

# The Development of the Quality Ceramic Glazes for Small and Medium Ceramics Enterprises: Experimental Research Using Sodium Carboxymethylcellulose as an Additive in Glaze Recipes

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## Abstract

The problem of applying ceramic glazes to ceramic products first appears during the preparation of ceramic glaze recipes, an issue that is especially evident in the entrepreneurial sector in small and medium-sized ceramic enterprises. Unlike large-scale ceramics factories, these enterprises often lack advanced laboratories or specialized devices for controlling the quality of ceramic glazes. This experimental study aims to ensure the quality of ceramic glazing recipe application by providing applied chemical solutions that are determined by the proportions of additives they contain. Specifically, this experimental study focuses on the use of sodium carboxymethylcellulose as an additive that contributes to controlling the quality of ceramic glazing. In its main outputs, this study aims to provide accurate ratios of additives for glazing recipes that correspond to target application techniques at the level of small and medium-sized ceramic industries.

**Keywords:** Ceramics, Glaze, Sodium Carboxymethylcellulose.

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## INTRODUCTION

Glazes add value to ceramics by improving their appearance, including color and shine, and by making ceramic products waterproof (Pradell & Molera, 2020) [1]. Additives for ceramics glazes are materials that are added to glazes to ensure their physical working properties. They usually burn away during firing in kilns. Chemical additives in glaze recipes control the glaze's consistency, adhesion, suspension, dry hardness, rheology, speed of drying, and so forth (Andreola *et al.*, 1998) [2]. While it is common for the glazes used by independent ceramicists to contain zero additives, industrial ceramic production requires the availability of additives to ensure the quality and consistency of the glaze between similar ceramic products. When glaze compositions are prepared as aqueous suspensions, the frit is wet milled with additives and water in an alumina ball mill to obtain a glaze suspension with the appropriate rheological properties for subsequent application (Gazulla *et al.*, 2012) [3].

A variety of chemical additives are used to control the quality of ceramic glazes, with the most recognizable being classified under categories that include gum solutions, sodium silicate, wax resist substances, bentonite, and others. This study was based

on an additive material that falls under the category of gum solutions: sodium carboxymethylcellulose (CMC). CMC was developed in Germany during the World War I era as a potential substitute for gelatine (Glicksman, 2019) [4]. Feddersen and Thorp (2014) asserted that CMC is useful for its ability to control the rheology and viscosity of aqueous systems and to form strong, tough films, and is particularly effective when large volumes of CMC are used in paper, textile processing, detergents, drilling fluids, and protective coatings (Whistler, 2014) [5]. As CMC is used by the ceramics industry to suspend solids and to act as a green strength binder prior to firing (Whistler, 2014), it has no effect on the ceramic glaze after the end of the firing process in ceramic kilns. For this reason, CMC is considered an additive to the ceramic glazing recipe, not a constituent substance that affects the color or texture of the final product.

Carboxymethylcellulose, mostly used as sodium salt (NaCMC), is one of the most generally used polyelectrolyte cellulose derivatives (Lopez *et al.*, 2014) [6]. NaCMC is an anionic, water soluble polyelectrolyte with vast applications, including ceramics glazing. However, it should be noted here that the (CMC) material has many uses in the field of ceramics: it is used

not only in the composition of glazes, but also in the preparation of clay for industrial purposes. For example, according to Cerrutti *et al.*, (2017) [7], all CMC materials reported proved to be good additives to stabilize aqueous alumina suspensions with high solid concentrations.

The importance of this study lies in its exploration of the appropriate proportions of CMC for ceramic glazes used in ceramics factories, especially small and medium-sized enterprises. In the ceramic industry, CMC plays an important role in glaze formulation for different purposes, including viscosity modification, suspension stabilization, and enhancing adhesion properties. Thus, CMC was developed as an effective additive in ceramic glaze formulation because of its exceptional properties, which can considerably enhance the performance of glazes.

As mentioned, the most fundamental function of CMC in ceramic glaze is viscosity modification; to control the viscosity of the glaze slurry, CMC facilitates the proper application of the glaze to ceramic bodies. Other than viscosity, CMC also acts as an efficient suspending agent by creating a protective colloid around the coloring particles (pigments or artificial stains), thereby avoiding aggregation and sedimentation. Furthermore, CMC encourages better adhesion of the glaze coating by forming a thin layer over the ceramic body surface. We conclude from the foregoing that (CMC) plays at least three main roles in the production of effective ceramic glaze: viscosity, adhesion, and stable suspension.

CMC gum is used to over-glaze colors applied by stamping or painting, granting them a paint-like consistency. This type of gum is also essential in transparent glazes that need to adhere to and spread evenly over underglaze decoration. Furthermore, glazes with high frits benefit most from CMC gum additions since they lack clay content to harden and suspend them. From the foregoing, we can conclude that less CMC gum is needed for those ceramic glazes that contain enough clay (kaolin-bentonite clay, or ball clay), and vice versa. Conversely, the higher the clay content in the ceramic glazes, the lower the quality and brightness of their colors. For this reason, many small and medium-sized ceramics factories prefer CMC gum.

Regardless of its various benefits, the application of CMC in ceramic glaze preparation involves some challenges, the most important of which is optimizing the concentration of CMC to achieve the desired rheological properties without negatively affecting other aspects of glaze performance, such as color characteristics. This research focuses on adjusting CMC amounts in ceramics glaze recipes specifically to recommend a practical guide for small and medium-sized ceramics enterprises. To do so, we must first

explore the synergistic interactions between CMC and other additives added to glaze properties.

### **Research Methodology: Experimental Tests in Glazing Laboratory**

**Stage 1:** Review of previous laboratory research at SQU glazing laboratory

During the previous years, the researcher used CMC material in several of his studies related to the production of ceramic glazes. To evaluate the clays of Wadi Al jizi and Wadi Mistal for ceramics industry applications, especially when used with frits to develop glazes, the chemical compositions of the ceramic glaze included CMC material (Almamari, 2023). In the direction of explore the possibilities of using Omani earthenware clays (OECs) and frits to create glazes that are suitable for local Omani ceramic works, some ceramic glaze recipes were prepared by adding small percentages of CMC material (Almamari, 2023). Before that project, the researcher investigated the possibility of using White Zircon Borax Frit (WZBF) to develop matte and opaque stable glazes that are suitable with local Omani pottery clay bodies, and some of glaze recipes include CMC as additive material (Almamari, 2022). In a previous study conducted in 2020, the researcher carried out laboratory experiments within his study in which he used Frit 3110. The experiments in that study mainly evaluated the use of Ferro Frit 3110 in different glazing recipes (Almamari, 2020). Additionally, by examining the Alanwar Ceramic Tiles Plant (ACTP) sample of local clay, the experimental work provided one of the first investigations into how educational and industrial enterprises can take advantage of local clays to produce slip casting slurries using CMC in that project (Almamari, 2020). Similarly, in a study conducted to compare the quality of pigment types from Zhong Guan Ceramic (Z.G.C.) pigments and Pottery Crafts (PC) pigments, the project aimed to determine which provides better results for teaching and artistic production in ceramic laboratories, and CMC used in developing glaze recipes (Almamari, 2020). Finally, to elevate sculpture ceramics artwork quality by providing a variety of glazing textures and decorative recipes, CMC was introduced in all glaze recipes in the project (Almamari, 2019).

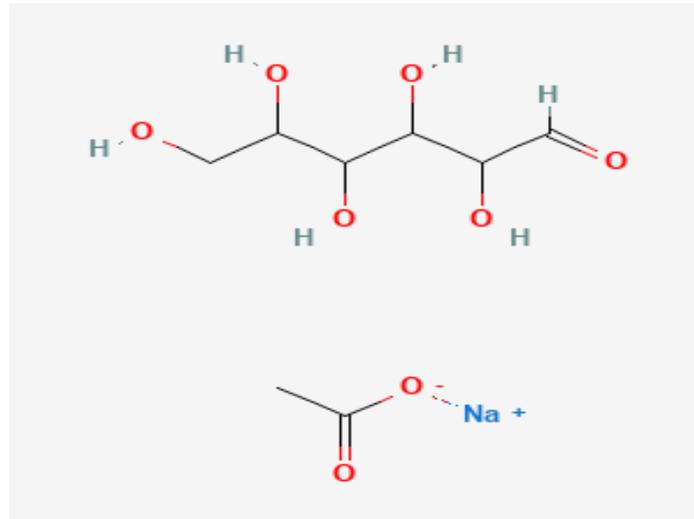
However, despite those experiments conducted over more than five years, CMC material remained marginal and was added in random proportions to improve the quality of the ceramic glaze. Therefore, this study aims to focus on improving ceramic glazes by using precise proportions of CMC material that are suitable for ceramic glazes and their applications.

**Stage 2:** Experimental Tests in Glazing Laboratory

The sample laboratory experiments of CMC [C<sub>6</sub>H<sub>7</sub>O<sub>2</sub>(OH)<sub>2</sub>OCH<sub>2</sub>COONa] N material for this study were selected from the production of (YuCMC) Company, which is classified as ceramic-grade CMC

(Product Description, Appendix 1). Figure 1 shows the chemical structure of CMC.

(Adapted from the National Institutes of Health).



**Figure 1: Chemical Structure of Sodium Carboxymethyl Cellulose (CMC)**

To ensure the measurement of the glaze quality after the addition of CMC, two fixed ceramic glaze recipes with all their components were used: Recipe 1 was to be fired in an electric kiln atmosphere at a temperature of 1063 °C (Cone 04–Orton Firing Chart),

while Recipe 2 was to be fired in an electric kiln atmosphere at a temperature of 1222 °C (Cone 6–Orton Firing Chart). Tables 1 and 2 show the chemical composition of the two recipes and the proportions of each component applied in this study.

**Table 1: Low Temperature Glaze Recipe (Cone 04)**

Recipe 1	
Dry Materials	Weight
Lead Bisilicate	60 g
Cornish Stone	30 g
Whiting	3 g
China Clay	3 g
Total	100 g
+ Colorant (Stain)	Blue Stain (3 g)

**Table 2. Mid-Range Temperature Glaze Recipe (Cone 6)**

Recipe 2	
Dry Materials	Weight
Soda Feldspar	30 g
Potash Feldspar	30 g
Flint	15 g
China Clay	10 g
Bone Ash	10 g
Talc	5 g
Total	100 g
+ Colorant (Stain)	Red Stain (3 g)

Ceramic glaze recipes weighing 100 g were prepared in the dry state before adding water, and CMC was added to each recipe in increments of 0.5 g per

recipe. Table 3 shows the addition of CMC to the glaze recipes prepared in laboratory experiments for Recipe 1 and Recipe 2.

**Table 3: Addition of CMC to Glaze Recipes for Recipes 1 and 2**

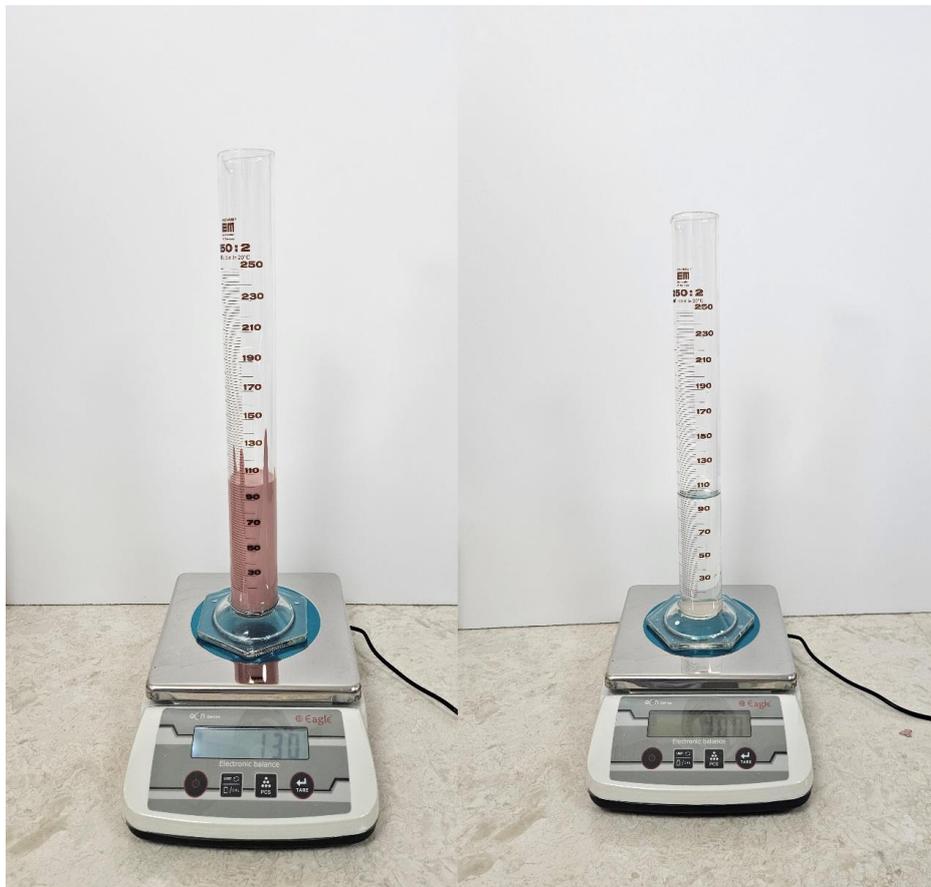
<b>Recipe 1</b>		
<b>Recipes Codes</b>	<b>Recipes Weight (Dry)</b>	<b>CMC Addition (g)</b>
Test 1/1	100 g	0.5 g
Test 1/2	100 g	1.0 g
Test 1/3	100 g	1.5 g
Test 1/4	100 g	2.0 g
Test 1/5	100 g	2.5 g
<b>Recipe 2</b>		
<b>Recipes Codes</b>	<b>Recipes Weight (Dry)</b>	<b>CMC Addition (g)</b>
Test 2/1	100 g	0.5 g
Test 2/2	100 g	1.0 g
Test 2/3	100 g	1.5 g
Test 2/4	100 g	2.0 g
Test 2/5	100 g	2.5 g

To ensure that all 10 glaze recipes were equal in the blend of all their components, the mixing process was carried out using a high-precision electric stirrer with digital display with a maximum stirring viscosity of 20,000 mPa.s. Each glaze recipe was mixed for 10 minutes at a rotation speed of 2,000 rpm.

### Methods for Measuring the Quality of Ceramic Glaze Application

The quality of the ceramic glaze of the samples composed in the laboratory was evaluated by four measurements:

- 1. Measuring specific gravity:** The specific gravity of all ceramic glaze samples was measured using a high-precision sensitive electric scale according to the law of weight of 100 ml of glaze divided by the weight of 100 ml of water (Figure 2).

**Figure 2: Measuring specific gravity of glaze samples**

## 2. Measuring smoothness of ceramic glaze when using a brush:

A mechanical instrument was developed to test an equivalent measurement between samples that differ from each other by the amount of CMC substance. This tool ensured the similarity of the test conditions; specifically, the movement of the brush, the amount of glaze that the brush absorbed, and the ceramic surfaces on which the glaze was applied. The brush was dipped into each of the 10 glaze samples applied in this study

and then passed over a ceramic surface with a numerical division of 1 cm (Figure 3). To measure the smoothness level of the ceramic glaze samples, it was assumed that the smoothness was greater, and thus better for ceramic applications, the longer the color extended over the surface of the ceramics slab. Based on this assumption, the smoothness level was determined by three levels: high smoothness (more than 6 cm), medium smoothness (between 4 cm and 6 cm), and low smoothness (less than 4 cm).

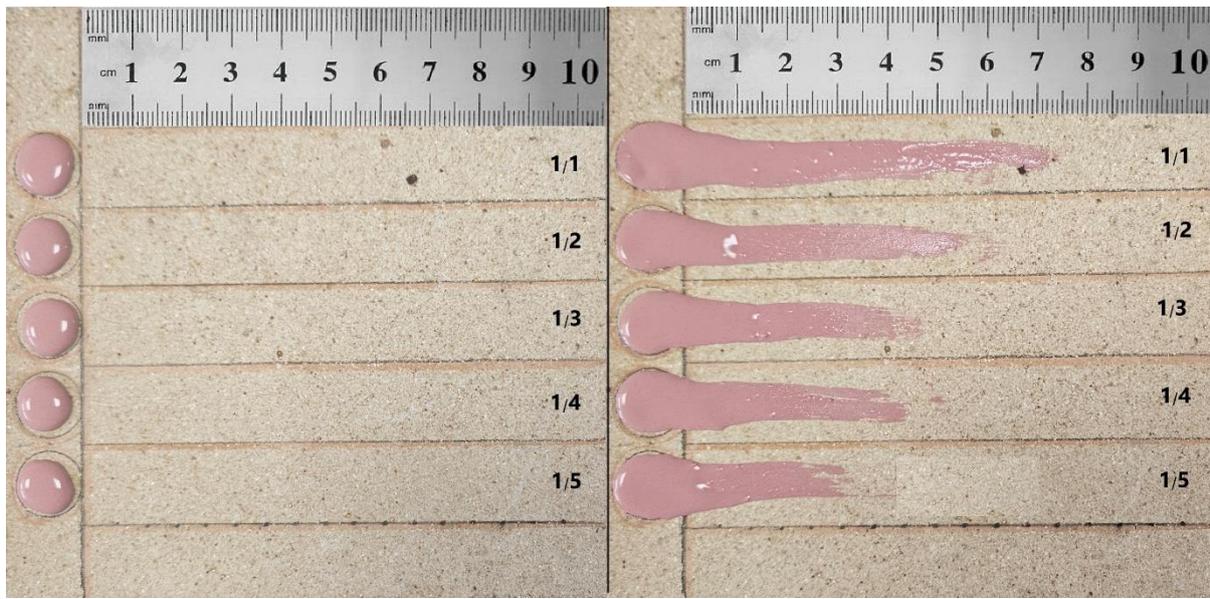


Figure 3: Smoothness measurement tool

## 3. Measuring the quality of glaze after firing:

The five samples of ceramic glazing belonging to Recipe 1 were fired in an electric kiln at a temperature of 1063 °C (Cone 04–Orton Firing Chart), while the five glazing samples belonging to Recipe 2 were fired in an electric kiln at a temperature of 1222 °C (Cone 6–Orton Firing Chart). Both firing processes were carried out in an oxidizing atmosphere, and the glaze test samples were placed on one shelf to ensure the equalization of heat inside the kiln chamber. Five of the paint defects were examined: crazing, shivering, crawling, pinholing and pitting, and blistering.

## 4. Measurement of glaze quality through direct experimentation by professional ceramicists (Independent Evaluation Team):

As a secondary measure to test the quality of the ceramic glazes, five professional potters, each with more

than 10 years of experience in ceramics factories, were invited to try out the study samples. A sample comparison instrument was built to reflect the impressions of the potters concerning the different qualities of the project's samples.

## RESULTS AND DISCUSSION

The correlation between adding CMC to glaze recipes and elevating the quality of glaze for ceramics applications was tested using four instruments: specific gravity, glaze smoothness instrument, firing impact, and professional potters' testing. Table 4 includes the results of the laboratory testing of three of the instruments (specific gravity, glaze smoothness instrument, and firing impact).

Table 4: Test Results of Specific Gravity Ratio, Glaze Smoothness, and Glaze Firing for all Samples

Recipes Codes	Specific Gravity Test	Glaze's Smoothness Test	Firing Test
Test 1/1	1.44	High Smoothness	No Defects
Test 1/2	1.48	High Smoothness	No Defects
Test 1/3	1.50	High Smoothness	No Defects
Test 1/4	1.52	High Smoothness	No Defects
Test 1/5	1.54	High Smoothness	No Defects
Test 2/1	1.48	High Smoothness	No Defects

Recipes Codes	Specific Gravity Test	Glaze's Smoothness Test	Firing Test
Test 2/2	1.50	High Smoothness	No Defects
Test 2/3	1.53	High Smoothness	No Defects
Test 2/4	1.55	High Smoothness	No Defects
Test 2/5	1.57	High Smoothness	No Defects

Regarding the fourth evaluation instrument (measurement of glaze quality through direct experimentation by professional ceramicists [potters]), which recorded the potters' impressions of the quality of the glaze samples during actual use in the studios where they worked, these opinions were studied to come up with final judgments about the best proportions of CMC to add to the ceramic glaze.

It was decided that the best method to adopt for this investigation was to create glaze recipes with different quantities of CMC. The quality of the glaze was measured by a constant variable represented by CMC, and that material changed by an average of 0.5 g from one glaze recipe to another. Although they constituted a secondary research instrument, the selected potters who comprised the Independent Evaluation Team (IET) played an important role in evaluating the results after each glaze sample was tested, especially concerning specific gravity, smoothness of the glaze, and firing.

The clearest finding to emerge from the analysis is that the IET identified the addition of 0.5 g of CMC to the 100 g ceramic glaze recipe as the best ratio if the glazing is applied by electric spraying devices. As far as meeting the main objectives of the research, the most important result was that all members of the IET agreed that the best results for glazes applied by hand brush were achieved by adding 1.0 g of CMC to any 100 g glaze recipe.

One unanticipated result was that increasing the percentage of CMC dulled the color of the fired ceramic sample, a condition that is like what happens to ceramic glazing when the proportion of clay in glazing recipes is increased. In general, all the potters participating in the glaze sample testing agreed on the importance of adding CMC to the ceramic coating because it has a direct impact on upgrading the glaze specifications for all ceramic glazing application techniques, including spraying, dipping, and brush painting.

However, the discussion held among the professional team of ceramicists (IET) highlighted the significance and variation of CMC that can be used in ceramic industries. It was noted that this material has numerous scientific and practical applications, and its composition varies depending on whether it is intended for use in ceramic manufacturing or, for example, in the food industry. Upon examination and comparison, CMC, when used as a binding agent, is typically of high purity in food-related industries and must comply with strict health and safety standards. However, such stringent

requirements are not necessary when this chemical material is used in ceramic manufacturing. Therefore, CMC specifically formulated for ceramic applications (YUCMC- Ceramic grade) was used in its powdered form in this project (Appendix 1).

One of the most significant challenges facing the ceramics industry in relation to ceramic glazes is the subtle disparity between experimental laboratory tests and practical applications in real-world industrial settings. Therefore, the transition was made from the laboratory to the applied field by implementing the experimental samples from this study through a local institution specialized in the production of ceramic glazes.

Given that one of the objectives of this study is to test the professional practical application, a private organization's laboratory was utilized to implement the study's findings. The (Takumi Glaze) enterprise was selected as the experimental field for the research, and a set of ceramic glaze recipes in various colours was successfully applied. The researcher formulated 16 glaze recipes based on the findings of the previous study. These recipes were prepared using a variety of color tones by employing industrial ceramic pigments capable of withstanding extremely high firing temperatures ranging from 1020 to 1100°C. And, to ensure the accuracy of the testing process, all ceramic glaze recipes were passed through an ultra-fine sieve with a precision rating of (Mesh-200), which is among the highest standards used in ceramic glazing applications. The finer the sieve, the better the assurance that the glaze mixture will not settle at the bottom of containers over time.

In the laboratory of the (Takumi Glaze) organization, specialized recipes were used to prepare the ceramic glaze. A (Overhead Stirrer)-type mixer was employed, featuring a rotational speed capacity of (2000 rpm). To ensure the optimal application of the produced ceramic glaze recipes, high-quality earthenware clay cups were selected. These cups underwent a first firing without glaze (bisque firing) at a temperature of 950°C to preserve porosity in the ceramic body, allowing proper absorption of the glaze. This approach represents the most common practice in ceramic manufacturing institutions; therefore, it was essential to conduct the experiments in alignment with standard application methods used by ceramicists in production sectors.

After the ceramic glazes and ceramic testing pieces were fully prepared, the 16 cups were glazed with the experimental ceramic glazes recipes and all were

fired in an electric kiln at a temperature of 1100°C. Figure (4) presents the results of the application

following the completion of the firing process in the ceramic kiln.



**Figure 4: Ceramics cups produced by Takumi Glaze enterprise made using research results**

The results, following the firing of the cups in an electric kiln at a temperature of 1100°C, demonstrated that all glazing formulations exhibited the characteristics of high-quality ceramic production. Common glaze defects—typically encountered by independent ceramicists or small to medium-sized ceramic enterprises—were absent. Through the examination of the 16 cups, none of the recognized ceramic glaze defects—classified within this scientific and industrial field—were observed. All final outcomes derived from this study were entirely free from defects of pin-holing, crazing, blistering, crawling, and shivering.

Based on the findings presented, this study recommends determining precise ratios for the addition

of CMC (carboxymethyl cellulose) according to the practical method used for applying ceramic glaze to ceramic pieces. Accordingly, a concentration of 0.5% CMC is deemed optimal for glazes applied using electric spraying techniques, while a 1% concentration is more suitable for traditional manual application methods, such as brush application. It is important to note that this study was conducted under laboratory conditions using CMC (carboxymethyl cellulose) in its powdered form. The aforementioned ratios were measured based on the addition of CMC to other ceramic glaze components, which were also in powdered form. The table (5) presents the proposed ratios for adding CMC (carboxymethyl cellulose) to ceramic glaze in order to enhance glaze quality:

**Table 5: CMC proposed ratios for Ceramic Glaze according to applications techniques**

CMC ratios for Ceramic Glaze		
Application Techniques	Recipes Weight (Dry)	CMC Addition (%) as Weight (Dry)
Electric spraying technique	100 %	0.5 %
Brush technique	100 %	1.0 %

## CONCLUSION

The present study was designed to determine if adding sodium carboxymethylcellulose (CMC) to the glaze recipes of small and medium-sized ceramics and pottery enterprises elevates the quality of their products. The clearest finding to emerge from this study is that the best ratio for adding CMC to the 100 g ceramic glaze recipe is 0.5 g if the glazing is applied by electric spraying devices, and 1.0 g of CMC added to any 100 g glaze recipe if the glazing is applied by hand brush. More information on the effects of adding CMC to glaze recipes in different firing conditions would help us to establish a greater degree of accuracy on this matter. Considerably more work will need to be done to determine the optimal percentage of added CMC to glaze when making ceramic glazes in large quantities for mass production purposes.

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## Appendix 1: Ceramic-grade CMC (Product Description)

YUCMC Co., Ltd.



## Product Description - Ceramic Grade CMC

## Description:

Ceramic grade CMC is a special excipient, plasticizer and reinforcer for ceramic industry. It is a kind of anionic cellulose ether. It is a kind of derivatives with ether structure obtained by chemical modification of natural cellulose by grafting hydrophilic groups. CMC can be used in the ceramic industry as an excipient, plasticizer, enhancer for embryonic body, and as a thickening, dispersing and stabilizing agent in ceramic glaze and floral glaze.



## Scope of application:

Ceramic grade CMC is mainly used as an additive in the ceramic industry, and is applied in the ceramic embryo body, ceramic glaze paste and flower glaze.

Physical and chemical indexes (analytical methods are available, according to GB1886.232-2016) :

## CMC Parameters

Type	C1300	C1500	C1800	C25	CH10	TCH9
1% Viscosity	1200-1400	1400-1600	1600-2000	20-30	1000-1200	200-500
pH	6.5-8.5	6.5-8.5	6.5-8.6	6.5-8.5	6.5-8.5	6.5-8.5
DS	≥0.90	≥0.90	≥0.90	≥1.0	≥1.0	≥1.0
Moisture	≤10%	≤10%	≤10%	≤10%	≤10%	≤10%
NaCl	≤2%	≤2%	≤2%	≤2%	≤2%	≤2%
Gel Particles	≤10	≤10	≤10	≤10	≤10	≤10
Black Particles	≤8	≤8	≤8	≤8	≤8	≤8

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