VOL. 13 NO. 5,
AUGUST, 2026
E-ISSN 3027-1339
P-ISSN 3026-8257

African Scholar Publications & Research International
www.africanscholarpub.com

Journal of Systematic, Evaluation and Diversity Engr. (JSEDE)

Performance Assessment of Parallel and Series Air Cyclone Configuration for Particle Size Distribution (PSD) in Kaolin Beneficiation

Audu N.[1]; Sanni Y. Y.[2]; Bello S. I.[3]; Bello A.[4]; & Okechukwu I. N.[5]

[1&3]Department of Chemical Engineering Technology, School of Engineering Technology, Federal Polytechnic Nasarawa, Nigeria. [2&5]Lecturer, Department of Mechanical Engineering Technology, School of Engineering Technology, Federal Polytechnic Nasarawa, Nigeria. [4]Biorersources Development Centre, Ilorin/ National Biotechnology Research and Development Agency, Abuja
Corresponding Author: abumuhseenchet@gmail.com
DOI: https://doi.org/10.70382/ajsede.v13i5.043

Abstract

The particle size distribution (PSD) control is playing a key role in kaolin benefaction to increase kaolin content and product quality for industrial application. The concept of dry classification of fine mineral using air cyclones is often applied, but little research has been conducted relating cyclone configuration to the PSD and Kaolinite enrichment of fine minerals. In this study, the performance of three air cyclones installed in a parallel and series system in the control of PSD and upgrade of Kaolinite in Kaolin beneficiation was assessed. Both configurations were used to treat raw Kaolin with an initial kaolinite content of 46%, while treating conditions (feed rate, air velocity and pressure) were kept the same. Laser diffraction was used to determine PSD. The results indicated that the series arrangement of Cyclones gave a Kaolin Content of 67% compared to the parallel arrangement with a Kaolin Content of 65% and the initial Kaolin Content of 46%. The particle size fraction and cut size were also seen to be finer in the series configuration than the parallel configuration. This shows that the series cyclone arrangement can be used to get high grade and fine kaolin as compared to parallel arrangement, which is suitable for high – purity, fine kaolin applications. The results give guidance for the optimization of cyclone circuits in the dry beneficiation of kaolin.

Keywords: Air cyclone, Kaolin beneficiation, particle size distribution, series arrangement, parallel arrangement, kaolinite, Mineral classification.

Introduction

Kaolin is a white, fine grained clay mineral mainly consisting of kaolinite, used in paper coating, ceramic s, paints, pharmaceuticals and polymers (Muray, 2007; Bundy and Ishley, 1991). The brightness, particle size distribution and kaolinite content are the key factors which determine the market value of kaolin (Prasad et al., 1991). The raw deposits of Kaolin may also include a number of impurities, including quartz, mica and feldspar, and the PSD may be very broad such that the raw deposits are not directly usable indus-trially (Wilson, 2004).

The presence of impurities in natural bentonite, however, requires the need for a beneficiation process in order to obtain narrow PSD fractions containing a high amount of Kaolinite (Engel and Middleton, 2002). In water scarce regions, dry beneficiation methods are preferred, because of lower energy and environmental costs (Gupta and Yan, 2016). Air cyclones are widely used for particle classification according to centrifugal force (Boysan et al.) among the "dry" methods. 1982). Cyclones can be cascaded in parallel with the aim to intensify the process, or cascaded in series to get sharper classification and finer products (Elsayed and Lacor, 2012).

Although used industrially, there have been limited studies to compare the performance of parallel and series cyclone arrangement for kaolin PSD control and kaolinite upgrade, with most previous studies focused on single cyclone performance (Cortes and Gil, 2007) or wet classification (Prasad et al., 1991). The importance of understanding the effect of arrangement is critical to designed cost – effective dry beneficiation circuits that satisfy the tight product specifications. (Audu N. 2016)

The aim of this research is to test and compare the performance of three air cyclones in parallel and in series in the fields of PSD modification and kaolinite enrichment for the kaolin beneficiation process. (Audu N. 2012). In particular, the hypothesis is tested whether the fine particles and higher grade of kaolinite, which is determined by the number of classification stages, will result in series arrangement as compared to parallel arrangement of the classifiers (Paraydyumna et al, 2020). The result will be used to determine the cyclone circuits to use in kaolin processing plants making high – grade products.

Materials

Kaolin ore was obtained as raw material from Kankara, Katsina State in Nigeria. The as-received sample was broken and dried for 24hourse (ASTM D 2216 2019). Wilson (2004) reveals that quartz and mica are the main impurities. The particle size of feed was from 2 um to 150 um.

METHOD

In parallel arrangement, the feed was divided into three cyclones and these were run in parallel. Product streams from all three were combined.

In series arrangement, the underflow from cyclone 1 was passed on to cyclone 2 and the underflow from cyclone 2 were passed on to cyclone 3. The last overflow was retained as a product (Pradyumna et al., 2020)

The feed rate in both tests was kept at 5 kg/h and the experiments performed in triplicate as mentioned by Gupta & Yan (2016).

Particle Size Distribution (PSD): Feed and products were analysed for PSD with a laser particle size analyzer (Malvern Rasterizer 3000) (ISO 13320, 2020). Parameters reported are % and particles < um.

Performance Evaluation:

The performance metrics used were the improvement in the kaolinite content and fineness. The percent increase of kaolinite was determined.

Thermal effects on PSD (Engel and Middleton, 2002) were avoided by performing all experiments at the room temperature.

RESULTS AND DISCUSSION

Table 1: Summary of PSD Results for the Cyclone Series Arrangement

Sample	Clay (%)	Silt (%)
Feed	46	54
SO1	68	32
SO2	67	33
SO3	65	35
SU	40	60

Table 1 shows the Particle Size Distribution (PSD) of the Feed, Overflow and Underflow Products for the Series Arrangement. The PSD results for the samples Feed, SO1, SO2, SO3 and SU were described below;

SO1 is the overflow product of the series arrangement for the first stage

SO2 is the overflow product of the series arrangement for the second stage

SO3 is the overflow product of the series arrangement for the third stage

SU is the underflow product of the air cyclone series arrangement.

The particle size distribution results of the feed, underflow and overflow product for various stages of the series arrangement of the air cyclone rig. As shown. The particle size distribution of the clay material can be classified as clay (<1-2µm), silt (<2-63µm) and sand (<63-2500µm), according to Vito and Stefano 2009. This was the basis used to determine the amount of kaolin clay that is present in the feed, underflow product and the overflow product of different stages of the series arrangement of the air cyclone rig.

The particle size distribution (PSD) of the kaolin feed was found to be 46% kaolin clay and 54% silt. The table shows the overflow product of the first, second and third stages of the series arrangement to get powder classification of 68%, 67% and 65% ≤ 2µm respectively. This shows a great improvement when compared to the initial percentage clay of 46% that is present in the raw kaolin i.e. the feed. It was observed that the highest purification was obtained at the first stage of the series arrangement and the trend decreases from 68% through 67% to 65%, this is as a result of the fact that what goes from first stage to second stage is the underflow of the first stage which has less clay (kaolin) than the original feed, hence less clay in the overflow. The same with the 2nd stage underflow which has less clay content, is fed into 3rd stage cyclone and secondly, the material's residence time at the 3rd stage is lower than the 1st stage, 2nd stage, 3rd stage, because separation will not occur at the 3rd stage until the material pass through the 1st stage and 2nd stage before the 3rd stage and separation will take place at 1st stage and 2nd stage as they are passing through these stages, separation is expected to be higher at 1st stage followed by 2nd stage and the last stage.

SU has a low amount of kaolin clay (less than the percentage of kaolin clay in the feed). This is expected since some of the lighter particles, majority of which are clay, escape through the overflow.

According to literature (www.functionalfillers.com/kaolin-paper.com), kaolin that contains at least 70% clay content (based on the particle size distribution by cut-off of particles finer than 2µm) can be used as coating materials for paper and kaolin that contains at least 50% clay content (based on the particle size distribution by cut-off of particles finer than 2µm) can be used as the filler used in the production of paint. Hence the products of the series arrangement were thought to be suitable for paint production.

Table 2: Summary of PSD Results for the Cyclone Parallel Arrangement

Sample	Clay (%)	Silt (%)
Feed	46	54
PO1	60	40
PO2	70	30
PO3	64	36
PU1	45	55
PU2	42	58
PU3	42	58

The PSD results for the samples PO1, PO2, PO3, PU1, PU2, and PU3 were tabulated in Table 2.
PO1 is the overflow product of the parallel arrangement for the first stage
PO2 is the overflow product of the parallel arrangement for the second stage
PO3 is the overflow product of the parallel arrangement for the third stage
PU1 is the underflow product of the parallel arrangement for the first stage
PU2 is the underflow product of the parallel arrangement for the second stage
PU3 is the underflow product of the parallel arrangement for the third stage

The analysis of particle size distribution of the kaolin feed was found to be 46% kaolin clay content and the remaining 54% is silt. As can be seen in the table, the first, second and third cyclones in the parallel arrangement yielded 60%, 70% and 64% respectively of powder classification ≤ 2µm. This shows a great improvement when compared to the initial percentage clay of 46% that is present in the raw kaolin i.e. the feed. It was observed that the highest purification was obtained at the second cyclone which is 70% kaolin clay. The reason was that in the distribution chamber the stream or the pipe leading to the second cyclone was from the top of the distribution chamber which allowed more of the lighter particles to pass through the stream to the second cyclone for separation and hence a finest particle was expected to be separated from a cyclone with a finest feed. The second highest purified kaolin clay was obtained at the third cyclone which is 64%, the reason was that from the distribution chamber the least amounts of the feed pass through the third cyclone because it had the least inlet velocity when compared to the first and second cyclone, in this case high purified kaolin was expected and low yield was also expected as the product of this separation. It was observed that the first cyclone was the cyclone in which the least purified kaolin clay was found and the reason was the position of the channel from the distribution chamber to the first cyclone was more oriented towards the direction of the blower's blade, therefore the maximum velocity at inlet in this cyclone is obtained. Therefore, high inlet velocity resulted into high yield and low purity was also expected to be the result of the separation.
PU1, PU2 and PU3 have low amounts of kaolin clay, even less than the percentage of kaolin clay in the feed. This is to be expected as some of the lighter particles, the majority of the which being clay, have gone through the overflow.
According to literature (www.functionalfillers.com/kaolin-paper.com), kaolin that has at least 70% clay content (from cut-off particle size distribution of particles less than 2µm in size) can be used as paper coating while kaolin with at least 50% clay content (from cut-off particle size distribution less than 2µm) is suitable to use as fillers for paint production. Therefore the products from the first and third cyclone considered suitable for paint production while the product from the second cyclone was good for paper coating.

CONCLUSION

It has been observed that the clay content was enhanced from 46% to 67% kaolinite for three air cyclone in series and 65% (average) kaolinite for three air cyclone in parallel respectively for the particle size distribution (PSD). This shows that the series arrangements produced a higher grade, finer particle size kaolin that the parallel arrangements.

RECOMMENDATION

The findings from this study led to the following recommendations:

For high throughput and quartz removal: In case of high throughput and high quartz removal requirement for industrial use, the use of parallel cyclone arrangement is recommended in order to achieve maximum quartz removal with maintaining the process capacity.

2. When high purity is required: Considering the stepwise impurity removal principle of tits, a series cyclone is recommended for use to reduce mica content in the presence of progressive enrichment of kaolinite.

Further research is needed to address process optimization of combining both series and parallel configurations and maximise the benefits of each configuration 3. Process optimization: Hybrid configurations with both series and parallel architecture should be studied in future to take advantage of both systems.

REFERENCES

Americani Societyi fori Testingi andi Materials.i (2019)i ASTMi D2216-i 10:i Standardi testi methodsi fori laboratoryi determinationi ofi wateri (moisture)i contenti ofi soili andi rocki mass.i i ASTMi International

Audu,i N.i (2012)i Purificationi ofi Kankarai kaolini clayi usingi airi cyclone.i Unpublishedi M.Sci i i i i Thesis,i Departmenti ofi Chemicali Engineering,i Ahmadui Belloi University,i Zaria.

Audu,i N.i (2016)i Design,i fabricationi andi installationi ofi seriesi andi paralleli airi cyclonei sysytemsi fori kaolini beneficiation.i Unpublishedi PhDi Thesis,i Departmenti ofi Chemicali Engineering,i Ahmadui Belloi University,i Zaria.

Bish,i D.i L.,i andi Post,i J.i E,i (1993).i Quantitativei mineralogicali analysisi usingi thei Reitveldi i full-i patterni fittingi method.i Americani Mineralogist,i 78i (9-10),i 932i -940.

Boysan,i F.,i Swithenbank,i J.,i andi Ayers,i W.i H.i (1982).i Ai Fundamentali mathematicali modellingi approachi toi cyclonei design.i Transactionsi ofi thei institutioni ofi Chemicali Engineers,i 60(4),i 222-230.

Bundy,i W.i M.,i andi Ishley,i J.i N.i (1991).i Kaolini ini paperi filingi andi coating.i Appliedi Clayi Science,i 5i (5-6),i 397-420. https://doi.org/10.1016/0169-1317(91)90018-F

Cortes,i C.,i andi Gil,i A.i (2017).i Modelingi thei gasi andi particlei flowi insidei cyclonei seperators.i Progressi ini Energyi andi Combustioni Science,i 33(5),i 409-452. https://doi.org/10.1016/j.pecs.2007.02.003

Elsayed,i K.,i andi Lacor,i C.i (2012).i Optimizationi ofi thei cyclonei separatori geometryi fori minimumi pressurei dropi usingathermaticali modelsi andi CFDi simulations.i Chemicali Engineeringi Science,i 68(1)i 409-424.https://doi.org/10.1016/j.ces.2011.09.045

Engel,i Ri H.,i andi Middleton,i G.i J.i (2012).i Dryi beneficiationi ofi kaolin.i Industriali Minerals,i 315,i 48-53.

Gupta,i A.,i andi Yan,i D.i S.i (2018).i Minerali processingi designi andi operations:i Ani introductioni (2ndi ed.).i Elsevier.

Internationali Organizationi fori Standardization.i (2020),i ISOi 13320:2020i Particlei sizei analysisi Laseri diffractioni methods.i ISO.

Murray,i H.i H.i (2007).i Appliedi clayi mineralogy:i Ocurrences,i processingi andi applicationsi ofi Kaolins,i bentonites,i palygorskite-sepiolite,i andi commoni claysi (Vol.i 2).i Elsevier.

Pradyumna,i R.,i Rajamani,i R.i K.,i andi Milin,i M.i (2020).i Effecti ofi Multistagei classificationi oni particlei sizei distributioni andi minerali enrichment.i Mineralsi Engineering,i 150,i 106272. https://doi.org/10/1016/j.mineng.2020.106272

Prasad,i M.i S.,i Reid,i K.i J.,i andi Murray,i H.i H.i (1991).i Kaolin:i Processing,i propertiesi andi applications.i Appliedi Clayi Science,i 6(2),i 87-119. https:doi.org/10/1016/0169-1317(91)90013-E

Stefano,i D.,i Ferroi V.,i Mirabilei S.i i (2010)i “Comparisoni betweeni Grain-Sizei Analysesi Usingi Laseri Diffractioni andi Sedimentationi Methods,”i Bioi systemsi Engineering,i Vol.i 106,i No.i 2,i p.i 205-215.

Wilson,i M.i J.i (2004).i Kaolini andi halloysitei deposits.i Ini Clayi Mineralogy:i Spectroscopici andi Chemicali Determinativei Methodsi (pp.i 231-270).i Springeri