various processes and convert it into usable energy forms, such as electricity or steam. Common waste heat recovery technologies include Organic Rankine Cycle (ORC) systems, thermoelectric generators, and heat exchangers [13, 15].

Batch centrifugal machine refers to a type of equipment used for separating materials or fluids based on density or particle size by rotating them in a cylindrical container [16].These machines are commonly used in various industries such as pharmaceuticals, food processing, and chemical manufacturing. The waste heat generated by a batch centrifugal machine can be managed efficiently, possibly through innovative techniques or practices, using a real-world case study as a basis for discussion and analysis [17]. Batch centrifugal machines are pivotal in various industries, facilitating the separation and processing of solid-liquid mixtures, as seen in sugar processing and pharmaceuticals [12, 18-19]. These machines operate by swiftly rotating materials within a drum, segregating denser substances towards the drum's periphery while retaining lighter components at the center [2, 16, 20]

The operation of batch centrifugal machines requires a substantial amount of energy, primarily in the form of electricity. The energy consumption of these machines is influenced by several factors, including the rotational speed, the duration of operation, and the physical properties of the materials being processed [21]. The mechanical components of the machine, such as the motor and bearings, also contribute to energy usage. Energy consumption in batch centrifugal machines can be categorized into two main components: energy used in maintaining the rotational speed and energy expended in the separation process. It is essential to distinguish between these components as they represent different opportunities for waste energy recovery [22]. Several studies have explored waste energy recovery in manufacturing and industrial processes. Researches has shown that industrial settings are particularly amenable to the implementation of waste energy recovery strategies due to the large quantities of energy involved in their operations [11, 23]. These studies focused on diverse industries, including steel manufacturing, chemicals, and cement production, highlighting the potential for cost savings and environmental benefits.

Waste energy recovery promises immediate economic benefits by enhancing manufacturing cost-effectiveness through reduced energy consumption and operational expenses [23-25]. Beyond economic advantages, waste energy recovery aligns with environmental sustainability goals by curbing carbon emissions and promoting cleaner industrial practices [26-27]. The pursuit of waste energy recovery stimulates technological innovation, fostering the development and adoption of energy-efficient technologies within industrial settings [28-30].

This present study aims at addressing energy consumption challenges associated with batch centrifugal machines through two primary objectives: The study seeks to quantify the energy consumption patterns of batch centrifugal machines, providing insights into their energy demands during operation. Additionally, the research aims at pinpoint areas of energy inefficiency inherent in batch centrifugal machine processes, including excess energy utilization and instances of energy .

2.Methodology

2.1 Research Approach

The objective of this study is to address the issue of energy inefficiency in batch centrifugal machines by exploring the potential for waste heat recovery. This study adopts a mixed-methods research approach, integrating both quantitative and qualitative methodologies. This combination allows for a comprehensive evaluation of energy consumption patterns and a thorough exploration of factors contributing to energy wastage in the batch centrifugal machine under investigation.

2.2 Data Collection

To assess energy consumption, primary data collection involves the installation of energy meters on the batch centrifugal machine. These meters capture real-time data on energy consumption, including voltage, current, and power usage during machine operation. Data was collected over an extended period to account for variations in energy consumption due to operational factors such as batch size and processing speed.

2.3 Data Collection Methodology

The comprehensive data collection methodology spanned six months to ensure a representative sample of machine operation. Continuous data collection captured variations in operational parameters, energy consumption, and waste heat generation. Meticulous instrumentation involved strategic placement of temperature sensors and installation of sophisticated energy meters and data loggers. Preliminary screening identified anomalies before statistical analysis identified trends, patterns, and correlations in the datasets.

Capacity of the electric motor used is a 3-phase electric motor. It is a variable speed electric motor with a capacity of 185kw.

The power of the rotating speed while on operation is calculated as follows:

$$P = IV\cos\Theta\sqrt{3} \tag{1}$$

Where,

P = power of the rotating speed

I = current (amperes)

V = Voltage (volts)

Cos Θ = Power factor (0.85)

The voltage while on operation is constant, with a value of 415volts.

To calculate for the current:

$$I = \frac{P}{V\sqrt{3}\cos\Theta} \tag{2}$$

During the centrifugal machine's operation, it undergoes four distinct speed stages: Low speed, medium speed, maximum spin speed and very low speed.

Initially, the centrifuge accelerates to a low speed, where the butterfly feed control valve and a flap valve open, enabling product flow down a feeding chute onto a flinger disc connected to the spindle. This action propels the product onto the inner wall of the basket, where it forms a uniform layer under centrifugal force. Liquor begins to flow out through the filtering screens and basket perforations, collected in the outer casing and discharged via pipe work beneath the machine. The Product thickness inside the basket increases until the feed detector triggers, and prompting the closure of the feed control valve. Water is sprayed inside the feed chute, followed by closure of the flap valve to prevent residual dark product from dripping onto the contents of the basket. The feeding rate depends on the degree to which the feed valve opens, which can be controlled manually or automatically.

After completing feeding, the centrifuge accelerates to a medium speed hold point, awaiting operator or sequence permission to proceed. Subsequently, it accelerates to its maximum spin speed. During this phase, liquor continues to purge from the product cake, and water and steam may be applied to remove any remaining mother liquor from the crystals. Runoff liquor purity increases, and a classification valve system may direct this liquor down a separate discharge pipe. The centrifuge pauses at spin speed for a preset time to achieve the desired level of crystal cake drying.

Upon completing spinning, the centrifuge decelerates to a very low speed. A discharge valve plate beneath the basket opens, and a plough blade cuts into the cake's top, slowly moving down the basket screens to discharge dried crystals through the basket bottom and down a chute onto a conveyor beneath the casing. The plough blade returns to its original position, the discharge valve closes, and the machine accelerates to feed speed to commence another cycle. During acceleration, the filtering screens may be sprayed with a small amount of water to prevent crystal clogging.

2.4 Data Analysis

Quantitative data collected through energy meters undergo analysis using SPSS version 21 and Microsoft Excel. Descriptive statistics was used to summarize energy consumption patterns, including mean usage, peak usage, and temporal variations, providing a quantitative overview of energy consumption characteristics.

The waste heat recovery discusses strategies and methods for effectively managing waste heat
generated by a batch centrifugal machine. This indicates the focus of the study on finding ways to optimize the handling of waste heat. This involves techniques to reduce heat loss, improve energy efficiency, or repurpose waste heat for other useful purposes.

The data collected were analysed statistically. The data were gotten in the operation of one cycle. The normal spinning time for one cycle is between 25-40 seconds.

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3.Result and Discussion

Table 1 presents a comparison of power consumption relative to current across different speed settings of the centrifugal machine. The table offers valuable insights into the relationship between power consumption and current across different speed settings of the centrifugal machine, which can inform decisions regarding energy efficiency, optimization, and operational performance of the equipment.

Table 1 shows the consistency and variation: across different speed settings, there's noticeable consistency in power-to-current ratios. For example, at the maximum spin speed setting, the power-to-current ratio remains constant at 185/300 across all entries. By comparing ratios within each column, fluctuations or trends was observed in power consumption relative to current at different speed settings. For instance, there might be variations in efficiency or energy consumption efficiency between different speed settings. This energy consumption represents a significant portion of the operational costs for sugar mills [21].

Table 1 reveals lower power-to-current ratios may suggest higher efficiency, indicating that the machine is utilizing less power for a given current, which could be desirable from an energy-saving perspective. The study further shows that there is repeatability or consistency in power consumption for similar current inputs such as 42/80" and 45/80 in the low-speed. High energy consumption contributes to increased carbon emissions, underscoring the need for more sustainable practices [31]. Waste energy recovery in batch centrifugal machines aligns with sustainability goals by reducing the environmental footprint of sugar processing [23].

Table 2 provides a detailed comparison of different modes of rotation based on the time taken for specific operations at various speeds, offering insights into the efficiency and suitability of each mode for different tasks.

Table 1. Reading of the Power required for the rotational speed of the centrifugal machine during separation operation.

S/N	Low Speed		Medium Speed		Maximum Spin Speed		Very Low Slow	
	Power	current	Power	current	Power	current	Power/	current
1	40	80	90	150	185	300	40	60
2	42	80	87	160	185	300	43	/65
3	45	80	88	150	185	300	45	68
4	50	78	85	150	185	300	45	65
5	45	80	87	150	185	300	50	70
6	42	80	87	160	185	300	43	65
7	42	80	87	160	185	300	43	65
8	40	80	90	150	185	300	40	60
9	45	80	87	150	185	300	50	70
10	50	78	85	150	185	300	45	65

Table 2 Reading of the rotational speed of the centrifugal machine during separation operation.

S/N	Low Speed		Medium Speed		Maximum spin Speed		Very Low Speed	
	Speed	Time	Speed	Time	Speed	Time	Speed	Time
1	450	27.9	450	10.0	1000	40.0	450	24.3
2	450	28.2	450	8.0	1000	40.0	450	24.3
3	450	28.1	450	7.98	1000	39.5	450	23.9
4	450	29.0	450	7.90	1000	39.8	450	23.4
5	450	28.0	450	8.0	1000	40.0	450	24.3
6	450	29.1	450	7.98	1000	39.7	450	23.4
7	450	29.0	450	7.92	1000	40.0	450	24.2
8	450	28.1	450	7.97	1000	40.0	450	24.0
9	450	28.3	450	9.90	1000	40.0	450	24.3
10	450	27.9	450	10.0	1000	40.0	450	24.3

Table 3. Calculation of the average energy (ten cycles) used in maintaining the rotational speed of a Centrifugal machine during separation operation.

S/N	Mode of rotation	Power (KW)	Speed (RPM)	Current (AMP)	Time (sec)	Voltage (Volt)
1	Low Speed	44.1	450	79.8	25.57	415
2	Medium Speed	87.3	450	152	8.51	415
3	Maximum Spin Speed	185	1000	3000	39.9	415
4	Very Low Speed	44.4	450	65.6	23.94	415

The study shows the consistency in speed/time ratios across different trials for each mode of rotation, relatively consistent speed/time ratios was observed. For instance, in the low speed mode, the speed varies around 450 RPM, and the time taken ranges from approximately 27.9 to 29.1 seconds.

The comparison across modes was that low speed operation was consistently taken around 28 seconds and medium speed operation is faster, consistently taking around 8 seconds. Maximum spin speed was consistently takes 40 seconds, indicating a longer but consistent duration, while very low speed shows similar with consistent operation takes around 24 seconds.

The study observed that maximum spin speed mode consistently takes the longest time, indicating that it might be optimized for thorough or heavy-duty operations while the medium speed mode consistently takes the shortest time, possibly indicating a mode optimized for faster but less thorough operations. The low speed and very low speed modes have similar time duration, but very low speed might indicate an even slower setting suitable for delicate operations. The speed remains relatively consistent within each mode across different trials, indicating stable performance within each setting.

Table 3 provides a comparison of different modes of rotation based on power consumption, speed, current draw, duration, and operating voltage. The maximum spin speed mode was designed for heavy-duty operations, consuming the most power and drawing the highest current, while the medium speed mode is more energy-efficient but operates for shorter duration.

From the table 3, the machine is changing phase from slow speed to medium speed; it is observed that all the parameters from power to time are accelerating. The maximum spin speed mode consumes the highest power at 185kw, followed by medium speed" at 87.3kw. Low speed and very low speed modes consume relatively lower power. Similarly, maximum spin speed naturally has the highest RPM at 1000, while the other modes maintain a consistent 450 RPM while the maximum spin speed again stands out with the highest current draw at 3000 AMPs. Medium speed has the second-highest current draw at 152AMPs.

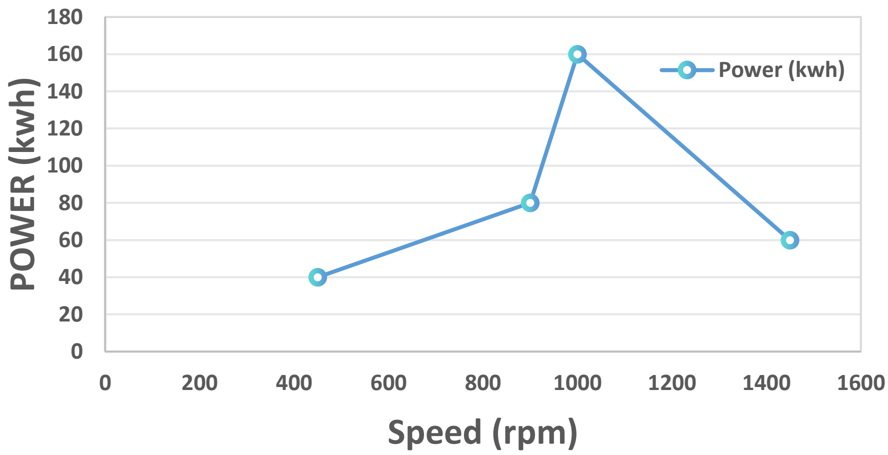

Figure 2. A graph of power against Speed

The medium speed has the shortest duration of operation at 8.51 seconds, while "Maximum Spin Speed" has the longest at 39.9 seconds and all the modes operate at the same voltage of 415 Volts. Waste energy recovery in batch centrifugal machines can be applied to similar machinery in different sectors, enhancing the broader understanding of energy-efficient manufacturing practices [32].

The figure 2 illustrates the energy consumption trends of the batch centrifugal machine across multiple operational runs. The x-axis denotes speed (rpm), while the y-axis represents energy consumption (kWh). Each line corresponds to a distinct operational run (labeled 1to 4). The graph reveals a noticeable upward trajectory in energy consumption with increasing operational speed and duration. Particularly noteworthy is Run 3, characterized by the longest duration and highest speed, which exhibits the highest energy consumption. This preliminary visual representation serves as a reference for comprehending the variations in energy consumption during different operational runs. Analysis of the collected data unveiled distinct energy consumption patterns for each run, mirroring the observed upward trend in energy consumption over time. Longer operational duration correspond to higher energy consumption, reaffirming the intuitive correlation between operational duration and energy usage.

4. Conclusion

This study has shed light on the substantial potential for waste heat recovery in batch Through centrifugal machines within industrial processes. comprehensive analysis, we have identified the significant energy consumption and waste heat generation associated with these machines, highlighting the urgency for implementing effective recovery strategies.

Our investigation into various waste heat recovery methods has demonstrated their feasibility and efficiency, providing valuable insights into practical approaches for reclaiming and reusing heat energy. Moreover, the assessment of potential energy savings and environmental benefits has underscored the importance of integrating waste heat recovery systems into batch centrifugal processes. By providing practical recommendations for industries to optimize their energy use through waste heat recovery, this study offers tangible solutions for enhancing both energy efficiency and sustainability. It is evident that the implementation of waste heat recovery technologies holds immense promise in mitigating energy wastage and reducing environmental impact. The findings of this study emphasize the crucial role of waste heat recovery in driving towards a more sustainable future for industrial operations involving batch centrifugal machines.

Based on the findings of this study, the following recommendations are proposed to optimize energy efficiency and promote sustainability in industrial processes involving batch centrifugal machines: prioritize the installation of waste heat recovery systems such as heat exchangers and thermal storage systems; invest in energy-efficient equipment with built-in waste heat recovery mechanisms; optimize operating parameters like temperature, pressure, and cycle times; provide training programs to raise awareness among operators and maintenance staff about waste heat recovery and energy conservation; collaborate with energy management consultants, researchers, and technology providers to explore innovative establish monitoring systems to track energy consumption, waste heat recovery rates, and process efficiency; and engage in industry partnerships and collaborative research projects to share knowledge and best practices. By implementing these recommendations, industries can maximize the potential of waste heat recovery in batch centrifugal processes, contributing to enhanced energy efficiency, cost savings, and environmental stewardship.

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