4

Off White Earthen Pots: A Material-Based View on its Sustainability in Jodhpur City

4.1 INTRODUCTION

The porous off-white color water pots from Jodhpur, Rajasthan, India are very effective in their function of cooling water [Roux, 2015]. The evaporative cooling of water is an age-old technology [Roux, 2015; Olorunmaiye, 1996]. Sensible heat helps moisture oozing out of porous water pots to evaporate [Olorunmaiye, 1996]. This means latent heat is gained by the oozed water molecules [Olorunmaiye, 1996]. The porous nature of the water pots helps to provide enough quantitative water transport to sustain evaporation on the outside wall of the water pot [Olorunmaiye, 1996]. This removal of latent heat from the outside surface of the water pot creates an effective thermal imbalance between the water inside the pot and the external surface of the pot [Olorunmaiye, 1996]. The age of use of the pot is a function of the rate of oozing or permeation of water through the porous structure [Roux, 2015].

As described in chapter-1 method of evaporative cooling is very effective in hot and dry climates [Mittal *et al*., 2006]. This encourages many potters from Rajasthan (a desert state of India) to craft various products of storage for perishable food items, fruits, vegetables, dairy product, and for air conditioning. The pot manufacturing process make the suitable use of local material and craft, this can be verified from use of donkey dung in manufacturing of pots as well as for pottery wheels [Roux, 2015]. Chapter-1 of this thesis has already acknowledged the availability of Equus in this region. Many researches looking this traditional method of cooling to develop alternative solution over cooling methods due to ozone-depleting substances and greenhouse effect by the CO_2 emission, energy saving, zero operating and maintenance cost and other economic factors. The clay pot evaporative cooler is an eco-friendly for human comfort. It can also be used as sustainable development for rural people and socio-economic problems [Ramkumar and Ragupathy, 2016].

(a)

(b)

Figure 4.1: (a) Off-white pots manufactured in Rajasthan (b) Red color pots manufactured in Gujarat

Red color water pots (as shown in Figure 4.1b) from the neighbouring state of Gujarat, India are also sold in Jodhpur city [Sikdar and Chaudhuri, 2015]. People of Jodhpur prefer the local off-white pots (as shown in Figure 4.1a) over red pots. This popularity is supposed to be based on traditional cultural influences or medicinal value rather than technical functionality of the water pots [Roux, 2015; Mahendra, 2014]. This discussion is encouraged by the recent and first ever ethnographic study of off-white water pots by Roux, 2015. Refrigerating water using earthen jars is both energy saving and economical compared to electric refrigerators [Sikdar and Chaudhuri, 2015; Plappally and Lienhard, 2012]. The energy aspect is hence been brought into context with technological functionality and its cultural material sustainability through the ages [Pfaffenberger, 1992; Oldham, 2011]. Therefore, physicochemical and functional properties of the off-white water pots manufactured in Rajasthan and red pots from Gujarat are analyzed and studied for the first time. Irrespective of the location, pots are characterised by a specific distribution of thickness with respect to their heights as illustrated in Figure 4.2. It is to be understood that the effectiveness in defining such minute detail regarding structure of a baked material requires a powerful scientific explanation. The approximate illustration thus provided in Figure 4.2 is of handmade donkey dung and off-white pot respectively from the same potter from Banad village, Jodhpur, Rajasthan.

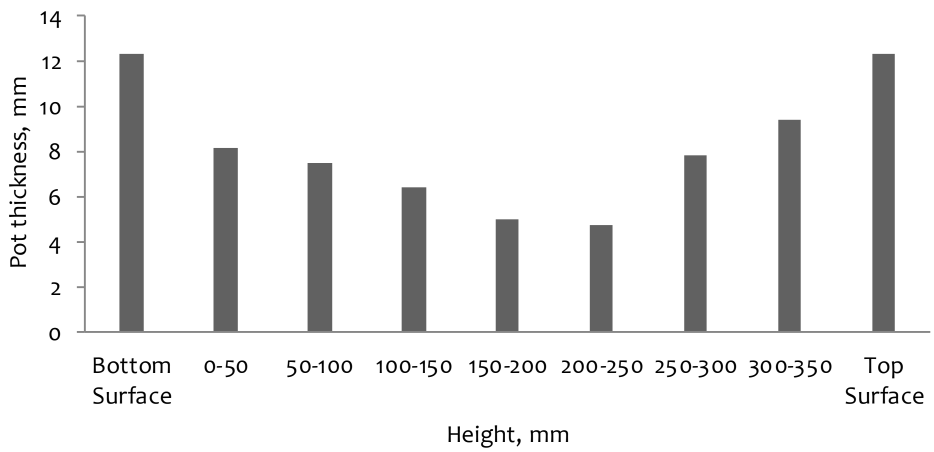


Figure 4.2: Variation of thickness with variation of the height of pots

4.2 POT MANUFACTURING IN WESTERN RAJASTHAN: A TRADITIONAL PROCESS

Table 4.1: Chemical characteristics of water in Pachpadra [Paramasivam and Mhaisalkar, 1990]

	Pachpadra	Acceptable for use
pH	7.9	7-8.5
Conductivity (µS/cm)	19000	
TDS	9100	500
Total Hardness	2170	200
Ca	276	75
Mg	360	30
Fe	0.19	
Mn	0.03	
Na	710	
K	352	
Cl^-	4550	200
So_4^{2-}	1125	200
Nitrate NO_3^-	311	45
Fluoride Fl^-	2	1

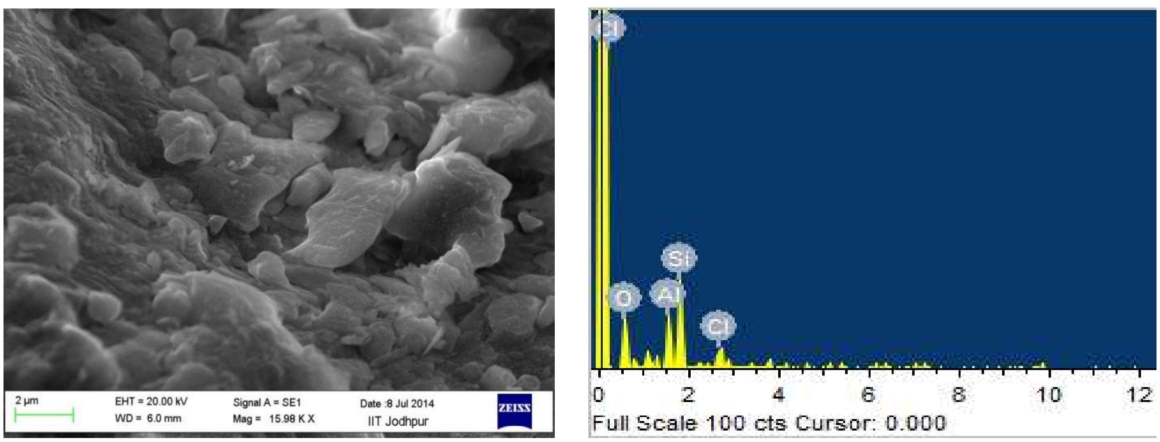
On reviewing the literature on the geological aspects of north-western India, it is expounded that Luni, the river, which flows into the Rann of Kutch (the marshy salt tract in Gujarat, India) transports salt from the salty earth at the Luni river basin in Rajasthan [Oldham, 2011]. Oldham, 2011 also assumes a ponding of seawater or an arm of seawater nearby Luni in the post tertiary times. This assumption is seconded by the fact that Pachpadra was major lake of salt in Barmer [CGWB, 2008].

Specific conductance in Barmer ranges between 385 to 46,580 µmhos/ cm. at 25 °C in Pachpadra [CGWB, 2008]. It is to be noted that seawater conductivity is close to 50,000 µmhos/cm [RMC, 1990]. Table 4.1 provides the compositional aspects of Patodi village water in Pachpadra district of Barmer, Rajasthan, India. Table 4.1 also confirms the salty characteristics of the soil at Pachpadra.

4.2.1 Traditional Method of Selection and Processing of Raw Materials

(a) Clay

The selection of clay is very important act of pottery. The potters used only the clay from the same location their ancestors used to gather from. The clay is derived from local sources such as small ponds (*Nadis*). In these natural depressions on the earth crust, the clay gets deposited due to natural weathering process [Handler, 1963; IBM, 2014]. The kaolin-based clay excavated from these locations in bulk is dumped at a specified location near to the potter's house where it is sundried. The degeneration process makes the soil better to work. The soil samples from Sar village have been analyzed under the SEM and spectra is plotted in Figure 4.3 below. It is observed that the clay contained large amounts of chlorides.



(a) (b)

Figure 4.3: (a) SEM image of the clay of Sar village, Jodhpur, Rajasthan [Carl Zeiss EVO 18 SEM, IIT Jodhpur] (b) EDS plot for the clay of Sar village, Jodhpur, Rajasthan [Carl Zeiss EVO 18 SEM, IIT Jodhpur]

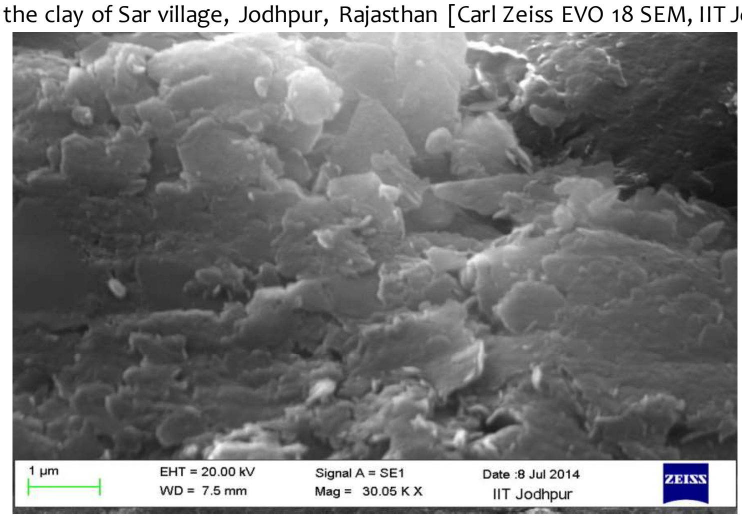


Figure 4.4: SEM Image of saltpetre or kalmishora [Carl Zeiss EVO 18 SEM, IIT Jodhpur]

(b)Tempering Material

Different tempering materials including sand, grit, lime, granite grit, mica, and lime have been used by potters in the different parts of the country. Mixing a calculated amount of tempering material makes the soil and sawdust composite firm and fit for mixing and throwing onto the wheel. Saltpetre (chemically potassium nitrate) is crystalline in structure [Hill, 1981]. It is used as a tempering additive by potters of western Rajasthan. This material helps to bring the ball or plastic-fired clay to the leather-hard stage. Saltpetre has been analyzed using SEM and image is shown in Figure 4.4. Saltpetre which is not a combustible material but when heated at more than 550 °C, it decomposes brilliantly with a noise. This will provide an enhanced atmosphere for better combustion which will be location specific [Freeman, 1957; Jones, 1826].

(c) Organic Ingredient

Donkey dung finds its use in pots manufacturing at Pachpadra at western Rajasthan. In present days donkey dung is getting substituted by sawdust to the basic clay composites used to manufacture the pots, cooking vessels, flower vase etc. The pots made of using donkey dung are light in weight (4.20 kg) compared to off-white pots (4.35 kg) made of using sawdust. However, use of donkey dung in pots manufacturing needs more effort than sawdust as donkey dung fibers are much adhesive in nature than sawdust. Local potter community acknowledges the role of women potters in processing the organic ingredients as well as clay for mixture preparation. The people of western Rajasthan cite donkey dung use as a medicinal material for preventing eyes infections. Donkey dung composite does not require tempering using saltpetre as used in sawdust-based pots manufacturing.

4.2.2 Mixture Preparation for Cruse Manufacturing

Traditionally three ingredients, salty clay, sawdust and granite gravels are used to form the mixture for pot manufacturing. The composition of a single pot is obtained considering that mixture is used for making 25 similar pots. The mixture content 5 *Tagri* (local volume, 1 *Tagri* =9 Liter water) of that clayey soil. About fifteen liters of water is added to produce the green mix. The other constituents are 1 *tagri* of sawdust (obtained from the nearby area) and 2 kg of saltpetre. The variation in concentration of each constituent affects the various physical, chemical, and cooling properties of the pots. For example, an increase in sawdust will definitely increase the cooling capacity. However, instead of sawdust if animal dung is used then cooling capacity is increased relatively higher manner. On other hand the excess of sawdust and saltpetre causes leakage. The mixture is generally prepared by male potters [Home, 1952].

4.2.3 Throwing or Turning of Green Composite

Figure 4.5: Electrically operated pottery wheel

As discussed in previous sections, women potters help in preparation of raw material and mixture while men potters cast the pots on the wheel that may be hand operated or an electrically driven wheel. An electrically operates pottery wheel is shown in Figure 4.5. Shaping the clay using the potter's wheel is called "throwing" (coming from the old English word "thrawan" which means to twist or turn) [Krueger, 1977]. Here required an amount of previously prepared mixture is flung upon flat wheel surface then thumb, fingers and palm are used to draw into a cylinder-shaped the product and then detached from the base using a thread. At the time of gradually shaping the clay the wheel rotates at variable speeds to get the final shape of the pot. The raw shape is obtained from hand building which is purely random and depends on potter's experience in pot manufacturing.

As previously discussed, the wheel used in this operation is spun by hand, wooden stick, or by an electric motor [Dumont, 1952]. The pot manufacturing process on pottery wheel includes various steps like centering, opening, pulling, shaping, and turning. These processes are similar and used in the manufacturing of flower vase, utensils and other earthenware also. It is similar to turning process (which is performed on lathe machine) in which the job is held between the jaws of the machine and extra material is removed to get the desired shape. Further, the green vessel is preheated under sunlight during winter. However, during summer it is done under the shade.

Curing under the sun provides optimum hardness and plasticity for further processing. Then "hand building" is used and "paddling" is performed, which provides the required shape and size for the pots [Kramer, 1997]. In this process one-day aged greenware is held between thigh, foot, and supported from inside while beating with tradition tools. During beating moderate pressure is thus applied with each of the strokes while turning slightly [Dumont, 1952]. This results in plastic clay to deform as intended by the potter. During this paddling process some potters use sawdust which acts as lubricant similar to the lubricant used in other manufacturing processes. The strength gets increased due to the compaction with time during this process. Once the shape is prepared final finishing is given by applying water. The shape gets paddled using "*Thapi*" and "*Kunderi*" (small and big size paddles) to give a required size. These tools are illustrated in Figure 4.6. Once shaped the thrown pot looks similar as shown in Figure 4.7.

Figure 4.6: Traditional paddling tools used in Indian pottery manufacturing

(a)

(b)

Figure 4.7: (a) Thrown cruse (b) Paddled cruse

4.2.4 Firing the Greenware in Klin

Manufacturing of pots is a seasonal process and is not carried out during rainy and summers periods in western Rajasthan [Vincentelli, 2000]. As far as baking is concerned it has traditionally been done using two firing techniques open firing and firing in a kiln [Ravi *et al*., 2007]. Out of these two techniques open firing is oldest and still popular among potters of different parts of India [Ravi *et al*., 2007]. The kiln preparation and loading require 2-3 hours while the firing time depends on the type of firing method used. The firing is usually done in the night and then the ripe products are laid in the furnace until next morning for cooling [Roux, 2015].

For an Asian potter, type of baking is a technical process choice rather than thought of design [Guo, 2017; Roux, 2015]. These procedural choices correspond to the local cultural traditions, climate, hereditary knowledge inertia, and social narratives related to local deities [Guo, 2017; Roux, 2015]. The technological changes are more resistant to adoption in domestic manufacturing than decorative styles [Habicht-Mauche, 2006]. The firing process is usually done on a flat surface where the raw products are arranged in a circular pattern over a bed of dried chopped grass or similar materials from agriculture waste. Agriculture waste, animal dung, twigs; leaves are used as a fuel in this technique [Roux, 2015].

Firing provides temperatures of 500 °C to 850 °C [Vincentelli, 2000]. This technique did not leave much waste and hence less technological evidence of its practices [Vincentelli, 2000]. The open firing process may not need infrastructure but requires great technical expertise and observational skills to obtain required results [Perryman, 2008]. Potters did practice sustainable knowledge transfer of this technology within their own household [Perryman, 2008]. Another observation antithesis to ethnographic thought process is that technology transfer is performed by potter women (in India) inheriting and transferring the materials knowledge of the soil, mixes additives and the transport phenomena in clay [Kramer, 1997].

4.2.5 Pot Decoration and Finishing

Generally, the pots used for rituals and other festive occasion are decorated using clay, lime, and other materials. The decorative work is usually done by women potter in the family. The artistic work on pots increases aesthetic value thereby increases the cost also.

4.3 EXPERIMENTAL METHODOLOGY

4.3.1 Selection of Sample Pots

In the earlier section the processes of manufacturing the cruse by native potters was elaborated. Once produced they are marketed as Rajasthani and Gujarati variety pots considering their location of origin. For the present study off-white pots made of salty clay were procured from a potter in Banar, Jodhpur, India [Roux, 2015; Oldham, 2011; CGWB, 2011]. The culturally significant manufacturing process of these pots is extensively studied elsewhere [Roux, 2015]. Similarly, the red pots made of black soil were procured from a pottery shop in Jodhpur, Rajasthan, India [Sikdar and Chaudhuri, 2015]. One pot among each is carefully circumferentially cut using a ceramic (Bosch GDC121 professional) cutter. These cuts were made at every 50 mm from the base considering it as the first cut.

4.3.2 Characterization of Off-White and Red Pots

The chemical constituents in the off-white and red water pots were found using X-ray fluorescence spectroscopy (XRFS) at AIRF, JNU, New Delhi, India. The distinction in the firing temperature of off-white and red water pots was elucidated using Fourier transform infrared spectroscopy (Bruker TM Vertex, 70V, Germany) [Annamalai *et al*., 2014]. The IR study was performed after a day of local manufacturing. These cruse samples are gathered such that cruse internal and external surfaces also get analyzed using scanning electron microscopy (SEM). The XRF, SEM, and FTIR data from an average of four separate samples are taken from two off-white and two red pots respectively.

4.3.3 Compressive Strength Tests

Compression tests were performed on specimens from both off-white and red pots with a mean thickness of 6 mm, an area of 10 mm x 20 mm. The specimens were derived distinctly from specific height ranges 0-50 mm (base of the pot), 50-100 mm, 100-150 mm, 150-200 mm, 200-250 mm and 250-300 mm respectively. An average of 30 samples was derived from each height range in order to satisfy the central limit theorem [Ang and Tang, 1975]. All specimens derived belonged to a distinct off-white and red pot respectively. They were manually shaped by ceramic cutter (20 mm x 20 mm). These samples were tested for compression following ASTM 1358 standard on a UTM (Model EZ-50, Lloyd Instrument, Germany). The loading rate of 1mm/min was applied [Luong *et al.*, 2011]. Tests were conducted at a temperature of 27 °C and a relative humidity of 20-25%.

4.3.4 Water Cooling Studies

Water temperature is measured at regular time intervals once water is filled in the water pots for cooling. Distinct quantitative conditions of filling the water pots (four individual pots of each variety) are also analyzed. Type-T thermocouple (Z2-T-2M (IEC), Lab facility, UK) is used for measuring timely changes in water temperature, dry bulb and wet bulb temperature inside the closed pots, and ambient daytime temperature at indoor open studio at IIT Jodhpur old campus at MBM college Jodhpur [Eckert and Goldstein, 1976]. The USB-TC-08 (Pico Technology, UK) data logger is connected to the T-thermocouples and personal computer.

4.4 RESULTS AND DISCUSSION

4.4.1 X-Ray Fluorescence Results

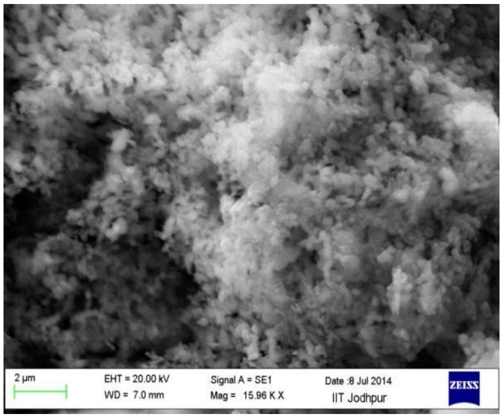
Table 4.2: Chemical constituents present in red and off-white water pots

Element (weight %)	Red pot	Off- white pot
CH_2	5.883	4.639
SiO_2	57.87	54.43
Na_2O	0.63	2.23
Al_2O_3	17.55	15.55
CaO	2.25	8.13
Fe_2O_3	8.22	7.34
K_2O	3.23	2.76
MgO	2.82	3.14
P_2O_5	0.18	0.25
TiO_2	0.87	0.74

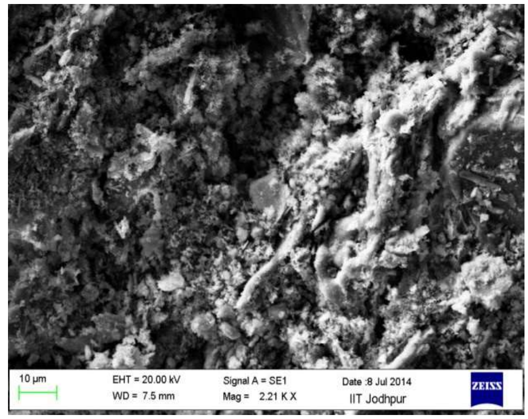
Table 4.2 shows the presence of different chemical constituents in the off-white and red water pots (XRFS measurements). These measurements are denouement from florescence spectroscopy of sixteen samples as exclaimed above in Section 4.3.2. SiO_2, Al_2O_3, CaO, and Fe_2O_3 are major constituents of off-white water pots while SiO_2, Al_2O_3, and Fe_2O_3 dominated the red water pots. High Na_2O content in off-white pots supports the salty nature of the soil used in off-white pot manufacture [CGWB, 2011; Oldham, 2011; Roux, 2015]. Comparatively low Fe_2O_3 and higher MgO is observed in off-white pots than in red pots.

4.4.2 Internal and External Surface Topology

The internal wall of the pot is red in color. This is clear from the comparatively high percentage of Ca and Fe in the composition as discussed in section 4.4.1. It is also to be noted that the anaerobic conditions that may prevail within the pot during the firing process. This enhances the combustion to occur at an excess of carbon dioxide and the escape of water vapour and other gases are directed from inside to outside of the pot. Close observations also reveal that the chlorides in the clayey soil as well as in water will play a role in the transport that will occur across the porous media and the electro-kinetics during the sintering process. Chlorides in water will be in the form of hydrochloric acid. The internal requirement of a granular yet smooth surface with an arrangement of close pack structures is depicted in Figure 4.8. The outside or external view of the pot is white colored. The abundant Mg and Ca compounds in soils will oxidize to form MgO and CaO which combine to form a white amorphous mass. The oxidation is also enhanced by the combustive atmosphere created due to the oxygen evolved from saltpetre at high temperatures.



(a)



(b)

Figure 4.8: (a) Internal and (b) External surface topology of off-white pots [Carl Zeiss EVO 18 SEM, IIT Jodhpur]

4.4.3 FTIR Spectroscopy Results

Figure 4.9 elaborates the presence of quartz (794, 690 and 460 cm^{-1}), iron oxides (583 cm^{-1} and 521 cm^{-1}) and Si-O stretching (1019 cm^{-1} and 982 cm^{-1}) in both type of water pots [Palanivel *et al*., 2011; Ravisankar *et al*., 2013; Velraj *et al*., 2009]. The pronounced character of calcite (1440 cm^{-1}) in the spectra of off-white water pot sample indicates that pots were not fired above 800 °C in comparison to red water pots from Gujarat [Gunasekaran and Anbalagan, 2007; Palanivel *et al*., 2011]. Calcite decomposes in the range 800-850 °C depending on the crystal size [Gunasekaran and Anbalagan, 2007; Palanivel *et al*., 2011]. This study also enumerates the energy intensive firing requirement for red pots in comparison to off-white pots.

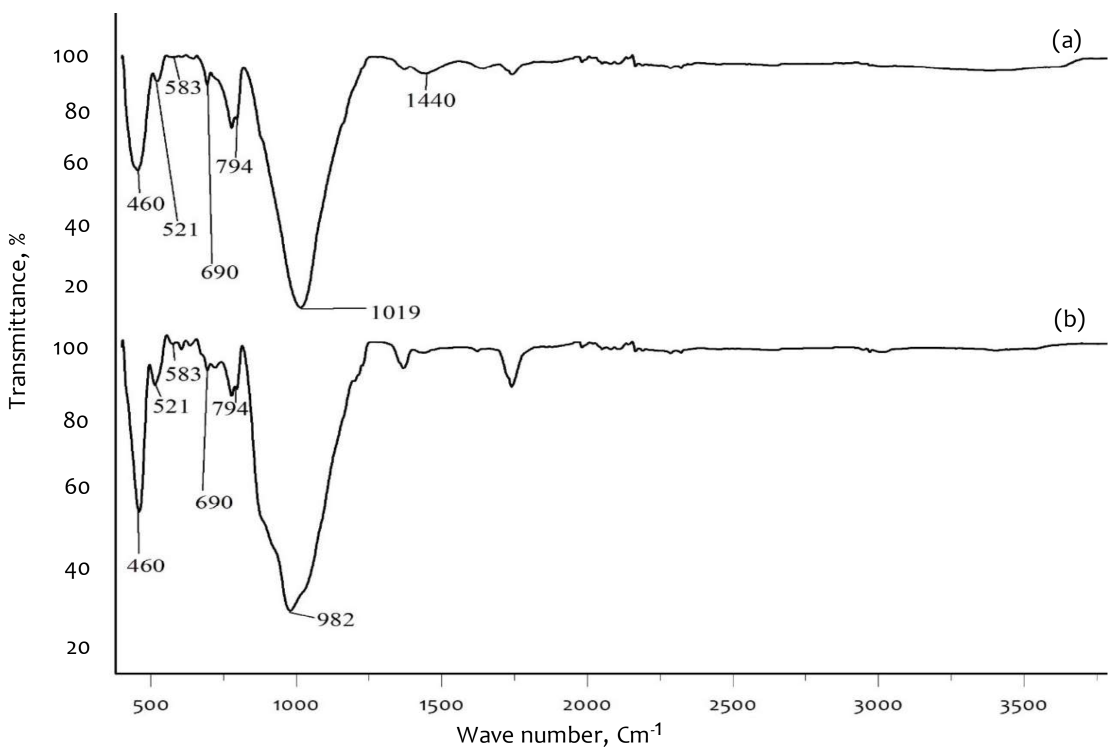


Figure 4.9: FTIR Spectra of (a) off-white water pot (b) red water pot [Origin Pro 16 Software, IIT Jodhpur License]

4.4.4 Modeling Compressive Strength of Cruse

Compressive strength studies were performed on the cut samples (Bosch GDC121 professional) from distinct height of the cruse with the base as the first cut (0-50 mm). From Figure 4.10 below, a non-linear variation of compressive strength versus height of water cruse is observed. This hints at a probabilistic modeling strategy as enumerated in Plappally *et al.*, 2011. An enumeration of the model development is reviewed in section 2.8.4. To apply this model here two new parameters compressive strength Y_{pot} and height of water pot X_{pot} are defined, which mathematically can be represented by Eq.(4.1).

$$ln\, Y_{pot}\ \alpha\ ln\, X_{pot} \text{ where, } \alpha \text{ is symbol of proportionality} \tag{4.1}$$

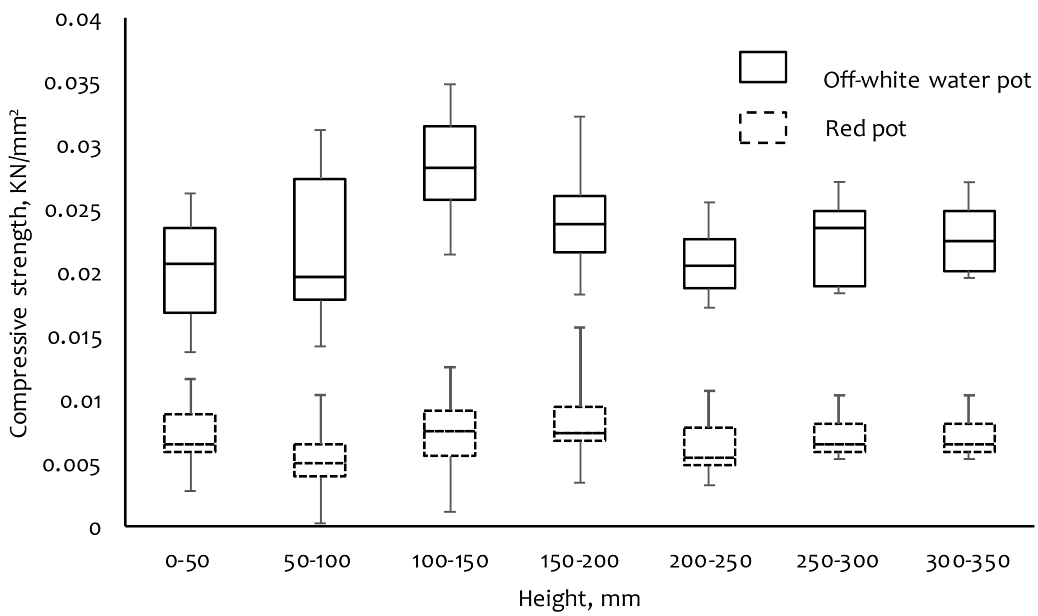


Figure 4.10: Strength as a function of the height of the off-white and red water pots

It is also known that quotient variable in $\frac{ln\, X_{pot}}{ln\, Y_{pot}}$ can help reduce the response variable $\ln Y$ yet preserving its properties [Plappally *et al.*, 2011]. This would mean a non-linear relation between $\frac{ln\, X_{pot}}{ln\, Y_{pot}}$ and $ln\, X_{pot}$ [Plappally *et al.*, 2011]. This non-linearity can be written by Eq.(4.2) [Plappally *et al.*, 2011] as,

$$\frac{\ln X_{pot}}{ln\, Y_{pot}} = a_1 + b_1\, ln\, X_{pot} \tag{4.2}$$

Table 4.3: The regression models for compressive stress conforming to Eq.(4.2) for both off-white and red water pots

	a1	*b1*	R^2	error, s
Off-white pot	0.0169	-0.239	84.1	0.08807
Red-pot	0.0429	-0.206	79.6	0.08688

In Eq.(4.2), a_1 represents the model constant while b_1 is the coefficient of the predictor variable $ln\, X_{pot}$. From the data as enumerated in Figure 4.10, the Eq.(4.3) models the compressive strength of the off-white and red water pots. These distinct models are represented in Table 4.3 shows a high coefficient of determination $R^2$and a very low value of model error s. Hence a generalized model of compressive strength Y_{pot} can be expressed in the form of Eq.(4.3) as

$$Y_{pot} = e^{\frac{\ln X_{pot}}{a_1+b_1 ln X_{pot}}} \tag{4.3}$$

4.4.5 Water Cooling Studies

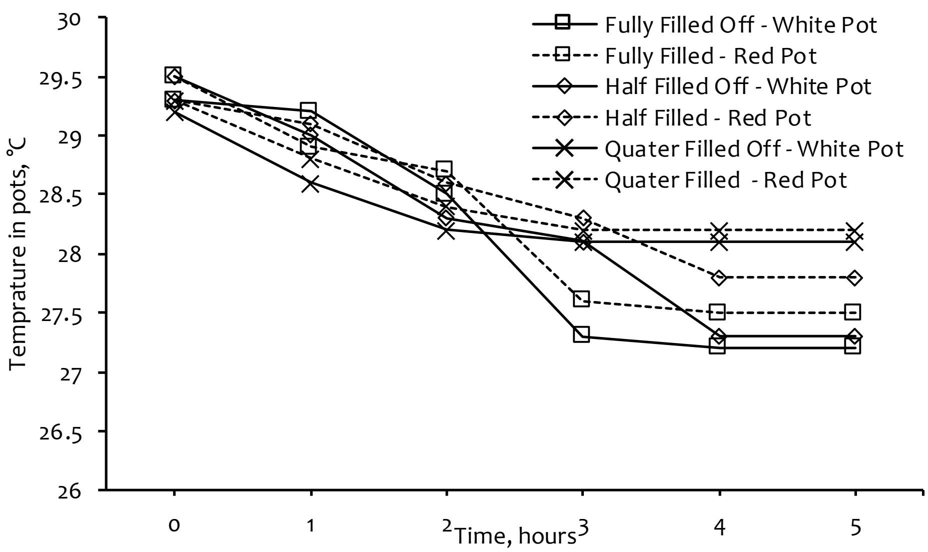


Figure 4.11: Water temperature profiles of pots during August at Jodhpur, Rajasthan, India

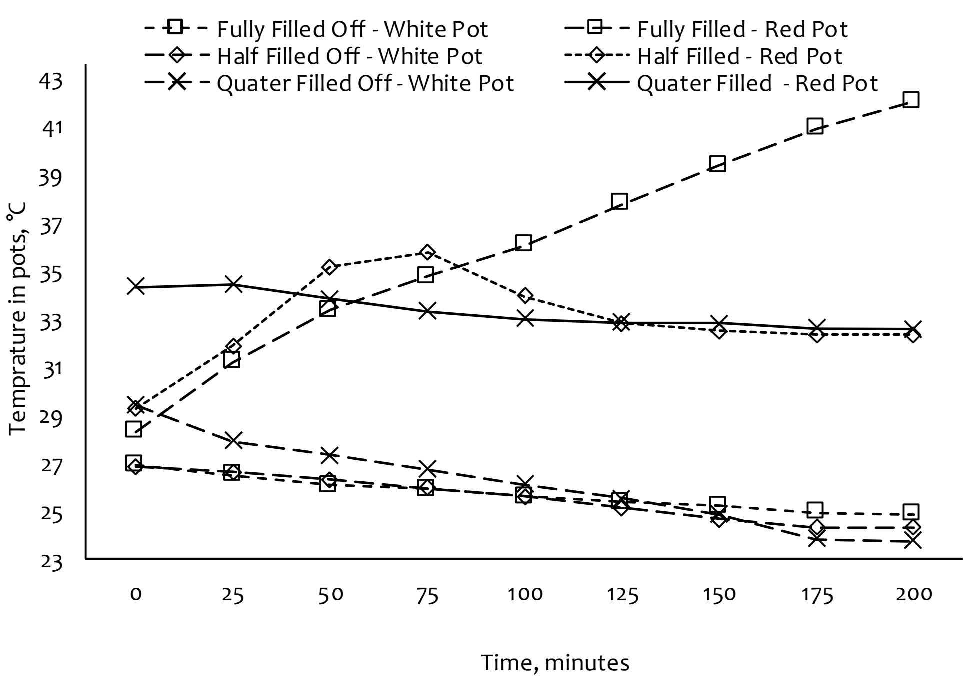


Figure 4.12: Water temperature profiles of pots during November at Jodhpur, Rajasthan, India

The graph in Figure 4.11 shows water cooling studies in the off-white pots and red pots during the first week of August (with an outside dry bulb temperature of 36 °C). Each point in the data set represents an average of 4 individual pots of either variety. Considerable effective cooling is observed for fully filled off-white pots as compared to other cooling processes. Figure 4.12 illustrates the cooling tests (average from

4 individual pots) performed during the first week of November in Jodhpur (with an outside dry bulb temperature of 28 °C). The maximum cooling rate is observed for quarter filled off-white pots as compared to other cooling processes during this study. The Thermodynamic analysis behind the variation in the temperature in Figure 4.11 and Figure 4.12 are beyond the present purview and is to be performed in future work citing Olorunmaiye, 1996.

4.5 SUMMARY AND CONCLUDING REMARKS

Cooling of water is very effective with the use of off-white pots rather than red pots at Jodhpur, India. Off-white pots also have better compressive strength compared to red pots. The compressive strength of a water pot studied here is a non-linear function of water pot height. The water pots take 2 hours to provide water at the coolest possible temperature. Off-white pots have less sintering heat requirements due to high calcite concentrations compared to red water pots. These may be some of the technological characteristics which may be reasons for the sustenance off-white pots usage in traditional practices across western Rajasthan. Strength and cooling behaviour will be explored through the support of micro-structural and thermal kinetics studies as an extension to this work. The production techniques elaborated here in the literature are widely used by the potters of India, but there was no scientific explanation on the facts that off-white pots have much more uses in western Rajasthan. This chapter also predicts the structural strength of cruse material derived from a specific height as a function of same for the first time.

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