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IDENTIFYING THE INFLUENCE OF INLET VELOCITY CHANGES TO PRESSURE DROP AND COLLECTING EFFICIENCY IN STAIRMAND AND LAPPLE TYPE CYCLONE SEPARATORS

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The object of this research is to compare the performance of Stairmand and Lapple type cyclone separators. The main problem to be solved in this research is determining which Stairmand or Lapple type cyclone separator is more suitable for integration into the pyrolysis system. The comparison is based on key performance indicators: pressure drop and collecting efficiency. The research findings indicate that both Stairmand and Lapple cyclone separators exhibit similar trends in pressure drop and collecting efficiency. As inlet velocity increases, the pressure drop also increases for both types. However, the collecting efficiency initially rises but then declines when inlet velocities exceed 13 m/s. The Lapple variant achieved a peak collecting efficiency of 98.94 % and pressure drop 16.26 mbar at an inlet velocity of 13 m/s, whereas the Stairmand design reached 97.33 % and pressure drop 12.16 mbar at 13 m/s inlet velocity. The Lapple type cyclone separator outperformed the Stairmand type in terms of both of pressure drop and collecting efficiency. This superiority is attributed to the specific design features and characteristics of the Lapple type. The superior performance of the Lapple type cyclone separator can be explained by its unique design elements that contribute to improved particulate matter separation and pressure drop. These elements may include differences in cylinder height and particulate matter outlet diameter. Based on the findings of this research, the Lapple type cyclone separator is recommended for integration into pyrolysis systems. However, it is important to consider the specific operating conditions of the pyrolysis process, such as temperature, the particulate matter size distribution, flow rate, and desired separation efficiency

Keywords: cyclone separator, pressure drop, collecting efficiency, Stairmand and Lapple type

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1. Introduction

The use of fossil fuels has impacted global warming and reduced the number of discoveries on Earth. To address this issue, it is crucial to find new and renewable energy sources that are both effective and available in large quantities to meet renewable energy targets. One such alternative energy source is biofuel, which is renewable, sustainable, and environmentally friendly. Biofuel is an excellent alternative to fossil fuels, as it can be produced from abundant biomass and emits fewer greenhouse gases. Currently, efforts are being made to process potential biomass for biofuel production by characterizing its qualitative and quantitative properties and converting it into bio-oil through pyrolysis and thermolysis [1].

Pyrolysis is a technology used to produce bioenergy by heating biomass without oxygen, resulting in the production of syngas, bio-oil, and solids in the form of charcoal or biochar [2]. The bio-oil produced can be used as liquid fuel, feedstock for chemicals, and feedstock for biochar production [3, 4]. The results of pyrolysis consist of the following: biochar (charcoal), activated charcoal, charcoal briquettes, bio-oil, and syngas. Biomass consists of 38–50 % cellulose, 23–32 % hemicellulose, 15–25 % lignin and other components (inorganic and extractive) with a total percentage of 5–13 % [5]. Biomass pyrolysis has proven to be a viable biochemical conversion pathway due to its ability to increase the chemical and calorific value of biomass feedstocks [6]. This conversion method can produce 70–95 % bio-oil by weight of the material [7]. Biomass pyrolysis combustion temperature ranges from 300–1000 °C [8]. Although this technology is still in the development stage, many studies have been conducted to improve the efficiency and product quality of pyrolysis, as well as to optimize the sustainable use of biomass.

The main component in the pyrolysis system that separates the syngas from the particulate matter is the cyclone separator. The condensed syngas becomes bio-oil [9]. Cyclone separators in the Industrial world are very useful and are still being developed for the separation of gaseous fluids from solids. Cyclone separators are more efficient when working at low pressure. The cone shape of the cyclone induces the gas or fluid flow to rotate, creating a vortex, so that the solid material will separate to the bottom of the cone, while the clean gas will flow back up through the center of the cyclone. In its development, it was noted that the cyclone can achieve efficiencies of up to 90 % or even more for particles with sizes greater than 10 μm with high density [10]. The performance of cyclone operation can be determined by collecting efficiency and pressure drop. The approach to evaluating cyclone performance is based on empirical observations of the complexity of the flow in the cyclone and the variety of geometries that exist [11]. This experiment is focused on determining the optimal inlet velocity point and can be related to the collecting efficiency to determine the performance of the cyclone separator.

Therefore, studies on the comparation of the effect of inlet velocity on performance of 2 types of cyclone separators that will be used in the pyrolysis system are relevant.

2. Literature review and problem statement

Cyclone is a component used to separate particles dispersed in a gas stream as [12]. This research has regarding the effects of body height (*hb*), conical height (*hc*), and vortex finder height (S) on cyclone pressure drop but has not researched the influence of particulate matter outlet diameter on pressure drop, because it varies with changes in the cyclone body diameter.

The dispersed particles will hit the cyclone walls due to centrifugal force, so that the particles will fall and be separated by the upward fluid flow [13]. The effect of the particulate matter outlet size on pressure drop in cyclone separators has not been investigated. This may be because previous research prioritized examining the impact of counter-cones on ash removal, gas velocity profiles, and pressure drop during gasification.

The performance of a cyclone separator is commonly evaluated based on pressure drop and collecting efficiency [14]. The relationship between the size of the particulate matter outlet and pressure drop in cyclone separators has not been investigated. This is likely due to past research focusing on the effects of solid loading and inlet shape on cyclone performance in circulating fluidized bed processes.

Generally, pressure drop is defined as the differential pressure between the inlet and top outlet [15]. The problem of how the outlet diameter of particulate matter affects pressure drop has not been fully studied because in the research study about the swirling motion of the particles within the cyclone causes friction with the walls, and the energy of the gas is lost as it passes through the outlet tube.

Collecting efficiency refers to the percentage of solid particles that can be separated from the gas in the cyclone separator [16]. The unexplored problem is not researched in the influence of particulate matter outlet diameter on pressure drop, because this research looks for the effect of the nozzle on the inlet side on the performance of the cyclone separator.

Variations in velocity significantly affect collecting efficiency; the higher the inlet velocity, the fewer particles escape, and the more particles are trapped [17]. While previous studies have primarily investigated the effects of inlet velocity and inlet width on cyclone separator performance, the impact of outlet diameter on pressure drop remains an understudied area. This research utilized computational fluid dynamics (CFD) to analyze the influence of these parameters on particle separation efficiency within the cyclone separator.

A pressure drop that is too low can reduce the separation efficiency of particles in the cyclone separator. A low pressure drop means that the gas flow velocity inside the cyclone is slow, giving smaller particles more chances to exit with the outgoing gas flow. This can result in the desired particles not being adequately separated, thus lowering the separation efficiency. On the other hand, a pressure drop that is too high can impact the separation capacity of the cyclone separator. A high pressure drop causes the gas flow velocity to increase, allowing larger particles to be separated effectively. However, if the pressure drop is too high, the gas flow can become too fast, affecting the separation of smaller particles. Ideally, an optimal pressure drop should be found that allows for efficient particle separation.

Optimization of cyclone separator performance includes adjusting the inlet flow velocity, which can affect particle separation performance. Proper flow adjustments, including appropriate flow velocity and uniform flow distribution, can enhance separation efficiency. Performance optimization of the cyclone separator should be carried out by considering the operational conditions and the characteristics of the particles to be separated.

The paper [18] presents research results from the Lapple model which produces a collection efficiency of 86.47 %, with parameters like inlet flow velocity, the particle size distribution in feed, dimensions of inlet and outlet ducts and cyclone affects the performance of cyclone significantly, and haven't analyzed about the influence of particulate matter outlet diameter on pressure drop, because focus to collection efficiency.

The paper [19] present to explain and design the Stairmand cyclone type and multi cone to control dust emissions particularly of coarser nature from a typical cement grinding unit by using Stairmand design model. Particle size (5–10 μm), the collection efficiency (88 %). Particle size (20–30 μm), the collection efficiency (96 %). So, the higher the particle size can the higher the collection efficiency. The influence of particulate matter outlet diameter on pressure drop remained unexplored because previous research has primarily concentrated on the impact of multi-cone designs on cyclone separator performance.

The increase in cyclone performance is influenced the effect of inlet flow velocity, outlet diameter, and the helical angle of the inlet channel on the cyclone separator [20]. The influence of particulate matter outlet diameter on pressure drop remained unexplored because the previous studies on cyclone separators have primarily concentrated on the impact of inlet channel helical angle on pressure drop.

Collection efficiency as a function of particle size and energy consumption (pressure drop) as a function of inlet velocity.

All this suggests that it is advisable to conduct a study on analyze the of effect of changes in inlet velocity on the performance of Stairmand and Lapple type cyclone separators which difference on particulate matter outlet diameter. Superior type cyclone separator will be used in pyrolysis systems.

3. The aim and objectives of the study

The aim of the study is to identifying the influence of changes in inlet velocity values on pressure drop and collecting efficiency for 2 types of Cyclone Separator (Stairmand and Lapple) which will be used in the pyrolysis system.

To achieve this aim, the following objectives are accomplished:

– to investigate the impact of varying inlet velocity on the performance of Stairmand Cyclone Separators;

– to investigate the impact of varying inlet velocity on the performance of Lapple Cyclone Separators;

– to compare the collection efficiency between Stairmand and Lapple Cyclone Separators under different inlet velocity conditions.

4. Materials and methods

4. 1. Object and hypothesis of the study

Object of this research is performance of Stairmand and Lapple type cyclone separator. Performance of cyclone separator based on pressure drop and collecting efficiency.

The main hypothesis of the study is the cyclone separator performance of Lapple type better than Stairmand type. The smaller outlet dimension of the Lapple cyclone separator, compared to the Stairmand type, results in a higher pressure drop. This elevated pressure drop is directly correlated with an enhancement in cyclone performance.

Assumptions made in this research is constant temperature. So, this research ignores temperature changes.

Simplifications adopted in this research is ignores temperature changes, scale down the dimensions of these 2 types of cyclone separators so that they can be easily tested in test bends.

4. 2. Installation of testing equipment

The methodology in this study, which begins with the installation of testing equipment such as: blowers, piping systems, and cyclone separators. Furthermore, measuring instruments are installed: flow meter after the blower, and pressure gauge on the inlet and outlet sides of the cyclone separator. To obtain accurate measurements of fluid flow velocity and fluid pressure to be known, easily displayed and stored data, a speed sensor and a pressure sensor connected to Arduino Uno and a computer installed with python software are installed.

The type of speed sensor used is MPXV7002DP and the type of pressure sensor is the WPT-G1/4-0010 model, while the Arduino Uno R3 ATmega 328P and Python software version 3.6.

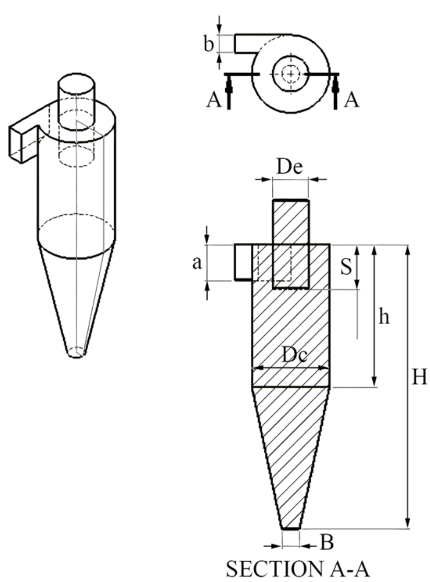
After everything is installed, the next step is to calibrate the measuring instruments (flow meter and pressure gauge), by adjusting the fluid flow rate and measuring the resulting pressure. The calibrators used are flowmeter and pressure gauge. While the results of the calibration equation are inputted in python.

Furthermore, when the flow meter is set to a speed of 5 m/s, the pressure at the inlet and outlet of the cyclone separator is seen. This is done for inlet speeds ranging from 5, 7, 9, 11, 13, 15, and 17 m/s. And from each entry speed, 100 data of inlet and outlet pressure of the cyclone separator were obtained, then averaged. The comparison of these two pressures shows the pressure drop.

To measure the material collected in the cyclone separator, a material with a size of 41.5 µm and a mass of 50 grams is prepared. This material is then inserted into the piping system leading to the cyclone inlet, then given a fluid velocity of 5 m/s which flows the material towards the cyclone inlet, then collected at the lower outlet of the cyclone separator and some come out towards the upper outlet of the cyclone separator. This experiment was carried out 5 times, then averaged, for each entry speed, starting from 5, 7, 9, 13, 15, and 17 m/s. The ratio of incoming material to that displayed at the bottom outlet of the cyclone separator is called collecting efficiency.

4. 3. Dimensions of cyclone separator

The types of cyclone separators used in this study are Stairmand and Lapple type cyclone separators. Dimensional details are shown in Fig. 1.



a. Stairmand type dimension
Cyclone Diameter (DC) = 2" (2 inch pipe), with details:

a	=	1"
b	=	0,4"
S	=	1"
De	=	1"
h	=	3"
H	=	8"
B	=	3/4 "

b. Lapple type dimensions
Cyclone Diameter (DC) = 2" (2 inch pipe), with details:

a	=	1"
b	=	0,5"
S	=	1,25 "
De	=	1"
h	=	4"
H	=	8"
B	=	1/2 "

Fig. 1. Cyclone separator design

To better understand the differences between the two types of cyclone separators, the designs of these separators are illustrated in Fig. 2. The examined two types of cyclone separators namely Stairmand Type and Lapple Type.

Fig. 2. Two types cyclone separator

The cyclone separator performance testing system (collecting efficiency) can be seen in Fig. 3 below.

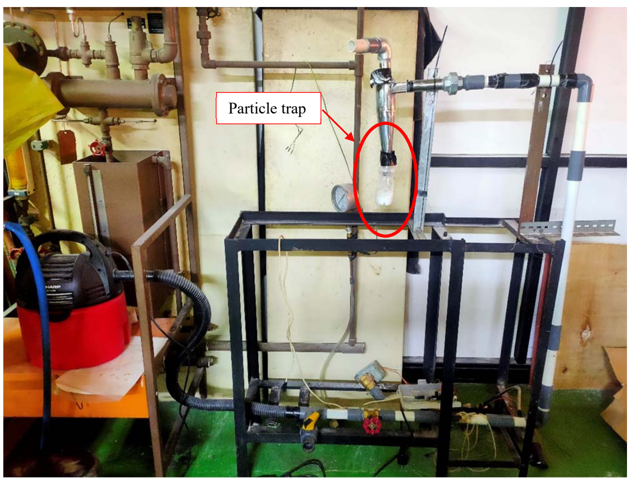


Fig. 3. Cyclone testing system

Furthermore, the collected particles were then weighed using a digital scale as shown in Fig. 4 below.

Fig. 4. Measurement of collected particles

Fig. 4 illustrates the measurement process of the collected particles

4. 4. Data capture flow

Data collecting is done using a pitot tube sensor to measure inlet velocity (m/s). The velocity sensors as input, are integrated by the Arduino Uno micro-controller and connected to the GUI (Graphical User Interface) on the computer device to retrieve the desired data and record it through Microsoft excel.

Graphical user interface (GUI) was displayed in detail in Fig. 5 which illustrated of this application of cyclone separator in this study.

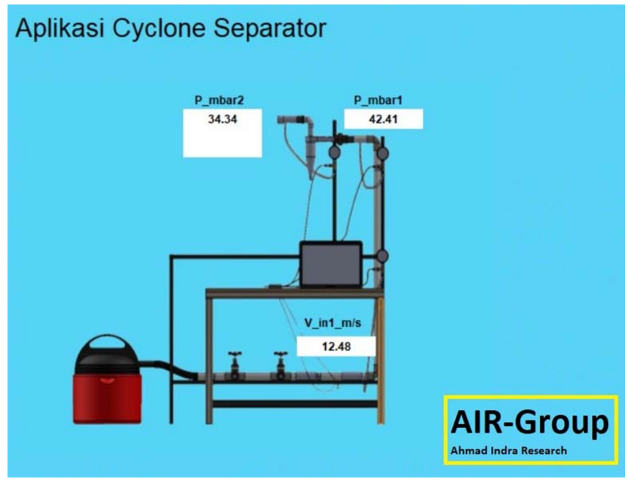


Fig. 5. Graphical user interface display

Fig. 5, also explain the flow of data collecting of inlet velocity variations (m/s), by first inserting particles in the test system Before testing, all sensors and measurement tools are calibrated. Subsequently, the effectiveness of the cyclone separator in terms of its collecting efficiency was assessed by altering inlet velocities at 5 m/s, 7 m/s, 11 m/s, 13 m/s, 15 m/s, and 17 m/s, employing particles of 41.5 μm.

5. Results of analysis of inlet velocity changes to performance of 2 type cyclone separator

5. 1. The impact of varying inlet velocity on the performance of Stairmand cyclone separators

Table 1 presents results from Stairmand type testing, detailing various parameters at different inlet velocities. Each row corresponds to a specific inlet velocity (m/s) and reports the differential pressure (ΔP in mbar).

Table 1

Stairmand type testing results

Inlet velocity (m/s)	ΔP (mbar)	Total mass of particles entering the cyclone (gr)	Mass of particles collected by the cyclone (gr)	Collecting efficiency
5	2.21	45.14	37.13	82.26 %
7	4.08	45.63	39.86	87.35 %
9	6.03	46.90	43.84	93.48 %
11	9.63	47.68	45.85	96.16 %
13	12.16	47.86	46.58	97.33 %
15	15.90	47.90	46.05	96.14 %
17	19.94	48.63	46.68	95.99 %

As the inlet velocity increases, the pressure drop generally increases due to higher kinetic energy imparted to the particles and increased frictional losses within the cyclone.

The maximum collecting efficiency is 97.33 % at a speed of 13 m/s. Based on the graph above, the efficiency of a Stairmand cyclone, or any cyclone separator, is influenced by several factors, including the inlet velocity.

The performance of the Stairmand cyclone separator was significantly affected by changes in inlet velocity. As the inlet velocity increased, the collection efficiency generally improved, reaching a maximum at 13 m/s. However, higher inlet velocities also resulted in increased pressure drops, with a peak of 19.94 mbar at 17 m/s.

5. 2. The impact of varying inlet velocity on the performance of Lapple cyclone separators

Table 2 shows different parameters measured at various inlet velocities. Each row represents a specific inlet velocity (meters per second) and the corresponding differential pressure (measured in millibars).

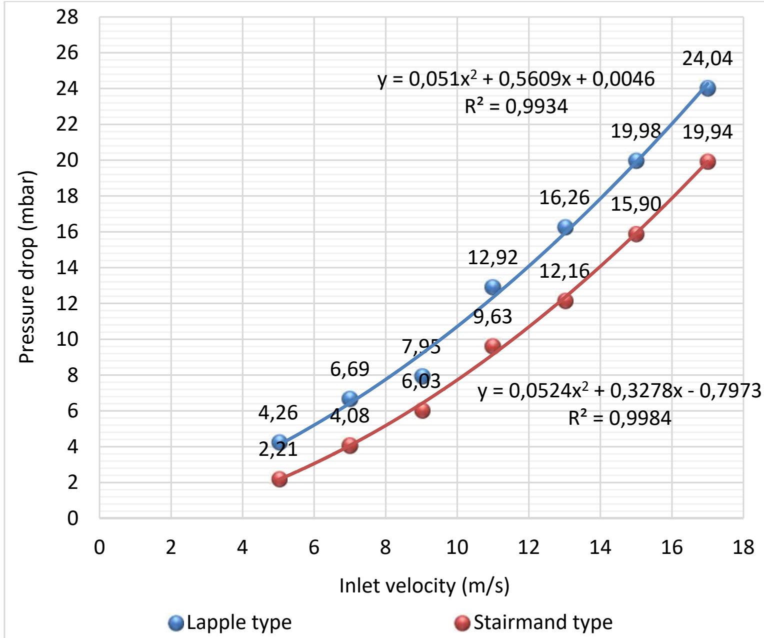


Fig. 6. Comparison of Lapple and Stairmand type results

Table 2

Lapple type testing results

Inlet velocity (m/s)	ΔP (mbar)	Total mass of particles entering the cyclone (gr)	Mass of particles collected by the cyclone (gr)	Collecting efficiency
5	4.26	46.81	39.99	85.43 %
7	6.69	47.18	42.19	89.42 %
9	7.95	47.62	45.41	95.36 %
11	12.92	47.91	46.58	97.22 %
13	16.26	48.04	47.53	98.94 %
15	19.98	48.08	46.90	97.55 %
17	24.04	48.36	46.97	97.13 %

As the inlet velocity increases, the pressure drop generally increases due to higher kinetic energy imparted to the particles and increased frictional losses within the cyclone.

Similar to the Stairmand cyclone, the performance of the Lapple cyclone separator was also influenced by inlet velocity variations. The Lapple cyclone separator's collection efficiency increased with inlet velocity, reaching its peak at 13 m/s. The pressure drop for the Lapple cyclone separator was higher than that of the Stairmand separator, peaking at 24.04 mbar at 17 m/s.

5. 3. Comparison of the collection efficiency between Stairmand and Lapple Cyclone Separators under different inlet velocity conditions

Furthermore, Fig. 6 demonstrates the comparison of Lapple and Stairmand type results. The comparation of inlet velocity variation are observed trough the pressure drops versus inlet velocity.

In additional, Fig. 7 demonstrates comparison chart of speed variation on collecting efficiency of two cyclone types. The comparation of inlet velocity variation are observed through the collecting efficiency versus inlet velocity.

Based on the outcomes of the performance testing for two types of cyclones, the Lapple type highest value of collecting efficiency is 98.94 % at inlet velocity of 13 m/s than Stairmand type, 97.33 % at same inlet velocity.

So, the optimal inlet velocity range for maximum collection efficiency for both cyclone separators is 13 m/s.

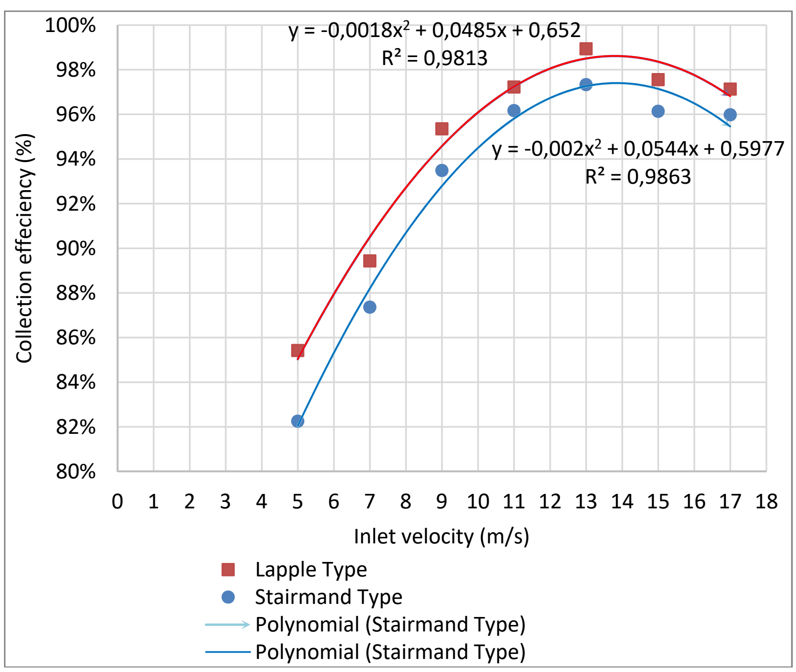


Fig. 7. Comparison chart of speed variation on collecting efficiency of two cyclone types

6. Discussion of results study on the performance of Stairmand and Lapple type cyclone separators

Tables 1, 2 show that the inlet velocity increased, the pressure drops also increased, while the collection efficiency initially rose but then declined after the velocity exceeded 13 m/s. These phenomena are observed in both Lapple and Stairmand cyclone separators. The observed decrease in collection efficiency at velocities above 13 m/s can be attributed to particle re-entrainment. At these higher velocities, particles that would normally be collected at the bottom outlet are subjected to increased centrifugal forces and are carried upwards towards the cyclone's vortex finder.

Fig. 6, 7 illustrates that the Lapple type exhibits a greater pressure drop and maximum collecting efficiency compared to the Stairmand type. This phenomenon happens because the Lapple cyclone separator type has a smaller cross-sectional area for its lower outlet (B) at 1/2", which is in contrast to the Stairmand type with a larger outlet at 3/4". Consequently, this leads to a heightened downward fluid flow speed that increasing pressure drop and carries particles with it, resulting in an enhanced capacity to retain a greater amount of particle. According to the research [22] an outlet diameter of 0.4 m produces a higher collecting efficiency (97 %) than outlet diameter is 0.5 m (95 %). Paper [18], with various mathematical models (Lapple theory) in this study achieved an efficiency with the Lapple model of 86.47 % cumulatively.

There are several limitations of this study, one of which is the lack of computational testing using CFD (Computational Fluid Dynamics) to observe flow phenomena and the influence of increasing inlet velocity can increase pressure drop.

The disadvantage in this study does not address the potential impact of temperature factors on the performance. This may affect the generalizability of the findings to different temperature conditions.

Therefore, the next development that needs to be undertaken in this study is to employ computational modelling to understand fluid dynamics and analyze energy efficiency. However, researchers will face challenges such as resource constraints, complex fluid dynamics analysis, and temperature influences. Despite these difficulties, this study provides valuable insights into the performance of cyclone separators and paves the way for future investigations into the optimization of cyclone performance in pyrolysis systems.

7. Conclusions

1. The performance of the Stairmand cyclone separator was significantly affected by changes in inlet velocity. As the inlet velocity increased, the collection efficiency generally improved, reaching a maximum at 13 m/s. However, higher inlet velocities also resulted in increased pressure drops, with a peak of 19.94 mbar at 17 m/s.

2. Similar to the Stairmand cyclone, the performance of the Lapple cyclone separator was also influenced by inlet velocity variations. The Lapple cyclone separator's collection efficiency increased with inlet velocity, reaching its peak at 13 m/s. The pressure drop for the Lapple cyclone separator was higher than that of the Stairmand separator, peaking at 24.04 mbar at 17 m/s.

3. Lapple type has a higher collecting efficiency of 98.94 % at an inlet velocity of 13 m/s compared to the Stairmand type, which has an efficiency of 97.33 % at the same velocity. So, the optimal inlet velocity range for two types of cyclone separators to achieve maximum collection efficiency around 13 m/s.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Manuscript has data included as electronic supplementary material.

Use of artificial intelligence

The authors have used artificial intelligence technologies within acceptable limits to provide their own verified data, which is described in the research methodology section.

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