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Evaluation of Parallel and Series Air Cyclone Arrangements for Impurity Removal and Particle Classification in Kaolin Beneficiation

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Abstract

Kaolin beneficiation is necessary for improving the purity and industrial value of raw kaolin, by removing impurities such as quartz and mica and achieving the desired particle size distribution. This research evaluates the performance of air cyclone arrangements in series and parallel configurations for removal of impurities and particle classification in kaolin beneficiation. Particle Size Distribution (PSD) and X- Ray Diffraction (XRD) analyses were used to assess the effectiveness of both arrangements. The results show that PSD analysis indicated an improvement in kaolin content from 46% in the raw feed to an average of 67% for the series arrangement and 65% for parallel arrangement. XRD analysis revealed that the series configuration increased kaolinite content by an average of 62.2% while reducing quartz by 74.3% and mica by 68.3%. The parallel configuration achieved a higher increase in Kaolinite content of 67.8%, with quartz reduced by 86.3% and mica by 56.7%. The findings demonstrate that both series and parallel cyclone arrangement effectively beneficiate kaolin, with the series arrangement showing better mica removal and particle classification, while the parallel arrangement offers superior kaolinite enrichment and quartz reduction. This study provides useful insights for selecting cyclone configurations to optimize kaolin purity for industrial applications.

Keywords: Kaolin beneficiation, air cyclone, series arrangement, parallel arrangement, particle size distribution, XRD, Impurity removal

Introduction

Kaolin is an aluminosilicic clay mineral occurring in nature and used for its fine particle size, chemical inertness, low abrasive nature and whiteness. Common uses of it are in paper coating, ceramics, paint, rubber, pharmaceuticals, and cosmetics (Audu N., 2016)

Raw kaolin deposits, however, contain various impurities, such as quartz, mica, feldspar, iron and titanium oxides and organic matter, which are harmful (Aroke u. et. al., 2014)

These impurities lower brightness, make it more abrasive and decrease the industrial uses of kaolin.

Several wet and dry beneficiation processes are used for kaolin beneficiation, such as sedimentation, froth flotation, magnetic separation, leaching, and air classification (Virta and Robert, 2012)

Leaching, air classification and air cyclone separation are among the dry methods. Air cyclone separation is water free energy efficient and is preferred of dry methods as it is suitable in areas with restricted water resources. (Audu N., 2016)

Air cyclones separate particles due to the centrifugal forces acting on the difference of mass, size and density of the particles. The underflow contains coarse and dense impurities which are discharged and the lighter, finer kaolin fraction is carried out in the overflow (Audu N., 2012).

The cyclones can be operated in parallel to achieve higher throughput for the same cut size and in series to provide progressive classification and higher purity (Stefano D. et. al., 2012)

In parallel arrangement, the feed is fed to more than one cyclone simultaneously, in serial arrangement, the underflow from the first cyclone is fed to the second cyclone, and the underflow from the second cyclone is fed to the third cyclone to remove the impurities in step down process and to classify the fines (Aroke u. et. al., 2013)

Although cyclone configuration plays an important role in the dry beneficiation of kaolin, few studies have directly compared the performance of parallel and series air cyclone arrangements for kaolin beneficiation. Most of the studies performed are related to hydro cyclones and to mineral and dust collecting applications (Su Y. et. al., 2011)

The rising demand for high – brightness, low-impurity kaolin in Nigeria and other Kaolin-rich countries makes it necessary to use dry classification circuits optimized in order to yield the best product. (Svarovsky et. al., 2009)

Hence, comparative evaluation of purification of raw kaolin in the two different arrangements of air cyclone, namely parallel and series is the target of the study.

MATERIALS

The following materials and equipment were used for the study:

1. Raw Kaolin from Kankara, Katsina state. Nigeria
2. Air Cyclone Test Rig Three identical tangential inlet, reverse –flow, 1m, diameter, stainless steel air cyclones.
3. Auxiliary Equipment: induced draft blower, cyclone dust collector, pressure gauge, flow meter, digital weighing balance.
4. Analytical Instruments: Laser particle size analyzer, X- ray fluorescence XRF Spectrometer
5. PPE; Dust mask, safety goggles, hand gloves

SAMPLE PREPARATION

The sun–drying of Raw Kaolin was done for 48 hours, with the moisture content reduced to 2<%. It was then crushed and pulverized with a jaw crusher and ball mill, respectively, and sieved through 250 μm sieve to get uniform feed. The feed material was characterized for initial particle size, and chemical composition.

The experimental studies were made at feed rate of 5kg/hr and inlet velocity of 18m/s. Two cyclone setup was tried.

Parallel Arrangement

Feed was pneumatically discharged and divided in three, the same amount into each parallel cyclone. The mixture of overflows from both cyclones was collected and purified. The underflows were gathered individually.

Series Arrangement

The first cyclone was filled with the feed. The underflow from the cyclone 1 was directly fed as input to cyclone 2 for secondary classification, the underflow from cyclone 2 was directly fed as input to cyclone 3 for third classification. The overflow products of cyclone 1, 2, 3 were taken as desired/purified products of stage 1, 2 and 3 respectively.

All runs were performed with sufficient steady state conditions for 30 minutes. ALL products were weighed and kept in an airtight container.

RESULTS AND DISCUSSION

XRD Analysis of the Feed and Overflow Products of the Series Arrangement

Figure 1 shows the XRD pattern of the feed, series overflow products of stage 1, 2, 3 depicted as SO1,SO2 and SO3 respectively. The feed showed very strong peaks at 2Ɵ of 12.35, 24.88 and 26.65°and strong peaks at 8.8, 17.4 and 45.24°.

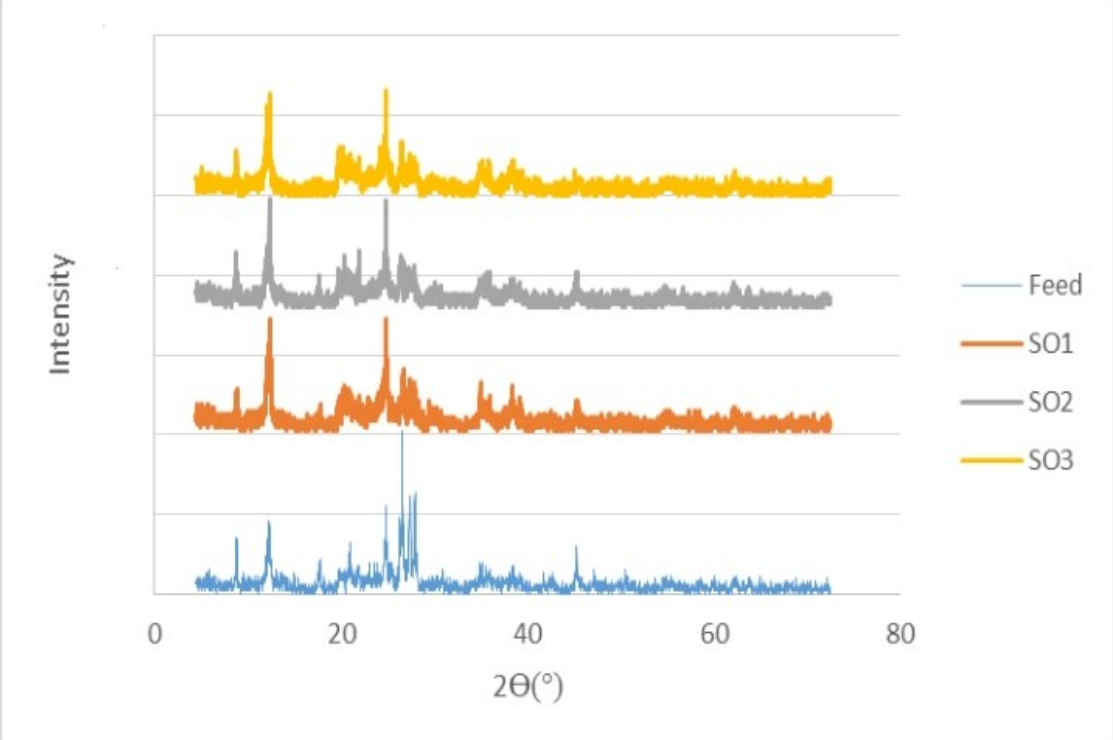


Figure 1: XRD pattern of the feed, series overflow products of stages 1, 2,3 depicted as SO1,SO2 and SO3 respectively.

Where K is kaolinite, Q is quartz and M is mica.

The kaolinite characteristic peaks in the XRD patterns are usually 2Θ diffraction angles of 12.35, 24.88 and 45.24°. For the Bragg angles 12.35, 24.88, 20.38 and 45.24° that correspond to the kaolinite mineral, it could be observed that the peaks were more prominent in SO1, SO2 and SO3 (product samples) after beneficiation as compared to raw sample SO0. It was also observed that the peak at 26.65° responsible for quartz became drastically supressed as shown in product sample SO1, SO2 and SO3.

The sample product of SO1 i.e the series overflow products of stage 1 was observed in the main characteristic peaks of kaolinite at Bragg's angle of 12.35 and 24.88 had intensities of about 72 and 75 counts respectively (as shown in Appendix B), which showed substantial increaments to their initial intensities of 40 and 52 count respectively, which were 80 and 44.2% improvement in the kaolinite concentration; hence, the level of beneficiation obtained at the SO1 has improve the raw kaolinite by an average of 62.1%. The peak at 26.65° corresponding to quartz was found to be drastically reduced from an initial value of 100 counts for the raw kaolin (the feed) to about 25 counts after the first stage of the series beneficiation. The mica peak' intensity also reduced from the initial 20 to 10 counts. Hence at this first stage of series arrangement the beneficiation resulted into reduction of the quartz and mica impurities by 75 and 50% respectively.

XRD Analysis of the Feed and Overflow Products of the Parallel Arrangement

Figure 2 shows the XRD pattern of the feed, parallel overflow products of first, second and third cyclone depicted as PO1, PO2 and PO3 respectively. The feed showed very strong peaks at 2Θ of 12.35, 24.88 and 26.65°and strong peaks at 8.8, 17.4 and 45.24°.

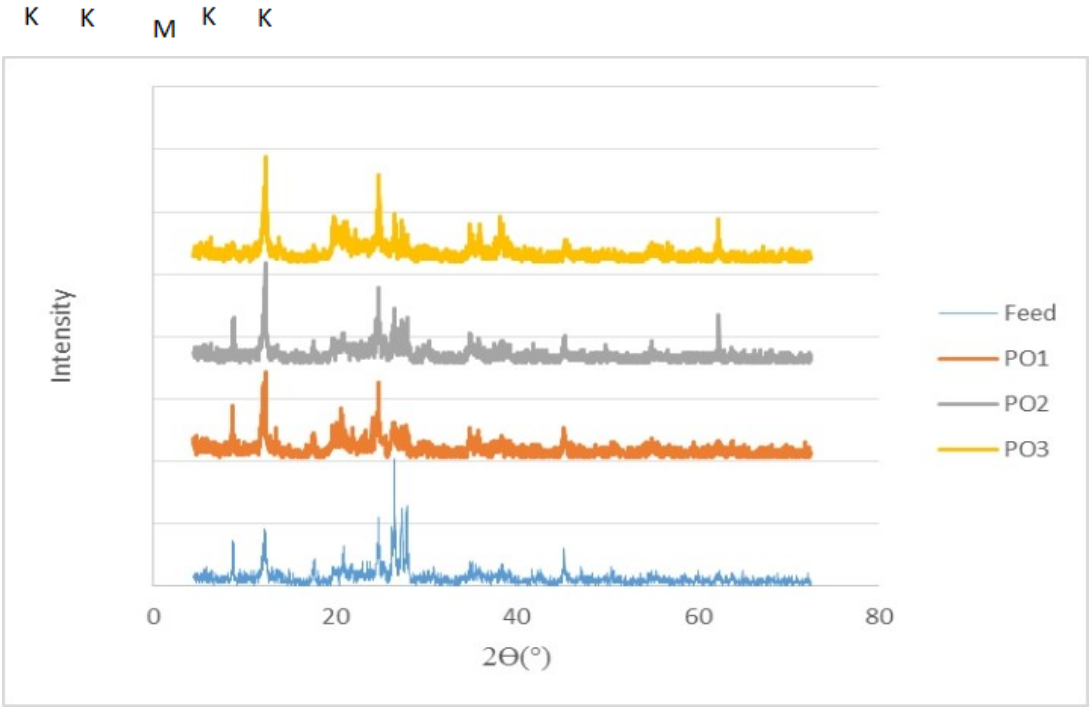


Figure 2: XRD pattern of the feed, parallel overflow products of first, second and third cyclone depicted as PO1,PO2 and PO3 respectively.

Where K is kaolinite, Q is quartz and M is mica.
The characteristic peaks of the kaolinite in the XRD patterns are typically 2Ɵ diffraction angles of 12.35, 24.88 and 45.24°. It could be observed that the peaks at Bragg's angles of 12.35, 24.88, 20.38 and 45.24° responsible for the kaolinite mineral were more prominent after beneficiation as shown in product samples PO1, PO2 and PO3. It was also observed that the peak at 26.65° responsible for quartz became drastically supressed as shown in product sample PO1, PO2 and PO3.
The sample product of PO1 i.e the parallel overflow products of first cyclone was observed in the main characteristic peaks of kaolinite at Bragg's angle of 12.35 and 24.88 with intensities of about 76 and 74 counts respectively (as shown in Appendix B), which show substantial increaments to their initial intensities of 40 and 52 count respectively, which were 90 and 42.3% improvement in the kaolinite concentration; hence, the level of beneficiated obtained at the PO1 has improve the raw kaolinite by an average of 66.2%. It was noted that the intensity of the peak at 26.65° corresponding to quartz was greatly reduced from 100 counts for the raw kaolin (i.e. the feed) to 18 counts at the first cyclone in parallel. The mica peak' intensity also reduced from the initial 20 to 10 counts. Hence at this first stage of parallel arrangement the beneficiation resulted into reduction of the quartz and mica impurities by 82 and 50% respectively.

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 results of the particle size distribution analysis of feed, underflow and overflow product for various stages of the series arrangement of the air cyclone rig. As shown. The particle size distribution of clay material can be classified as follows: clay (1–2μm), silt (2–63μm) and sand (63–2500μm) (Vito and Stefano 2010). This was used to calculate the percentage of kaolin clay present in the feed, the underflow product and the overflow product from various stages of the series arrangement of the air cyclone rig.
The particle size distribution analysis of the kaolin feed was shown to be 46% kaolin clay and 54% silt. It can be seen from the table that the powder classification for the first, second and third stage of the series arrangement were 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 achieved in the first stage of the series arrangement and the

trend decreases from 68% to 67% to 65% which is due to the fact that the underflow of the first stage is fed to the second step of the series arrangement; therefore, less clay (kaolin) is fed to the overflow of the second stage than the underflow of the first stage. With the second stage underflow which has less clay content, it is fed into the third stage cyclone and secondly, the time that the material will stay in the system reduces from the first stage to the second stage and further to the third stage, this was because the separation process will not happen at the third stage until the material passes through the first stage and second stage before reaching the third stage, therefore more separation is expected on the first stage followed by the second and finally the third stage.

SU has low amount 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 which are clay, will flow over the overflow. Literature (www.functionalcillers.com/kaolin-paper.com) indicates that kaolin containing at least 70% clay content (based on cut off particle size distribution of particles smaller than 2μm) can be used for paper coating and kaolin containing at least 50% of particles smaller than 2μm can be used as fillers in paint production. Thus the materials of the series arrangement were thought to be appropriate for the use of making paint.

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 particle size distribution analysis of the kaolin feed revealed that 46% of it was kaolin clay and 54% was silt. The table demonstrates that the overflow product produced from the first, second and third cyclone from the parallel configuration produced powder classification of 60%, 70% and 64% ≤ 2 μm 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 found that the highest purification was achieved by the 2nd 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 cyclone used, which is 64% purified, was the second least inlet velocity in the distribution chamber compared

to the first and second cyclone, hence a high purified kaolin (64%) was supposed to be produced and a low yield was also expected. The first cyclone was the one with the least purified kaolin clay since the channel from the distribution chamber to the first cyclone was more inclined towards the direction of the blade of the blower thus giving the maximum inlet velocity in the first cyclone. Therefore a high inlet velocity was expected to result in a high yield as well as a low purity because of the separation process.

The percentages of kaolin clay in PU1, PU2 and PU3 are small, and in fact are less than the kaolin clay in the feed. This is to be expected as a number of the lighter particles, most of which are clays, have passed through the overflow.

The minimum percentage of clay content for kaolin to be used as paper coating is 70% (particles finer than 2μm) and for paint production, it is at least 50% (particles finer than 2μm). Hence it can be concluded that the product from first and third cyclone were suitable to make paint and product from second cyclone is suitable for paper coating.

CONCLUSION

The study evaluated the performance of series and parallel air cyclone arrangements for impurity removal and particle classification in kaolin beneficiation. Based on PSD analysis, the kaolin content was significantly improved from 46% in the raw feed to an average of 67% using the series arrangement and 56% using the parallel arrangement.

XRD results further confirmed the effectiveness of both configurations. The series arrangement improved kaolinite by 62.2% an average and achieved substantial reductions in quartz (74.3%) and mica (68.3%). The parallel arrangement showed a greater improvement in kaolinite content (67.8%) and a higher reduction in quartz (86.3%), but a comparatively lower reduction in mica (56.7%)

Overall the series arrangement demonstrated better performance in mica removal and particle classification, while the parallel arrangement was more effective in kaolinite enrichment and quartz removal. Both systems proved viable for improving the quality of raw kaolin to meet industrial specifications.

RECOMMENDATIONS

1. **For high-purity kaolin requiring low mica content:** The series cyclone arrangement is recommended due to its superior mica removal and better control of particle size distribution.
2. **For maximum kaolinite recovery and quartz removal:** The parallel cyclone arrangement should be adopted, as it achieved the highest kaolinite enrichment and quartz reduction.
3. **Process optimization:** A hybrid series-parallel cyclone configuration should be investigated to combine the advantages of both systems for simultaneous high kaolinite content, low quartz, and low mica
4. **Industrial application:** The validated cyclone arrangements can be integrated into kaolin beneficiation plants to reduce reliance on chemical and wet beneficiation methods, thereby lowering cost and environmental impact
5. **Further study:** Future work should examine the effect of gas velocity, feed rate, and cyclone geometry on the efficiency of both arrangements to develop predictive models scale – up.

REFERENCES

Aroke,i U.i O.,i El-Nafatyi U.i A.i (2014)i XRF,i XRDi andi FTIRi Propertiesi andi Characterizationi ofi HDTMA-Bri Surfacei Modifiedi Organo-Kaolinitei Clay.i *Internationali Journali ofi Emergingi Technologyi andi Advancedi Engineering*.i ISSNi 2250-2459,i ISOi 9001:2008i Certifiedi Journal,i Volumei 4.

Aroke,i U.i O.,i El-Nafatyi U.i A.,i Oshai O.i A.i (2013)i Propertiesi andi Characterizationi ofi Kaolini Clayi fromi Alkaleri,i North-Easterni Nigeria.i *Internationali Journali ofi Emergingi Technologyi andi Advancedi Engineering.i* 3(11)387-392.

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.

Su,i Y.,i Zhengi A.,i Zhaoi B.i (2011).i Numericali Simulationi ofi Effecti ofi Inleti Configurationi oni Squarei Cyclonei Separatori Performance.i Powderi Technology*i* 210:i 293–303.

Svarovsky,i L.i (2009).i Characteristicsi ofi gasi cyclonesi -i flowi characteristics,i efficiencyi ofi separation,i recommendedi rangei ofi operation,i cyclonesi ini series.i Cyclonei Separation.i 98:22-45

Virta,i Roberti (2012).i Minerali Commodityi Summariesi (Technicali report).i U.S.i Geologicali Survey.i pp.i 44–45.

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.