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Derivation of Glaze from Cathode Ray Tubes (CRTs) for Ceramic Wares

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Abstract: *Introduction of digital display makes cathode ray tube to be largely obsolete. The tube with its screen becomes waste at the end of the products lifecycle. This study, which combined laboratory experimentation and studio practices, aimed at production of glass glaze with cathode ray tube screen. Cathode ray tubes of four different colours were used for the study. The tubes were washed, pulverized and sieved according to their colour, elementally analysed using Particle Induce X-ray Emission, and milled into two batches per colour with first batch mixed with ball clay and second batch mixed with ball clay and additive chemical material of borax. The glaze batches were applied on eight bisque-fired tiles and fired at 1100 ^{0}C. The glazes yielded greenish grey, greyish purple, transparent grey and dark grey. This is significance towards the diversification of Nigeria's economy for solving solid waste disposal challenges for a better and safe environment. The study has proven that cathode ray tubes with addition of borax and ball clay are suitable for glaze production and provided elemental information to guide the glaze formulation.*

Keywords: Art, cathode ray tube, ceramics, glaze and oxide analysis.

1. INTRODUCTION

Cathode ray tube (CRT) is a vacuum tube in which a hot cathode discharges beam electrons that pass through a voltage anode and are focused or deflected before hitting a phosphorescent screen [1]. The cells in vacuum tube are enclosed between two glass panels with metal element layer that contains the mixture of noble gases that X-ray through vertical and horizontal electrodes. Cathode ray tube was commonly used in television before the development of liquid crystal display (LCD) and plasma display panel (PDP). The hi-tech liquid crystal display (LCD) and plasma display panel (PDP) are designed with liquid crystal cells that change reflectivity in an applied electric field. With this advancement into digital display, cathode ray tube is largely obsolete and becomes waste at the end of the products lifecycle [2] [3].

In Nigeria, these tubes are indiscriminately disposed on open refuse dumps and as landfill (Plate 1). Cathode ray tube is a trioxide aluminium electric glass with a boron oxide that has been substituted by aluminium oxide and characterized by low alkali content [4]. This type of glass has high electrical resistivity and repulsive force as electric insulators. [5] observes the possible ways of extracting the pure silica from cathode ray tube by an alkali fusion route. Nonetheless, the glass in the component can be utilized in glass and ceramic industries. Cathode ray tube contains twelve components: rimband; funnel glass; frit; panel glass; shadow mask; fluorescent inver; electron beam; electron gun; neck glass; deflection yoke; magnetic shield and anodic button. Some of these components contain some impurities and contaminants materials which covered the glass functional layers. Typical cathode ray tube consists of pure silica called quart glass or fused quarts [6] [7]. The silica in cathode ray tubes comprises higher reciprocal of the conductivity than other glass types of alkali such as soda lime silica. These silica features are common to cathode ray tubes because of high electrical resistivity, high dielectric strength, low dielectric constant and relatively low dielectric loss [8].

Silica is nonetheless a major component of glaze. Percentage of silica in glaze composition determines the glaze strength and glossiness. The silica in cathode ray tube can be extracted and can be used for glass related products. Studies on silica and sodium silicate extraction from recycled cathode ray tube have been carried out by some scholars. [9] observes on how recycling of cathode ray tube can be as a source of silica or sodium silicate. [2] has experimented on cathode ray tube as material for clay body and base material for coloured glass with most colouring agent. [1] conducts a controlled test on cathode ray tube and galvanic as alternative source of alumina for anodized. [10] and similarly [11] experiments on cathode ray tube as additive flux in glasslike glaze production. Glass and glaze are not the same but are related. Frit is a synergy between glass and glaze and which in properties arrangement influenced glass or glaze results. Cathode ray tube glass is a brittle transparent solid with irregular atomic structure of higher percentage of siliceous dioxide [12] while glaze is a mixture of powdered materials that often include a pre-melted glass made into a slip for surface of a ceramic body [13].

Glaze is a vitreous glossy substance and fusion-bonded for gloss-coating of earthen-wares for strength, smooth surface and substrates chemical inert. Glaze, no doubt is a substance that is required on finished ceramic wares production [14]. [3] had earlier observed that glaze on the surface of a ceramic body makes it hard, non-absorbent and easily cleaned. Glaze consists of four key components. These components are silica, alumina, fluxes and colorant. Glaze derivation has posed serious challenges to formulators from materials processing to requisite balanced composition. The main parameters for glaze derivation are still unclear [15] and this is perhaps the reason that glaze derivation still maintains its artistic mystique and significance even in the face of comprehensive scientific study and understanding [16].

No doubt, glaze derivation is not alien to Nigeria. The glaze among the Nigerian cultures is however a form of liquid concoction that provides very thin shinning coating on ceramic wares [17]. Nonetheless, ceramic practice has generally moved on from the use of clay to high derivative substances such as enamel, cement, kaolin, glass and other materials used in informatics, electronics, biotechnologies, mechanical and power industry contexts [18] for ceramic glaze products like electrical insulator, heat resistor, part of aircraft and space shuttles, computer chips and some components of machine, submarines and blast furnace linings all of which require high temperature resistant, chemical resistivity and mechanical stability [19] [17]. Many of these products are encrusted with vitreous glossy (glaze) substance for stability processes against corrosion and fission. However, waste glass can be repeatedly used without any notable changes in their physical properties [2] [20] and could be considered as a substitute for glass former in recipes composition for ceramic glazes [21][22].

End of life cathode ray tube constitutes a serious disposal problem in several municipalities in Nigeria. The common disposing practice for this glass as non-recyclable material is landfill. Apparently, cathode ray tube is a non-biodegradable material and landfill practices contribute to environmental degradation. The economic wastage of non-utilization of cathode ray tube in recycling industries is a significant draw back to the economy of the country. However, the inadequate disposal of this material requires alternative usage because it can remain dangerous to humans and the environment.

Against the foregoing backgrounds, this study examined the possibility of glaze derivation from cathode ray tubes and elemental analyses of their chemical and physical properties. The aim of the paper is to produce ceramic glaze with cathode ray tubes and apply the glaze for the finishing of earthen ware. The objectives of this study are to: conduct elemental analysis of selected cathode ray tubes and other additive materials for glaze production; determine the appropriateness of cathode ray tube for glass glaze production; and to apply the produced glaze for the finishing of earthenware.

2. METHODOLOGY

The research design for this study combined three research components. These are field research, laboratory analysis, and studio artistic practice. Field research was used to determine all orthogonal variables that were encountered as a result of chemical composition of the materials, environmental implication, availabilities and collection. This method was necessary because end of life cathode ray tubes is commonly found in electrical workshops and waste dumps (Plates 1 and 2). The laboratory analyses were employed to determine the elemental and oxides concentration of the samples. The studio artistic practice was utilised for the glaze production and glazing.

Plate 1: Cathode ray tubes samples on waste dump

Plate 2: Cathode ray tubes

2.1 Samples Treatment and Oxides Analyses

Collected samples were subjected to two phase treatment to get rid of some non-glass coated materials. These foreign coated materials which are non-glassy required comprehensive cleaning. The collected cathode ray tubes were broken into small units before treatment. The process involved thorough washing and heating to thaw these extraneous materials before using them as glaze recipes. The materials were first washed with water and soap that emulsified impurities from the glass. The samples were dried after thorough washing before being subjected to the second phase of heating. The kiln used was wood fuel structured with heat resistant bricks layer and double skin insulators. The materials for the wall bricks were combination of dense refractory bricks and insulating foamy refractory bricks lining for the inner chamber. In the kiln are combustion area below the chamber and two large fire boxes area in opposite side of the structure.

The glasses were stacked in the crucibles before being placed in the kiln for heating (Plate 3). The heated pieces were observed through spy hole and chimney vapour after two hours and the fire was raised for actual firing until it's fired to 120 ℃ which took two hours thirty-two minutes (2 hrs 32 mins). The glasses were offloaded five (5) hours after firing. The offloaded glasses were subjected to second thorough washing to remove fly ashes and other contaminants. The samples were thereafter hammer-milled with jaw mill to break them into small chips. The cullet chips were re-washed (Plate 4) before being pulverised.

Plate 3: Sealing of kiln with bricks

Plate 4: Washing of hammer-milled cullets

The pulverization was done with Rocklabs Pulverizer Machine (model CRC 3E) at the Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife, Nigeria. For the purpose of elemental analysis and batch milling of glaze composition, pulveriser machine was regulated for one (1) minute on account of high siliceous oxide content of cathode ray tubes' glasses. Borax and ball clay were regulated for thirty (30) seconds. Thereafter, samples were sealed in plastics for further actions (Plates 5-7). To avoid samples intermixture during pulverisation, discs were washed after each operation with clean water and they were thoroughly dried before the next operation. This was done to prevent samples contamination and humidification respectively.

Plate 5: Pulveriser machine

Plate 6: Pulverised CRT

Plate 7: Pulverised borax and clay

After laboratory pulverisation of the samples has been satisfactorily done, samples were pelletized with carver hydraulic press for oxide analysis. The dried pelletized cathode ray tube, borax and ball clay were subjected to laboratory analysis of elemental properties. The qualitative and quantitative elemental properties of the samples were analysed through Particle Induce X-ray Emission (PIXE). This equipment analysed the elements and oxides of each sample in percentages.

2.2 Glaze Compositions

The pulverized materials were carefully measured to take into account the weight ratio of borax and ball clay to the primary samples (cathode ray tube). The milling exercises were done in two (2) phases of intermixture for each pulverized cullet sample to the addition of ball clay and ball clay/borax. The batch constituents by percentage were highlighted in simple addition ratio of hundred percent (100%) in Table 1.

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Table 1: Batch constituents by percentage (100%)

Sample Colour	Greenish Gray		Greyish purple		Transparent gray		Dark Gray	
Sample Batch	1	2	3	4	5	6	7	8
Compositions	$CRT_{gg}B$	$CRT_{gg}BB$	$CRT_{gp}B$	$CRT_{gp}BB$	$CRT_{tg}B$	$CRT_{tg}BB$	$CRT_{dg}B$	$CRT_{dg}BB$
Sample	90	70	90	70	90	70	90	70
Ball clay	10	10	10	10	10	10	10	10
Borax	-	20	-	20	-	20	-	20
Total	100	100	100	100	100	100	100	100

2.3 Studio Application

Eight small rectangular tiles of five centimetres by eight centimetres with numeric and alphabetic inscriptions at the back for identification were moulded. The engraved numerals were 1 to 8 while the alphabets were A and B. The inscriptions represented each sample batch mill composition. The purpose of the tiles was to test the glaze behaviours on the surface of the biscuit wares. The thoroughly exsiccated tiles were placed in the kiln for biscuit firing phase of the wares. The kiln was sealed immediately for pre-heating. The pre-heated pieces were monitored through spy hole and chimney vapour. After two hours, the process was raised for actual firing until it fired to 750 ℃ which took ten hours thirty-two minutes. The pieces were offloaded fifteen (15) hours after firing.

All the tiles were drenched in water and desiccated to permit the cullet ceramic glazes alignment and penetrability to the clay body. Cullet ceramic glazes were thereafter applied on the biscuit ceramic tiles. The cullet-ceramic-glazes were applied on the eight (8) biscuit ceramic tiles. Dipping method was adopted for the application after thorough and vigorous shaken of each glaze composition in the bottles (Plates 8-9).

Plate 8: Dipping of biscuit tile in a cullet-ceramic-glaze recipe

Plate 9: Cullet-ceramic-glaze dipped biscuit tiles

The glaze coated tiles were exposed to dry in open air. The drying period of each glaze compositions varied. Some dried quickly while some took several hours. After thorough desiccation of glazes on bisque wares, the coated-tiles were stacked in gas kiln with cone beside the spy-hole for easy examination of cone reactions to the heat. The kiln was sealed off with fired bricks leaving two spy-holes as monitoring channels to the kiln chamber. The firing was for eight and a half hours. Firing commenced at 8:34 pm and was stopped at 4:58 am when it became obvious that the 1100 ℃ temperature cone had bent. The kiln was permitted to cool for about fourteen hours that is from 4:58 am till 6:00 pm, before the glazed wares were off-loaded.

3. RESULTS AND DISCUSSION

The dominant oxides in the six (6) samples are (Na_2O, MgO, Al_2O_3, SiO_2, CaO, TiO_2, PbO B_2O_3 and FeO) while (P_2O_5, SO_3, K_2O, ZnO, ZrO_2, Sb_2O_5, Rb_2O, SrO and BaO) were not significant in terms of percentages and some were below detection limit of the equipment used in this study. The concentrations of each oxide in these samples are highlighted in Table 2.

Table 2: Oxide Properties of Cathode Ray Tube, Borax and Ball clay

Oxides	Greenish Gray	Greyish purple	Transparent gray	Dark gray	Borax	Clay
Na_2O	7.35	9.01	11.46	10.74	32.33	6.06
MgO	1.09	0.66	2.16	0.86	0.22	1.48
Al_2O_3	0.60	0.41	0.25	0.42	0.14	6.04
SiO_2	59.71	68.88	74.68	72.46	1.82	71.46
P_2O_5	0.15	0.19	0.11	0.13	0.02	0.18
SO_3	-	-	0.22	-	0.24	-
K_2O	7.85	5.63	2.47	3.48	-	6.74
CaO	1.20	1.60	3.47	3.99	0.43	0.49
B_2O_3	-	-	-	-	64.65	-
TiO_2	-	-	0.07	0.11	-	0.53
FeO	0.05	0.09	0.13	0.20	0.04	6.45
ZnO	0.22	0.10	0.03	0.07	-	0.01
ZrO_2	0.59	0.82	-	0.40	0.04	0.09
Sb_2O_5	0.14	0.28	-	0.02	-	0.42
Rb_2O	0.04	0.41	-	-	-	0.03
M_0O_3	0.08	0.11	-	0.05	-	-
SrO	2.77	2.83	0.77	1.31	0.03	0.01
BaO	5.72	8.76	4.09	3.75	-	-
PbO	12.43	0.63	0.11	2.01	0.05	-
Total	100.00	100.00	100.00	100.00	100.00	100.00

The glazes formulated with cathode ray tube and addition of ball clay and borax ($CRT_{cl}BB$) as flux came out better while cathode ray tube batch-milled with only ball clay ($CRT_{cl}B$) did not mature properly at 1100 °C but yielded matt with glossy-bubble effects. The visual results of the tiles are presented in the Tables 3 and 4. The tables indicated the kiln trial temperature results, as well as the colours appearance, matured surface quality of the glazes and resistance to flow of the glazes' batches.

Table 3: Plates and physical analysis of trial batches after kiln and firing

Glaze results	 Plate 10 Batch 1: $CRT_{gg}B$	 Plate 11 Batch 2: $CRT_{gg}BB$	 Plate 12 Batch 3: $CRT_{gp}B$	 Plate 13 Batch 4: $CRT_{gp}BB$
Recipe compositions	**$CRT_{gg}B$**	**$CRT_{gg}BB$**	**$CRT_{gp}B$**	**$CRT_{gp}BB$**
Test Ware	Tile	Tile	Tile	Tile
Output colour	Greyish-blue	Greyish-green	Greyish-green	Greyish-green
Matured surface quality	Glossy	Glossy	Glossy	Glossy
Modification	Required flux	Not needed	Adjust flux	Not needed
Composition evaluation	Fair	Good	Fair	Good
Resistance to flow	Thick	Thick	Thick	Thick

Table 3 presents the result of glazes formulated with greenish-grey and greyish-purple cathode ray tube glasses (CRT_{gg} and CRT_{gp}). The four batches in the table were fired at 1100 °C temperatures. Plates 10 and 12 were the results of the glaze compositions of batches 1 and 3 with addition of only ball clay. As reflected in the visual plates, the two batches required higher temperature of 1200 °C and above to optimize the glossiness. Plates 11 and 13 which are the results of batches 2 and 4, composed with addition of ball clay and borax gave good results in terms of glossiness and smoothness. Evidently, batches 2 and 4 are the most successful of the four batches. Their glaze results are between opalescent and glossy. The visual results of the four batches showed the significance of each composition to their thermal expansion and melting temperature.

The physical features of all four batches at 1100 °C are nonetheless good in terms of glossiness except pore formations in the batches 1 and 3. The optimize temperature demanded by batches 1 and 3 could be attributed to percentage of silica oxide in the glass type or glass-particle density which determines glossy effect. The melting temperature differences of the batches 2 and 4 with borax and batches 1 and 3 without borax can be attributed to oxides in the borax which contain more melting diminution of boron, sodium and potassium oxides. The pore formations on the surface of batches 2 and 4 results could equally be ascribed to thermal compatibility of the glaze materials and the host bodies which can be eradicated with addition of more binding materials.

Table 4: Plates and physical analysis of trial batches after kiln and firing

Glaze results	 **Plate 14** **Batch 5:** $CRT_{tg}B$	 **Plate 15** **Batch 6:** $CRT_{tg}BB$	 **Plate 16** **Batch 7:** $CRT_{dg}B$	 **Plate 17** **Batch 8:** $CRT_{dg}BB$
Recipe compositions	**$CRT_{tg}B$**	**$CRT_{tg}BB$**	**$CRT_{dg}B$**	**$CRT_{dg}BB$**
Test Ware	Tile	Tile	Tile	Tile
Output colour	Greyish-blue	Greyish-green	Greyish-green	Greyish-blue
Matured surface quality	Glossy	Glossy	Glossy	Glossy
Modification	Adjust flux	Not needed	Adjust flux	Not needed
Composition evaluation	Good	Good	Fair	Good
Resistance to flow	Thick	Thick	Thick	Thick

Table 4 shows visual results of glaze batches 5, 6, 7 and 8 formulated with transparent-gray and darkish-gray cathode ray tubes glasses (CRT_{tg} and CRT_{dg}). These four batches were also fired at 1100 °C temperatures. Surface morphology of the four batches is similar. There are noticeable bubbles and pores on the glazed tiles. The visual results from batches 5 and 7 indicated that these two glass types can be melted as glaze with only ball clay. To fully determine the cause of this inadequacy and overcome the bubbles and pores problems on the surfaces, chemical properties of the clays used for the biscuit wares may need to be determined in the subsequent studies. This is to determine their compatibility with chemical properties of the studied glaze materials. From the visual results, batches with addition of ball clay and borax (batches 6 and 8) and batches with only ball clay (batches 5 and 7) have temperature differences. The surface results of batches 6 and 8 appeared good while batches 5 and 7 contained bubbles and pore-formations. These defects can be minimized when the batches are subjected to heat temperature of 1200 °C and above. The addition of borax will also minimize the concentration of silica oxide that shifts the melting temperature of the batches to higher degrees.

4. CONCLUSION

The study has provided good information on both the physical and elemental properties of cathode ray tubes. It has indicated that cathode ray tubes have the potential to produce pure compound of silica for glaze components and that cullet of cathode ray tube produced essential glossy qualities in glass-ceramic-glaze formulation. The study has significantly established that glazes can be formulated from cathode ray tubes with the addition of flux and ball clay as binding material. This study has also showed the possibility of making glazes through waste glass material thereby preventing capital flight and at the same time cleaning the environment. This is significance towards the diversification of Nigeria's economy for solving solid waste disposal challenges for a better and safe environment. Adaptation of the findings of this study into studio ceramic art practices will be significant for development of the Nigerian ceramic industry and economic development of the country and other context similar to that of Nigeria.

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