Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 3159-0040
Vol. 1 Issue 4, November - 2014

EVALUATION OF THE FLUXING POTENTIALS OF OKENE POTASSIUM FELDSPAR FOR SILICATE CERAMICS PRODUCTION

F. I. ILOGHALU AND E. E. NNUKA

DEPARTMENT OF METALLURGICAL AND MATERIALS ENGINEERING
NNAMDI AZIKIWE UNIVERSITY
P.M.B. 5025, AWKA, NIGERIA

ABSTRACT

The Nigerian ceramic industrial sector is not only suffering from the dearth of indigenous trained ceramic engineers and the lack of tertiary institutions for producing such professionals, but it also suffers from Nigerian marketer’s/supplier’s persuasion for “imported”, “foreign” and “original”, without which our Nigerian ceramic industrial sector can thrive and even boom unto exportations. This work therefore went out to prove that Nigerian local fluxing materials are as good and in some cases, even better fluxes than some imported ones. Okene potassium feldspar from Kogi state was used exclusively in the development of soft translucent porcelains, everything from clays to filler (quartz) and flux coming from local sources. From so many porcelain body compositions with Nigerian clays, Kogi quartz and particularly Okene potassium feldspar, soft porcelain bulk densities (D_b) were raised to acceptable standard values of 2.03gr/ml, apparent porosities were lowered from very high values of 37% to almost 0.0%, while water absorption values were also lowered from very highly unacceptable value of 21.0%, to almost 0.0%, all at desirable terminal temperatures. Okene potassium feldspar was clearly seen to be a perfect flux for any ceramic product manufacture, comparable to any imported fluxing materials.

Key words: Flux, fluxing materials, fluxing minerals, feldspars, Okene potassium feldspar, silicate ceramics

INTRODUCTION:

The dictionary of chemistry gave the metallurgical and materials engineering meaning of a flux in two concepts, one; as “a substance added to another to assist fusion of the latter” and also as “a substance used to enable two pieces of metals to be joined together without their being oxidized”. (Sharp and Miall, 1971). Extending the idea of flow and joining to ceramics manufacture, the concept of melting, fluidity and joining applies equally, noting that both ceramics and metallurgical materials are formed and even used at high temperatures.

Therefore a flux can easily be defined as some special substance which must possess that needed low melting temperature so as to flow and join other substances/materials that need joining. However whereas flux can be used in welding to join two separate pieces of metals, besides serving as whole additive in melting and refining metallurgical systems, the use of flux in ceramics engineering involves a powder large-surface area compositional mixture, attaining sintering or surface sweating or partial melting that finally ensures the desirable mass joining and strength. It was defined (flux) as a substance that is added to a body to enable it to fuse more readily (Worrall, 1975). The flux added to ceramic bodies lowers the temperature of liquid formation during firing and when cooled, the formed glass melt binds the powder grains, giving the ceramics its strength at firing temperatures, sometimes as low as 700°C, especially for silicate ceramics. (Fuounier, 1973)

The most common fluxes are materials rich in alkali oxides like Na_2O, K_2O, or Li_2O. Calcium, CaO and magnesium MgO oxides also act as fluxes, but in combined form. (Worrall, 1975, Grainshaw, 1971). The most important fluxes for ceramic productions are the mineral forms known as feldspars, a group of minerals with similar chemical formulae incorporating silica and alumina:

Potash feldspar (orthoclase) $KAlSi_3O_8$
Soda feldspar (albite) $NaAlSi_3O_8$
Lime feldspar (anorthite) $CaAl_2Si_2O_8$

Each of the above is seen to consist of four unit formulae of silica, Si_4O_8, in which one or two of the four silicon (Si) atoms get replaced by Al and the charge deficiency made up by the addition of one atom of sodium, potassium or calcium. (Worrall, 1975).

Another mineral flux material is Nepheline syenite $Na(AlSi)O_4$. Another is lepidolite, a lithium-bearing mineral with the formula, $K(AlLi_2)Si_4O_{10}(OH)_2$, a mica mineral. Others are petalite $LiAlSi_4O_{10}$, spodumene Li $Al(SiO_3)_2$ and Wollastonite $CaSiO_3$, a flux which is particularly best for achieving very low moisture expansion products. (Worrall, 1975; Grimshaw, 1971). Other special case fluxes do exist, for example, animal bones, containing hydroxyapatite $Ca_5(OH)(PO_4)_3$, with traces of iron and calcium carbonate. Another is Cornish stone, with varied chemical formulae and varied natural stone colours of purple, mild purple, white and buff, as the cases may be. (Rhodes, 1973; Grimshaw, 1971).

Of all the above mentioned fluxes, the one dealt with in this work is the feldspar and particularly the potassium feldspars. Both text books and Raw Materials Research Development Council (RMRDC) technical brief on minerals in Nigeria have described feldspars as constituents of pegmatite rocks like granites and other igneous rocks, which are predominantly alkali-bearing, sometimes up to 60% in some rocks segments. (Grimshaw, 1971; RMRDC Tech Brief on minerals in Nigeria (feldspar), April 1999). The RMRDC tech brief went on to describe the rich pegmatite rocks of Kogi State, especially at Egbe, Udiarehu, Okene and Lokoja. Other areas mentioned include areas of Oshogbo in Oshun State, where up to 0.9 meter thick reserves have been assessed. In other places like Ijero Ekiti in Ondo State up to 1.2m thick potassium and sodium feldspar reserves have been assessed. Again Jiga Hill and Gwoza in Borno State and some parts of Adamawa State are said to contain huge reserves. Even about Shiroro Dam and Kubli area of Niger State, the typically pink potassium feldspar deposits stand out. Economic reserves are also identified in N/West of Abeokuta, around Aiyetoro. Here the reserve is said to be up to 40 – 60% and reserves are also said to have been located in Jaguna, Fami, Gbegbinlawo, Aiyedeti, Alakawe etc. of same Ogun State. (RMRDC, April 1999)

Structurally, the feldspar minerals belong to the framework (TECTOSILICATE) silicate structural group, in which each oxygen is shared by two tetrahedra as is exemplified in the minerals quartz and feldspar. In the feldspars some of the Si^{4+} are replaced by Al^{3+}, so that the resulting excess negative charges are satisfied by cations, especially the monovalents and divalent like; Na^+, K^+, Ca^{2+}. These cations getting into the structure are located outside the (Al, Si)O tetrahedra, thereby constituting a more open framework than that of quartz (SiO_2). It is indeed this more open structure of the feldspar minerals that makes them have lower melting temperatures and so importantly serve as fluxing materials for various ceramic body compositions during manufacture.

The final challenge after the foregoing expositions is to take the necessary step to characterize and assess our natural fluxing materials endowments; in this case starting with our feldspathic deposits, hence this project topic.

Materials and Methods

All materials for this research work were locally obtained. They compromise; Kankara clay from Katsina State, Nahuta clay from Plateau State and Nsu clay from Agbahara Nsu in Imo State. Others include quartz (silica) and feldspar (flux) from Kogi State, including Magnesium carbonate from Tagasinta, in the N. E. of Nigeria. Sodium silicate, plaster of Paris (P.O.P) and other laboratory equipment were located at the local markets, organizational laboratories.

Raw materials chemical analysis for the work were done by Plateau minerals Development Company and Projects Development Institute (PRODA), Enugu. The initial raw material firings were carried out in Science Equipment Development Institute (SEDI), Enugu, while the later firings were done with a GK4 1300°C kiln in Owerri, Imo State.

The primary and secondary comminution of raw materials; clays, quartz and feldspar, were done in PRODA workshop Enugu, while the dry sieve analysis was done at Nigerian Standard Organisation Lab. (SON), Emene, Enugu. Finally, all test samples at different stages were prepared with the standard specifications for preparing ceramics test pieces for different parameter determinations.

Raw materials dry sieve analysis:

Both the feldspar and quartz lumps were first crushed in PRODA workshop jaw crusher and pan mill respectively. Thereafter both were wet ball-milled for 12 hours. Both were next decanted, dried and subjected to dry sieve analysis.

Table 1, Sieve analysis data for 12 hours milled quartz

Sieve Size (um)	**Wt (gr)**	**Wt (%)**	**Cumulative % Retained (Oversize)**	**Cumulative % passing (undersize)**
-450 + 425	0.7	0.35	0.35	99.65
-425 + 300	0.3	0.15	0.15	99.85
-300 + 212	51.3	25.78	25.78	74.22
-212 + 150	108.7	73.59	73.59	26.40
-150 + 75	32.2	85.13	85.13	14.38
-75 + 63	5.4	93.10	93.10	6.89
-63 + 56	0.4	100	0	0

The particles sizes generated from the milled quartz fall within -450µm and +56µm sieves. The samples quantity was 100grams of dry quartz powder, dried overnight in an electric drier, loaded in a stack of sieves and placed on a sieve shaker and switched on. The time was set to allow for vibration for a period of fifteen (15) minutes, after which the vibrating machine stopped automatically. The sieves were removed one after the other, beginning with the topmost sieve. The quantity of powder remaining on each sieve was weighed and its weight recorded in the column for sieve mesh size, according to British Standard sieve requirements (BSS), to enable the final calculations for cumulative % retained (oversize) and cumulative % passing (undersize) to be made.

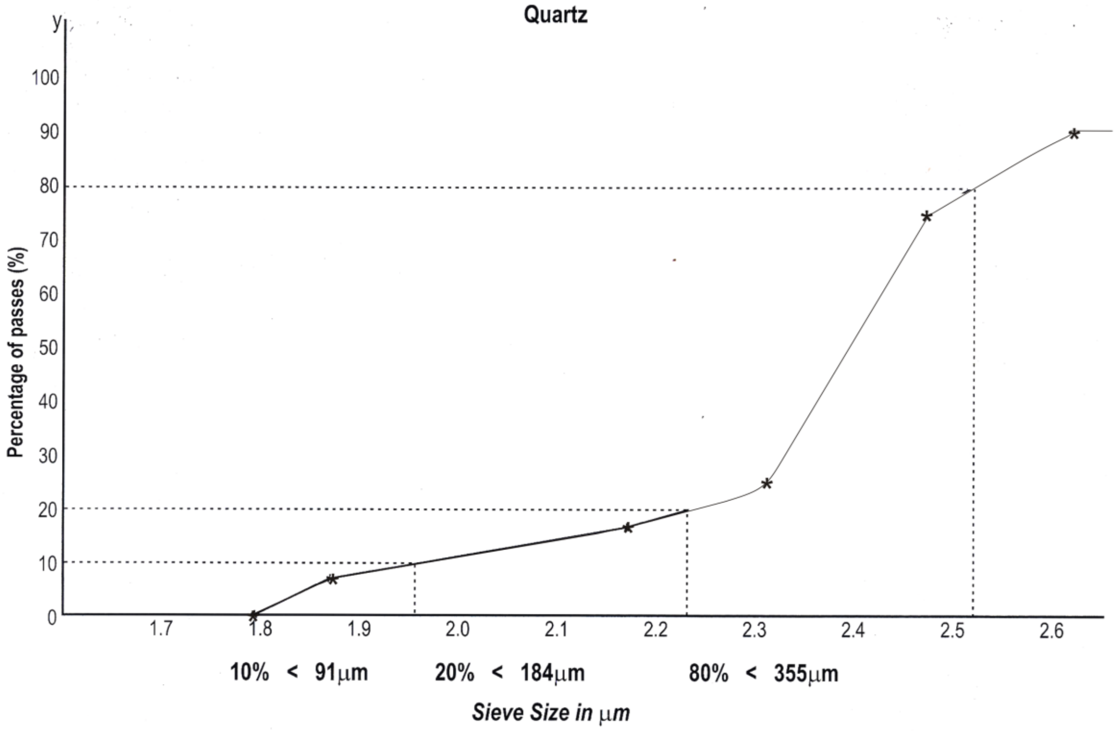

Fig 1. Particle size graph for 12 hours milled quartz

Fig 1 shows the plot of table 1. It is the plot of log of particles size for quartz against percentage undersize. It depicts that a large part of the particles, 10 t0 80% did fall within the range of 90µm to 350µm. This falls within the specification stipulated by the British Standard, BS410 or the American Society, for Testing Materials, ASTM, E11.70 and the German Standard, DIN 4188 for particles distribution for quartz powders used in the production of ceramic tablewares. It is known, that excessive fines in milled quartz is not good for silicate tablewares, because it causes excessive melts which do destabilize and deform the wares while being fired (King, 2005).

The feldspar powder had exactly the same treatment like the quartz powder, worked out of 100 grams of dried milled feldspar as depicted on table 2:

Table 2: Sieve analysis data for 12hrs milled feldspar powder.

Sieve Size (um)	**Wt (gr)**	**Wt (%)**	**Cumulative % Retained (Oversize)**	**Cumulative % passing (undersize)**
-450 + 425	0.2	0.1	0.1	99.9
-425 + 300	0.2	0.1	0.1	99.8
-300 + 212	0.6	0.3	0.3	99.69
-212 + 150	26.9	13.52	13.52	86.48
-150 + 75	90.7	52.70	52.70	47.29
-75 + 63	59.2	72.72	72.72	27.27
-63 + 56	20.8	93.69	93.69	6.31

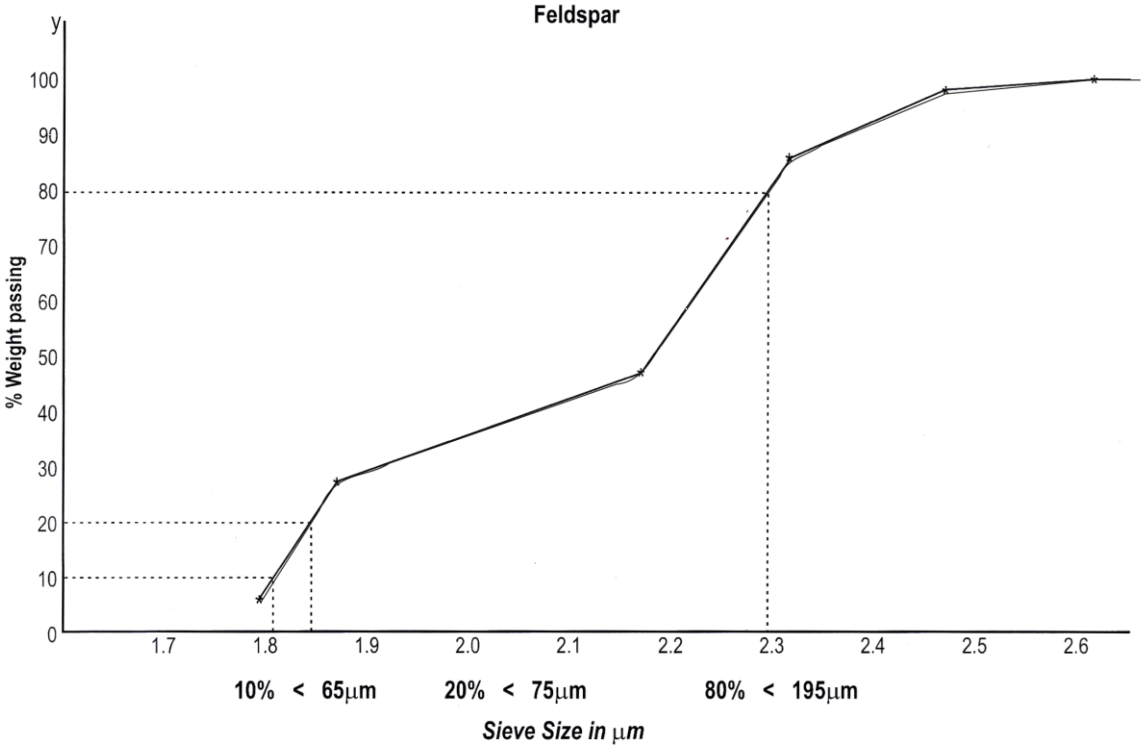

Fig 2. Particles size plot for 12 hours milled feldspar .

The data of the sieve analysis were then depicted in fig 2. This plot of table 2 data showed the log of particle size of feldspar powder, plotted against percentage undersize. The plot revealed that a great portion of the particles, 20 – 80%, fell between 75µm and <300µm. A greater percentage of the particles passed the 150µm sieve mesh and remained just above the 75µm sieve. This was seen to be acceptable, since it is a known practice in tableware production that the finer the flux, the greater its solvent action on the body constituents of a composition and at a cheaper/lower temperature. (King, 2005)

Ceramic body compositions and sample preparations:

The preparation of the clay body into which the flux was incorporated was done in three (3) stages, involving the raw clays beneficiation to remove gange and impurities, before the first and second/final body compositions, property tests and selections. Having decided on what proportions of the clays, Kankara, Nahuta and Nsu to use for porcelain compositions, quartz and feldspars were incorporated into as many as 77 compositions. While the clays and quartz were kept more constant as a unit, feldspar contents of the bodies were varied from 15 to 25% in body compositions which were replicated into 5/6 test pieces, measuring 6cmx2cmx1cm, each test piece with a 5cm wet shrinkage mark, making up altogether over 385 test pieces.

In this elaborate study, five (5) promising groups namely; compositions 1a1.1 to 1a1.6, 2a1.1 – 2a1.6, 3a1.1 to 3a1.6 4b1.1 to 4b.1.6 10a1.1 to 10a1.6 were singled out.

Next, one best in each of the five (5) groups, provided one of the final five (5) samples, whose porcelain translucency-sensitive properties, namely; bulk density (D_b) apparent porosity (P_{ap}) and water absorption (W_{abs}), were used to evaluate the fluxing capabilities of Okene potassium feldspar. In this paper, the parameters of only two (2) out of the five groups are used to illustrate the fluxing potentials of Okene potassium feldspar.

Results and Discussions:-

"Porcelain composition is adjusted according to the ease of forming and with regards to its firing behavior" (Kingery, 1976) It is known that in whiteware/porcelain bodies, clays serve as fabrication plasticizers and viscous melt provider at elevated temperatures. Silica serves as unreactive filler/stabilizer during drying and at lower temperatures, but as glassy melt at higher temperatures. Then feldspar is actually the solvent of the two previous materials, based on their percentage ratios and the temperature range attained during product firing. (Budnikov, 1964; Grimshaw, 1971; Uhlmann, 1976).

With the above literature background one notes that firing/reaction temperature is so vital for effective fluxing, so that as temperature increases bulk density (D_b) increases to an optimum value, apparent porosity (Pap) decreases, tending towards zero and water absorption decreases in figure too, assuming approximately half the numerical value of porosity figure. The numerical tables and the figure representations of this research are now best presented together to enhance clarity of conception.

Table 3: Numerical data of the effects of Okene potassium feldspar fluxing, 15-25%, on bulk density (D_b) of composition 4b.1 to 4b.6 at temperatures 1200^o to 1260^{o}c.

	1200^{o}C		**1220^{o}C**		**1240^{o}C**		**1260^{o}C**	
Code No	Feldspar (%)	D_b (g/ml)	Feldspar (%)	D_b (g/ml)	Feldspar (%)	D_b (g/ml)	Feldspar (%)	D_b (g/ml)
4b .1	15%	1.65	15%	1.78	15%	1.82	15%	1.95
.2	17%	1.62	17%	1.76	17%	1.83	17%	1.98
.3	19%	1.69	19%	1.84	19%	1.79	19%	1.99
.4	21%	1.64	21%	1.86	21%	1.79	21%	2.0
.5	23%	1.63	23%	1.93	23%	1.89	23%	1.98
.6	25%	1.7	25%	1.89	25%	1.89	25%	2.03

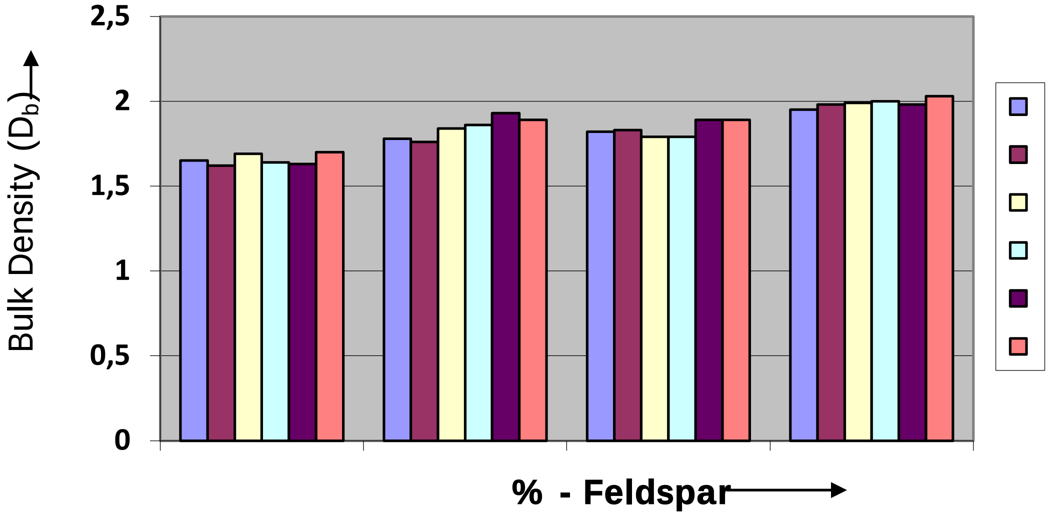

Fig 3 , Effect of Okene potassium feldspar fluxing, 15-25% on bulk density (D_b) of composition 4b.1 to 4b.6 at temperatures of 1200° to 1260°c.

The graph portrays the numerical data of table 3, presenting in bar chart form, the bulk density of the 4b group. Barring some bloating effect, the bulk density of this group presented an overall good plot, with an upward tilt, normally seen in bulk density values of ceramics as temperature or fluxing percentage increases. Except for small twisting at the 1220°C and 1240°C plots, the 1200°C and the 1260°C maintained a typical bulk density low to high value slant as temperature increased. The 1260°C at the top presented the groups highest bulk density of 2.03 gr/ml, confirming both temperature and fluxing effect from 15 to 25%.

Table 4: Numerical data of the effect of Okene potassium feldspar fluxing 15 to 25% on apparent porosity (Pap%) of compositions 4b.1 to 4b.6 at temperatures 1200° to 1260°C.

	1200°C		**1220°C**		**1240°C**		**1260°C**	
Code No	Feldspar (%)	P_{ap} (%)	Feldspar (%)	P_{ap} (%)	Feldspar (%)	P_{ap} (%)	Feldspar (%)	P_{ap} (%)
4b .1	15%	37.0	15%	27.85	15%	21.9	15%	10.61
.2	17%	38.3	17%	26.58	17%	10.6	17%	0.0
.3	19%	34.9	19%	13.69	19%	6.7	19%	0.0
.4	21%	34.6	21%	1.39	21%	1.6	21%	0.0
.5	23%	24.1	23%	1.49	23%	0.0	23%	1.61
.6	25%	11.4	25%	1.40	25%	1.3	25%	3.45

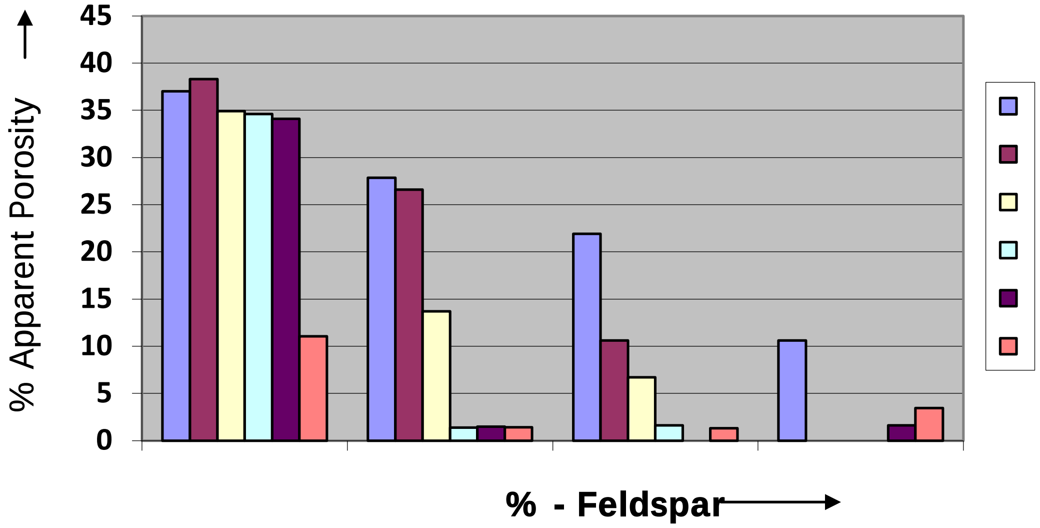

Fig 4, Effect of Okene potassium feldspar fluxing, 15-25%, on apparent porosity (Pap %) of compositions 4b.1 to 4b.6 at temperature 1200° to 1260°C.

Fig 4 represents plotted values of table 4, portraying the bar chart of apparent porosity of 4b group. The bar chart vividly shows how the apparent porosity of this group was very high at lower percentages of feldspar, almost at all temperature levels. The highest porosity of 37% was consequently registered as 15% feldspar at the lowest firing temperature of 1200°C and still remained as high as 10.6% porous, even at the highest firing temperature of 1260°C. Then with >20% fluxing, porosity which stood at best 34%, at the 1200°C firing, was brought down to 0% at the 1260°C firing. The bars show clearly how fluxing brought down sharply the porosities of all firings between 1200° and 1260°C, except for some eratic rise, which could be due to bloating or over-firing. In the same way the temperature effect was equally dramatic, since the porosity figures registered a wide shift down, away from previous values.

Table 5: Numerical data of effect of Okene potassium feldspar fluxing 15 tp 25% on water absorption (%) of compositions 4b.1 to 4b.6 at temperatures 1200° to 1260°C.

	1200°C		1220°C		1240°C		1260°C	
Code No	Feldspar (%)	W_{abs} (%)	Feldspar (%)	W_{abs} (%)	Feldspar (%)	W_{abs} (%)	Feldspar (%)	W_{abs} (%)
4b .1	15%	22.4	15%	15.6	15%	11.3	15%	5.43
.2	17%	23.7	17%	15.11	17%	5.3	17%	0.0
.3	19%	20.7	19%	7.49	19%	3.78	19%	0.0
.4	21%	21.0	21%	0.75	21%	0.8	21%	0.0
.5	23%	14.8	23%	0.78	23%	0.0	23%	0.81
.6	25%	6.7	25%	0.75	25%	0.8	25%	1.75

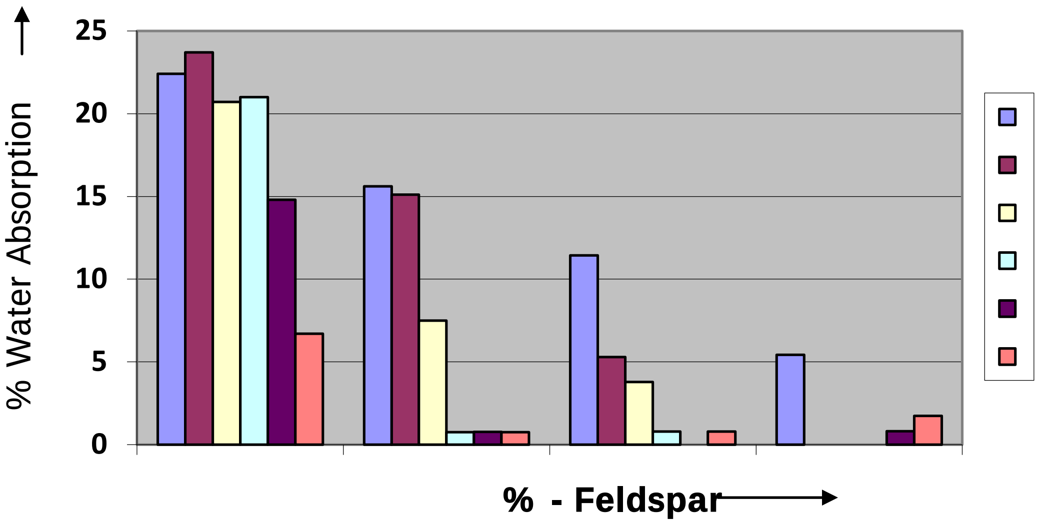

Fig. 5, Effect of Okene potassium feldspar fluxing 15 - 25%, on water absorption (%) of compositions 4b.1 to 4b.6 at temperatures 1200° to 1260°C.

The bar chart plot of water absorption for table 5, closely mirrowed the porosity pattern. The water absorption which was still too high, >22%, at the 1200°C firing, dropped like the porosity figure to 5.43% at the 1260^{oc} firing with 15% feldspar incorporation. Similarly at 25% feldspar input it dropped from 6.7% at 1200°C firing to almost 0% at the 1260°C firing. So both the temperature and fluxing effects were clearly dramatic, but for the slight erratic value at 1260°C, probably due to over firing effect.

A further demonstration of the fluxing power of Okene potassium feldspar is shown with the numerical data and bar chart plots of another test group 10a.1 and 10a.6. Again only three porcelain translucency-sensitive parameters are used for this demonstration.

Table 6: Numerical data of effect of Okene potassium feldspar fluxing 15 - 25% on bulk density (D_b) of compositions 10a.1 to 10a.6 at temperatures 1200 to 1260°C.

	1200°C		1220°C		1240°C		1260°C	
Code No	Feldspar (%)	D_b (g/ml)	Feldspar (%)	D_b (g/ml)	Feldspar (%)	D_b (g/ml)	Feldspar (%)	D_b (g/ml)
10a .1	15%	1.76	15%	1.98	15%	1.78	15%	1.92
.2	17%	1.6	17%	1.91	17%	1.8	17%	1.9
.3	19%	1.7	19%	1.92	19%	1.84	19%	1.95
.4	21%	1.7	21%	1.92	21%	1.90	21%	1.94
.5	23%	1.6	23%	1.95	23%	1.88	23%	2.03
.6	25%	1.7	25%	2.04	25%	1.89	25%	2.0

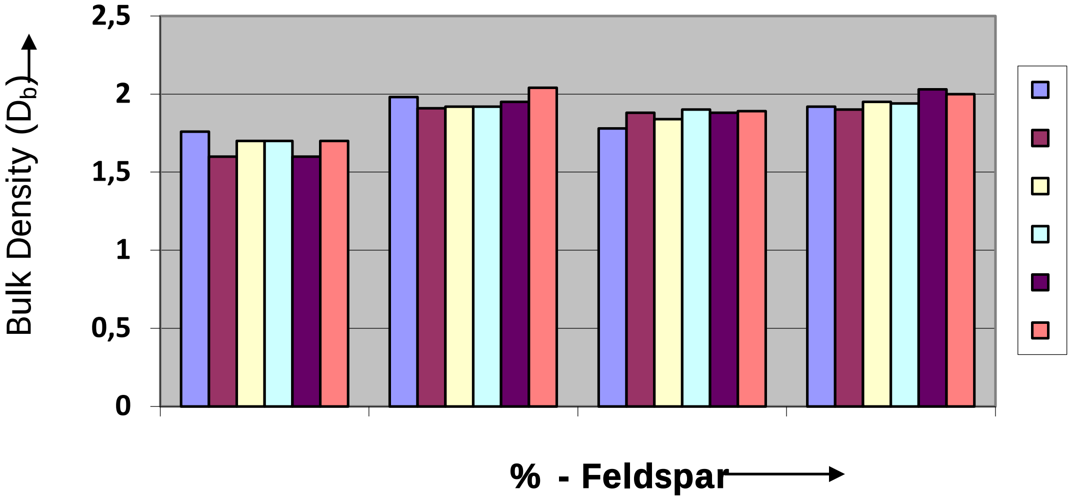

Fig 6: Effect of Okene potassium feldspar fluxing 15 - 25% on bulk density (D_b) of compositions 10a.1 to 10a.6 at temperatures 1200^{o} to 1260^{o}C.

The plot of table 6, the values of which averaged 1.65gr/ml at the lowest firing temperature of 1200^{o}C, rose to >2.03gr/ml at the 1260^{o}C firing. Except for some erratic points at the 1220^{o}C plot, the 1240^{o}C and the 1260^{o}C firings showed the expected upward trend of bulk density figures. On the whole, both fluxing and temperature effects were mildly effective.

Table 7: Numerical data of effect of Okene potassium feldspar fluxing 15 - 25% on apparent porosity (%) (Pap) of compositions 10a.1 to 10a.6 at temperatures 1200^{o} to 1260^{o}C.

	1200^{o}C		**1220^{o}C**		**1240^{o}C**		**1260^{o}C**	
Code No	Feldspar (%)	P_{ap} (%)	Feldspar (%)	P_{ap} (%)	Feldspar (%)	P_{ap} (%)	Feldspar (%)	P_{ap} (%)
10a .1	15%	35.6	15%	7.57	15%	9.37	15%	0.0
.2	17%	31.3	17%	4.76	17%	1.61	17%	0.0
.3	19%	29.9	19%	3.07	19%	3.17	19%	1.64
.4	21%	25.3	21%	1.44	21%	2.77	21%	1.75
.5	23%	24.1	23%	1.56	23%	3.2	23%	0.0
.6	25%	20.0	25%	0.0	25%	1.6	25%	1.61

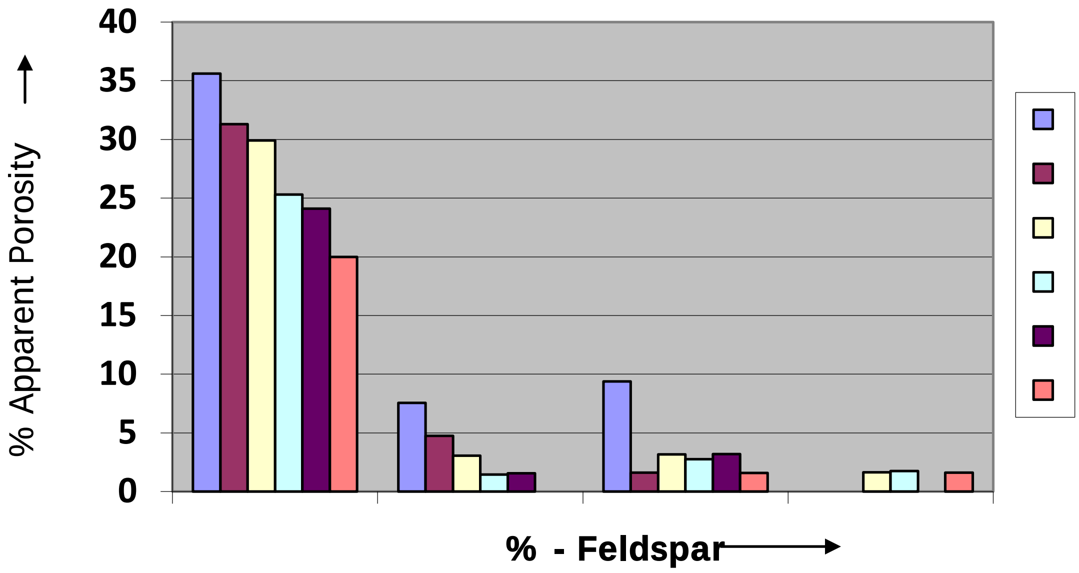

Fig 7, Effect of Okene potassium feldspar fluxing 15 - 25% on apparent porosity (%) (P_{ap}) of compositions 10a.1 to 10a.6 at temperatures 1200^o to 1260^{o}C.

The plot of table 7 for the 10a group had up to 35.6% porosity at the 1200°C firing. Although the body appeared hard to fuse at that 1200°C, nevertheless the power of graded fluxing showed a dramatic and sequential reduction of porosity from 35.6% at 15% feldspar to the lowest porosity of 20% with 25% feldspar incorporation. Notably the same compositionquickly yielded to fast fusion with only extra 20°C heat increase at 1220°C and further still at 1240°C. Strikingly the 1200°C plot alone showed the potentials of 15 to 25% Okene potassium feldspar.

Table 8. Numerical data of effect of Okene potassium feldspar fluxing 15 to 25%, on water absorption (%) of composition 10a1 to 10a.6, at temperatures of 1200°C to 1260°C.

	1200^{o}C		1220^{o}C		1240^{o}C		1260^{o}C	
Code No	Feldspar (%)	W_{abs} (%)	Feldspar (%)	W_{abs} (%)	Feldspar (%)	W_{abs} (%)	Feldspar (%)	W_{abs} (%)
10a .1	15%	21.1	15%	4.06	15%	5.2	15%	0.0
.2	17%	20.0	17%	2.5	17%	0.85	17%	0.0
.3	19%	17.9	19%	1.60	19%	1.72	19%	0.81
.4	21%	15.1	21%	0.75	21%	1.45	21%	0.88
.5	23%	15.1	23%	0.8	23%	1.7	23%	0.0
.6	25%	11.8	25%	0.0	25%	0.85	25%	0.81

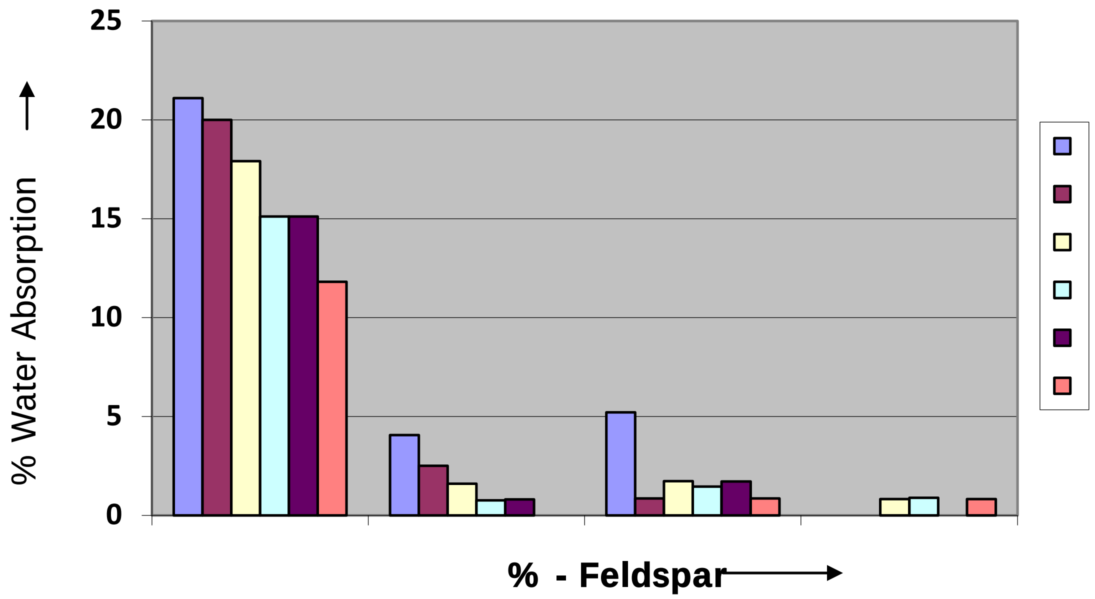

Fig. 8, Effects of Okene potassium feldspar fluxing 15 to 25%, an water absorption (%) of composition 10a1 to 10a6, at temperature of 1200° to 1260°C.

The bar plot of table 8 followed closely the porosity plot of figure 7. It indicated high existence of penetrable pores, 20% at the lowest fluxing of 15% and about 12% at the higher fluxing of 25% in the first/lowest test firing of 1200°C. Thereafter the percentage of penetrable pores was quickly reduced to 0% at 1260°C, starting with a striking 4% porosity recorded at the next lower firing of 1220°C. Both temperature and fluxing effects were active, but the temperature predominance was much more striking.

CONCLUSION:

The fact that the oxide analysis of Okene potassium feldspar had the highest major oxide, apart from silica (SiO_2) and alumina (Al_2O_3), as potassium oxide (K_2O), is a certification of the material that was used in this work. In the two group compositions whose properties were analysed , potassium feldspar inclusion was able to perform the usual function of a flux to a high degree of effectiveness. In the group body 4b, the bulk density of the body was improved from a low density (D_b) of 1.62 gr/ml to an acceptable value of 2.03gr/ml; their apparent porosity (P_{ap}), from a very highly unacceptable value of 37%, to almost 0%, which is most acceptable and their water absorption (W_{abs}), from a highly unacceptable value of 22.4% to almost the same 0%.

From the group 10a body, the bulk density (D_b) was improved from a low figure of 1.6gr/ml to a standard value of 2.03gr/ml, while the apparent porosity (P_{ap}) figure improved from an unacceptable value of 35.6% to desirable 0% and consequently it's water absorption moved down from 21% to almost 0%. The work of body fusion (fluxing) was clearly seen to have been done by Okene potassium feldspar, but in the usual conjunction with accelerating temperature effect. Okene potassium feldspar was seen to be a perfect flux for any ceramic fluxing, comparable to any imported fluxing material for ceramic productions.

This work served as a long needed boost to the factual implementation of Raw Materials Research Development Council (RMRDC) Technical Brief on Raw Materials in Nigeria (FELDSPAR), of April 1999.

Finally, feldspar is also an important mineral raw material not just for ceramics industries alone, but also for: glass, paper, chemical, agricultural, pharmaceutical, paint, plastics and rubber industries, where they serve as fluxes, fillers, extenders, etc.

ACKNOWLEDGEMENTS:

The authors cannot fail to make mention of the following organizations who were helpful in the execution of this work in terms of personnel and facilities: Raw Materials Research Development Council (RMRDC), Enugu, Projects Development Institute (PRODA), Enugu, Nigerian Standards

Organization (SON) Enugu, and a private ceramic furnace at Owerri.

REFERENCES:

Budnikov, P.P. “The Technology of Ceramics and Refractories” London, Edward Arnold, Pub. Ltd. 1964, Pp 512 – 519.
Burton, W. “Porcelain, its Nature, Art and Manufacture” Bastsford, London, 1906.
Campbell, J.E “The Art and Architecture Information Guide Series”, Vol. T. “Pottery and Ceramics”, a guide to information sources Gale Research 1978.
Ceramics Materials Info SOLU test.

Ceramics Today Articles – see www.ceramicstoday.com/articles/032497.htm
FORESIGHT, Ceramics Materials Info.
Grimshaw, R.W. “Physics and Chemistry of Clays”, London, Ernest Benn Ltd. 1971 Pp 29 – 34.

Grimshaw, R.W. “Physics and Chemistry of Clays”, London, Enerst Benn Ltd. 1971, Pp 37 – 54.

Jones, J.T. et al “Ceramics, Industrial Processing and Testing” IOWA State University Press, 1972.

Kingery, W.D et al. “Introduction to Ceramics” London, New York, John Wiley and Sons, Pub. Co. 1976, Pp. 655 – 669.

Lawrence, W.G. “Ceramics Science for the Potter,” Chilton Books Co. London, New York, John Wiley & sons, Pub. 1972, pp 33ff.

RMRDC Tech. Brief on Raw Materials in Nigeria (FELDSPAR), April 1999.

Rhodes Daniel “Clay and Glazes for the Potter” Pitman Pub. Co. 1975, Pp124ff U.K.

Sharp et Miall “Dictionary of chemistry” Forth Ed. Glasgow.Uk. P248

Worrall, W.E. “Clays and Ceramic Raw Materials”, London, Applied Science Pub. Ltd. 1975, Pp 24 – 33, 51 – 75, 198.

Wehmeir et Ashby “Oxford Advanced Learner’s Dictionary, Oxford University Press, UK, Pub.2000, P456

www.ceramic-materiala.com/ceramat/education282.html