Journal of Ayurveda and Integrative Medicine 14 (2023) 100762

Contents lists available at ScienceDirect

Journal of Ayurveda and Integrative Medicine

journal homepage: http://elsevier.com/locate/jaim

Original Research Article

Preliminary investigation of temperature and pressure profile of *pudam* in the preparation of Siddha medicine *Padigara parpam*

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A R T I C L E I N F O

Article history:
Received 26 August 2022
Received in revised form
21 June 2023
Accepted 22 June 2023
Available online 17 July 2023

Keywords:
Puta
Marana
Sindoor
Bhasma
Sharava

A B S T R A C T

Background: *Pudam* is one of the manufacturing processes used extensively in preparing *parpam* and *chenduram* in the Siddha healthcare system. The scientific understanding of the process is not fully understood.
Objective: In this work, our objective was to investigate the temperature and pressure profile of the *pudam* process and also to understand the porous nature and low thermal conductivity of the sealed *agal* (Earthen vessel) used by replicating the traditional manufacturing process of *Padigara parpam* medicine in a pit.
Materials and methods: The temperature and pressure profiles were recorded. The size and mass of the cow dung cakes required to conduct the *pudam* process were discussed. The *agal*'s porosity, thermal conductivity, and thermal diffusivity were experimentally determined. The pressure test of an empty *agal* was performed in an electric kiln and a pit to find the pressure development inside it and understand the sealed *agal*'s role.
Results: The maximum temperature of the *pudam* process was recorded as 807 °C, and the maximum heating and maximum cooling rate were calculated to be 30 °C/min and 8 °C/min, respectively. The holding time was found to be 66 min above 600 °C and 51 min above 700 °C. The maximum pressure built during the *pudam* process was 8.2 mbar.
Conclusion: The test results indicate that the bottom location of the sealed *agal* is the optimum place to record the temperature of a *pudam* process. The sealed *agal* does not allow pressure to build inside, and the *pudam* process can be considered a heating process that occurs at atmospheric pressure. Increasing the quantity of cow dung cakes for the exact size of the sealed *agal* and pit increases the raw material's temperature and holding time and reduces the maximum heating rate.

1. Introduction

Siddha's system of medicine is one of the oldest medicinal systems globally. The omniscient nature of this system has been combating diseases and maintaining human physical and mental health. The Siddha system encompasses many plants, metals and minerals, and animal-origin products in its alchemical preparations [1]. In the Siddha system, the raw materials must be purified before it is used to convert into medicine [2]. *Pudam*/*Puta* is one of the vital manufacturing and purification processes employed in Siddha and the Ayurveda system of medical practice [1–3]. The basic principle behind the *pudam* process is calcination, which aims to remove impurities and volatile substances; it nullifies all the harmful effects of the medicine and initiates the newer chemical compound formation [2–6]. Nisha et al. (2018) found the effect of the number of *puta*s on the particle size of *Lauha bhasma*, and the number of *puta* given to *Lauha bhasma* directly affected its particle size; more the number of *puta* results in finer *bhasma* [7]. The *pudam* process is carried out in an earthen device known as a sealed *agal*. This device has bottom closure and top closure. Once the raw materials are kept in the bottom closure, it is closed with the top closure and sealed with a traditional sealant made from a cloth smeared with water-wetted Termite cavern soil called *seelaimann*. Then, the sealed *agal* is dried under sunlight; once it is completed, it is kept in a pit covered by a specific number of dried cow dung cakes and fired; the

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Peer review under responsibility of Transdisciplinary University, Bangalore.

https://doi.org/10.1016/j.jaim.2023.100762
0975-9476/

process is called *pudam*. The number of *seelaimann* and the type of *pudam* differs with the type of medicine prepared. Depending on the heating method or exposure to the environment, the *pudam* can be classified into various types [2,4–6]; *Umi pudam*: Burying the medicine inside a pile of rice husk for a specific period; *Dhania pudam*: Burying the medicine inside a pile the unpeeled rice grains for a specific period; *Sooria pudam*: Keeping the medicine under sunlight; *Chandra pudam*: Keeping the medicine under the moonlight; *Amavasai pudam*: Keeping the medicine in the moonless night; *Paruva pudam*: Keeping the medicine in a specific season of the year; *Pani pudam*: Keeping the medicine in the winter season; *Pattai pudam*: Keeping the medicine inside the tree by drilling it for a specific period. Depending on the number of dried cow dung cakes used, the *pudam* can be classified into various types [2,4–6]; *Kaadai pudam*: One cow dung cake is used; *Gaudhari pudam*: Three cow dung cakes are used; *Kukku pudam*: Ten cow dung cakes are used; *Varaga pudam*: Fifty cow dung cakes are used; *Gaja pudam*: One thousand cow dung cakes are used; *Manalmarai pudam*: Ninety cow dung cakes are used; *Bhoomi pudam*: Goat manure is used.

The lacunae lie where the scientific principle behind the *pudam* process was not precisely elucidated. Most of the Siddha medicines preparation can be compared to the food cooking process involving complex chemical reactions, and all medicine formulations are similar to food recipes and in the form of art rather than science; this is one of the causes for the variations in the traditional medicines. These medicine preparation techniques were passed on from one generation to another as a custom practice, and the process was not yet scientifically quantified until recent times; some efforts are being made to standardize the manufacturing process of Siddha and Ayurveda medicines. The reason is that the traditional Indian medicine system has not evolved with the support of diverse expertise from different domains, including pharmacy, engineering, and technology, unlike the modern Western medicine system. Hence, the present work aims to scientifically understand the manufacturing process by comprehensively characterizing earthen enclosure material and process parameters. Parmar et al. (2010) reported the average temperature pattern of *Gaja puta* and *Ardhagaja puta* in preparing the *Vanga bhasma* [8]. Pathiraja et al. (2014) measured the temperature profile of *Maha puta*, *Gaja puta* and *Varaha puta* using a data logger [9]. Chavan et al. (2018) captured the temperature profile of the *pudam* process in preparing the *Shankha bhasma* [10]. The works mentioned above mainly focused on medicine preparation using *pudam* as a manufacturing process and capturing the temperature profile of *pudam*; however, the importance of the thermocouple locations for capturing the *pudam*, the importance of size and mass of the cow dung cakes, and the role of sealed *agal* in *pudam* was not discussed. Maggetti et al. (2011) evaluated the time–temperature profile of different spots in an earthen pot by experimental surface (bonfire) firings [11], and it was reported that the range of the thermal variation within one single firing was found to be as high as 390 °C, and up to 220 °C on a specific cross-section. Thér (2014) analyzed 72 experimental pottery firings, including pit firing and reported that the maximum temperature reached in the experiments varies from 574 °C to 1081 °C, the difference in maximum temperature varies from 129 °C to 354 °C, and the maximum difference in temperature varies from 276 °C to 790 °C [12]. However, the above experiments were done on sintering the earthen pot; but the process is similar to the *pudam* and illustrates differences in temperatures captured in different locations within a pot in each experiment. Recently, the electric furnace/kiln had been used to replace the *pudam* in preparing the Ayurveda medicines. Gupta and Patgiri (2012) prepared *Loha bhasma* in an electric muffle furnace with a maximum temperature of 600 °C with a 1-hr holding time [13]. Singh et al. (2016) prepared *Teekshna lauha bhasma* in an electric muffle furnace with a maximum temperature of 650 °C and a 1-hr holding time [14]. Kale and Rajurkar (2019) prepared *Vanga bhasma* in an electric muffle furnace with a maximum temperature of 600 °C with a 3-hr holding time [15]. Singh et al. (2019) prepared *Tamara bhasma* in an electric muffle furnace with 1st *puta* 700 °C for 60 min, 2nd *puta* 600 °C for 45 min, 3rd *puta* 500 °C for 30 min, 4th and 5th *puta* 500 °C for 25 min [16]. Pathiraja et al. (2020) measured the temperature profile of *Varaha puta* using a data logger and fed the temperature data to a muffle furnace in the preparation of *Swarna makshika bhasma* [17]. So far, no scientific work has been reported about the pressure developed inside the *agal* during the *pudam* process or on the significance of *agal* and *seelaimann* and their physical properties' influence on the *pudam* process.

The objective of this research is to study the *pudam* process by capturing the temperature and pressure profiles using modern scientific instruments and studying the role of *agal* and *seelaimann*. It may help in the scientific understanding of the *pudam* process and also gives further directions in converting the conventional *pudam* process to modern manufacturing method in near future.

2. Materials and methods

2.1. Agals for the experiments

The *agals* (top and bottom earthen enclosures) were made with the help of a potter, as shown in Fig. 1, which were used to ensure the way the traditional medicines are prepared. Each agal was made with a diameter of 175 mm, depth of 85 mm, and thickness of 5 mm. The diameter-to-depth ratio of the *agal* to be used in any *pudam* process is not available in the literature. The *agal* used by a few individual medical practitioners revealed that the diameter-to-depth ratio of the *agal* varies approximately from 1 to 4. For the current work, this ratio was taken approximately as 2. The top enclosures were fitted with stainless-steel pipe connectors to insert the thermocouple probe and a stainless-steel hose for measuring the pressure. The chemical analysis of clay was done using X-Ray fluorescence analysis (PANalytical, AXIOS). The density of sintered *agals* was found using the Archimedes principle as per ASTM B962-17 standards. The porosity of the *agal* was found using a Helium pycnometer as per ASTM B923-22 standards. The *agal*'s thermal conductivity and diffusivity were found as per the Transient plane heat source method (ISO-22007-2 standard) using a Hot disc thermal constants analyzer (Hot Disk, TPS2500).

2.2. Preparation of sealed agal

In this work, *Padigara parpam* Siddha medicine preparation procedures [18] were followed to study the *pudam* process in a pit. The purified powder of *Padigaram* (Potassium alum) was taken for the study as a raw material inside the *agal*. *Padigaram* was purified by heating it in an iron pan until it melted and formed a solid layer. Once it was cooled down, it was ground to powder and filled in the bottom *agal* for half of its volume, closed with the top *agal*, and sealed with the clay-smeared cloth called *seelaimann*, and the sealed *agal* was dried under sunlight as shown in Fig. 2. In the actual preparation of this medicine, the purified *Padigaram* needs to be ground in a *kalvam* (mortar and pestle) using egg white.

2.3. Cow dung cake requirements

The number of cow dung cakes required for the present study was twenty [18]. However, it was observed in recent works that the size of cow dung cakes used in the research varies in dimension and weight [8,9,17,19]. Thiyagarajan (1981) mentioned that the

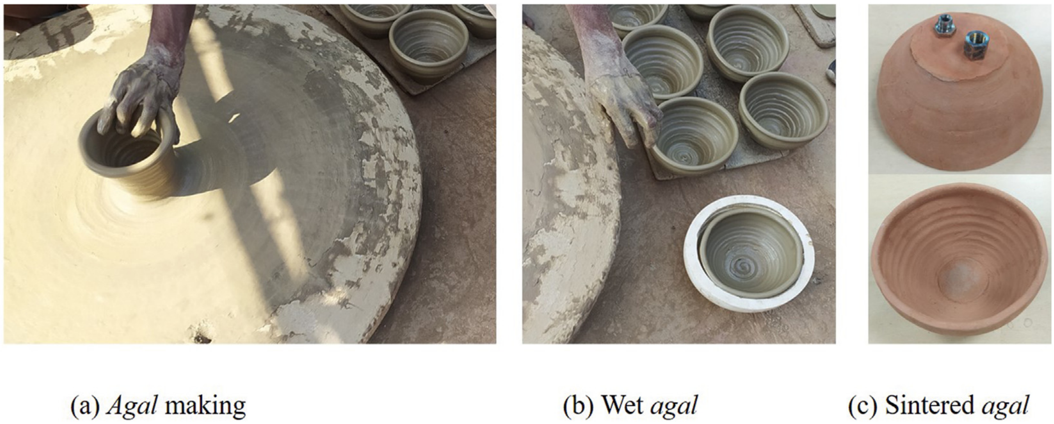

Fig. 1. Preparation of *agal*.

manually prepared cow dung size should be 30 cm in diameter and 1.25 cm in thickness. Also, it should not be contaminated by rice husk, rice straw, sawdust, or dried leaves [2]. Thus, the volume of a cow dung cake is calculated to be 884 cc as per the above dimension. For the present work, cow dung was collected from a local *Goshala* (cow barn) to ensure no external contaminants. Once the cow dung was shaped and dried, samples were taken to find its density using the Archimedes principle, and it was found that the density varied between 0.307 g/cc to 0.472 g/cc, so an average density of 0.389 g/cc was taken; these variations in the density were due to the traditional preparation method. The mass of a cow dung cake using the above volume is 344 g. Krishnamachary et al. (2012) reported that the mass of a cow dung cake used was 350 g [19], which was very close to the present value. Hence the mass of one cow dung cake was rounded to 350 g in the present work, so the mass of 20 cow dung cakes comes to be 7 kg. For the present *pudam* process, to avoid any variation in the amount of fuel due to the shape of the cow dung cakes, a total weight of 7 kg was used, which is equivalent to 20 cow dung cakes. The higher calorific value of the cow dung cake was found using the Oxygen bomb calorimeter (Parr, 1341) as per ASTM D5865, and it was found to be 12.3 MJ/kg; hence 7 kg of cow dung cake represents a total higher heating value of 86 MJ.

2.4. Replication of pudam in a pit

A *Kukku pudam* pit was constructed with a square dimension of 45 cm wide, and 2/3rd of cow dung cakes by mass was placed in it

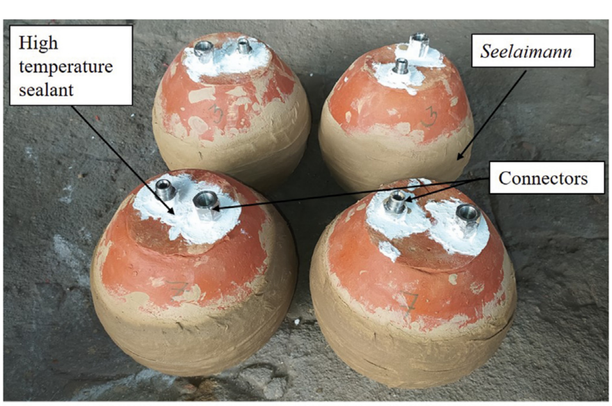

Fig. 2. Sealed *agals*.

[5]. The sealed *agal* was placed on top of it, and the remaining 1/3rd of the cow dung cakes were used to cover the sealed *agal* completely and fired, as shown in Fig. 3 & Fig. 4(b). The tests were conducted in two batches using 7 kg of cow dung cakes and 14 kg of cow dung cakes to find the effect of an increase in the quantity of cow dung cakes for the same size as the sealed *agal*, pit, and the same medicine preparation.

2.5. Pressure test of empty agals

Two kinds of pressure tests were conducted using empty *agal*s to understand the role of the porous structure of the earthen *agal* and *seelaimann* in the *pudam* process. In the first kind of test, a pair of empty *agal*s were taken and sealed using traditional *seelaimann* and heated inside a kiln (Nabertherm, N100) to measure the pressure and temperature rise, as shown in Fig. 5. In the second kind of test, a pair of empty *agal*s were taken and sealed using a leakproof epoxy adhesive so that the joint became leakproof, as shown in Fig. 6. These pressure tests were performed to quantify the pressure built during the *pudam* process and to understand the role of *seelaimann*.

2.6. Instrumentation and data acquisition

The pressure was measured with a pressure transmitter (measuring range 0–100 mbar), and the temperatures were measured using K-type thermocouples. The thermocouple mounting locations are shown in Fig. 3. The National Instrument's NI 9203 and NI 9212 data acquisition modules were used in conjunction with the LabVIEW software for the data acquisition, as shown in Figs. 4(a) & Fig. 6.

2.7. Heating and cooling rate calculation

A typical temperature profile of the *pudam* process is depicted as curve ABCD as shown in Fig. 7. Curve AB is called the initial phase of *pudam*, where temperature rises slowly, and curve BC is called the heating phase of *pudam*, where rapid combustion of cow dung cakes takes place, and curve CD is called the cooling phase of *pudam* where temperature started to decrease. The maximum temperature of the *pudam* is the temperature corresponding to point C. Maximum heating rate is calculated by finding the maximum value of the slope of the curve BC by considering any two points, and the maximum cooling rate is calculated by finding the maximum value of the slope of the curve CD by considering any two points. The holding time is the amount of time the raw material inside the

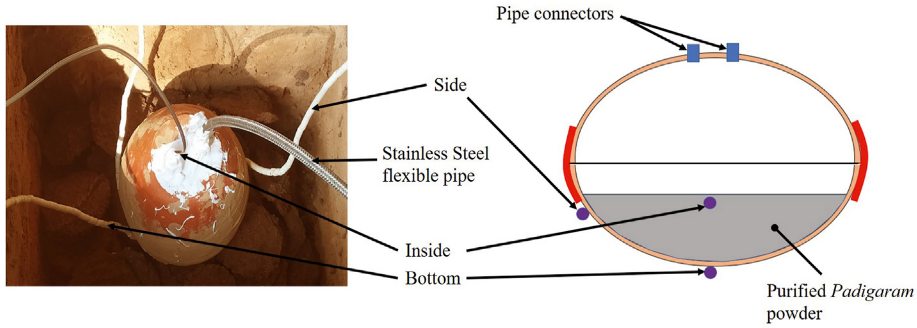

Fig. 3. Thermocouple mount locations.

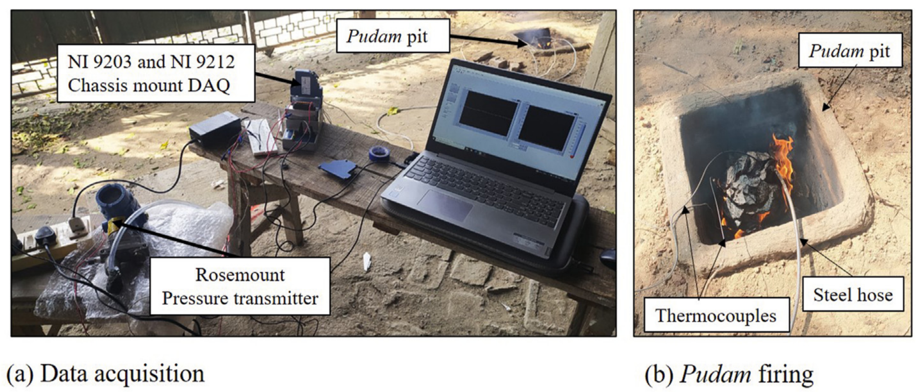

Fig. 4. Replication of *pudam* and data acquisition.

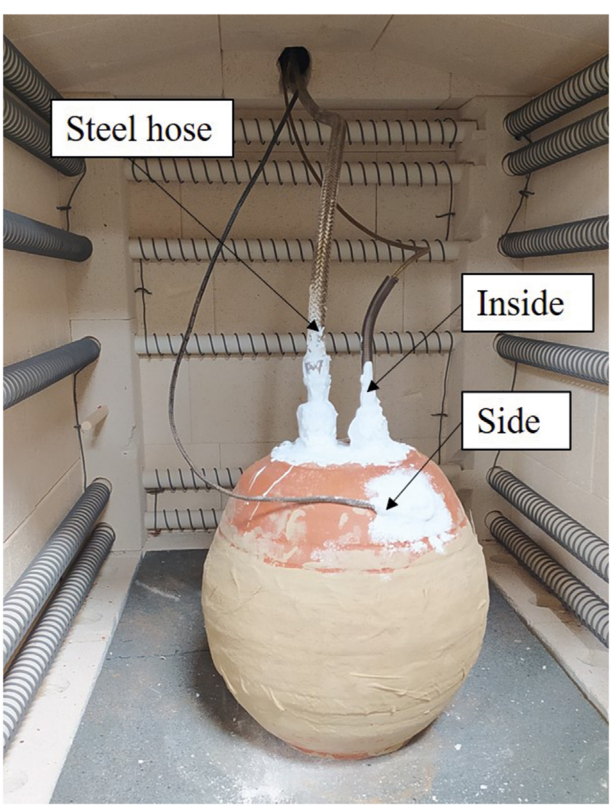

Fig. 5. Empty sealed *agal* in the kiln.

sealed *agal* is held at a constant temperature. The duration of holding time is vital in the penetration of heat from the raw material's outer surface to the raw material's inner core. Sufficient holding time would ensure that all the molecules in the raw material get raised to the same temperature, thereby ensuring the complete chemical reaction. Insufficient holding time would prevent all the molecules from attaining the same temperature. Fig. 7 shows that there is no considerable holding time found near the maximum temperature; hence the holding time for a particular temperature T is considered as the time duration of the *pudam* process above temperature T.

3. Results and discussion

3.1. Properties of sintered agal

The chemical analysis of the clay used for making the *agal* revealed that the oxides present were Silica (52%), Alumina (21%), Iron oxide (7%) and other oxides (4%). The density of sintered *agals* was found to be 1.6 g/cc. The porosity of the *agal* was found to be 33%. The *agal*'s thermal conductivity and diffusivity were found to be 0.45 W/m°K, 4.6×10^{-7} m^2/s, respectively. The disc specimens were used for finding the thermal conductivity and thermal diffusivity, and these disc specimens were made using the same clay which is used to make the *agal* and sintered along with the *agal* used for the experiments.

3.2. Replication of pudam in a pit

Fig. 8 shows the temperature and pressure profile of the *pudam* process in a pit for the test with 7 kg cow dung cake. At the start of

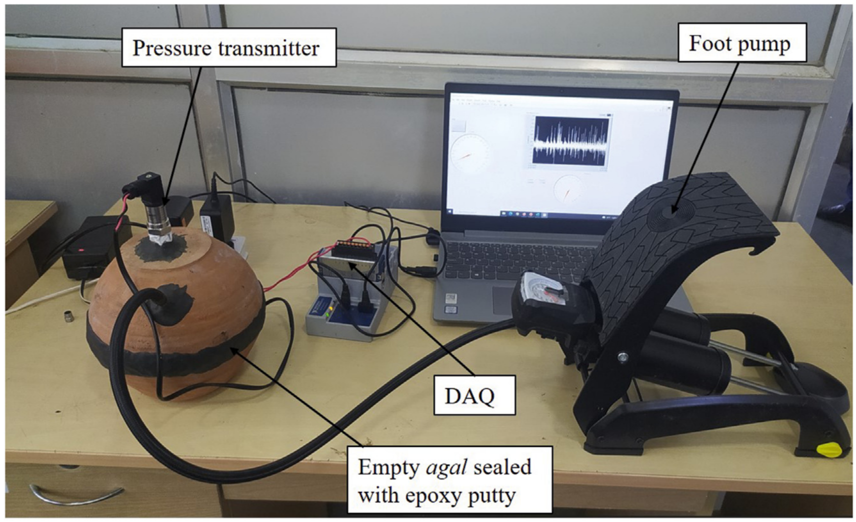

Fig. 6. Pressure test of empty sealed *agal*.

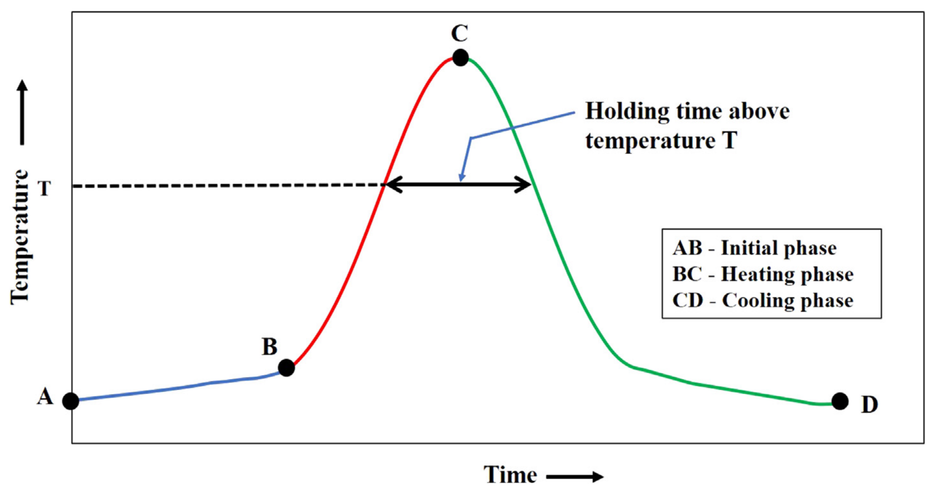

Fig. 7. Typical temperature profile of *pudam*.

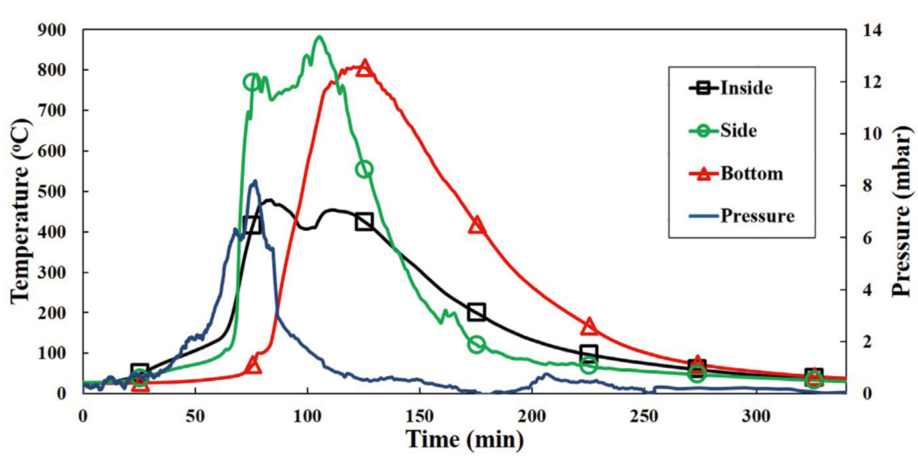

Fig. 8. Temperature and pressure profile of 7 kg cow dung cakes *pudam*.

the *pudam* ignition, the temperature rises very slowly, and this is due to the cow dung cakes getting heated and spreading the heat and flame to the surrounding cow dung cakes due to its internal ignition temperature. Jiang et al. (2020) reported that the internal ignition temperature of cattle manure is 61 °C to 172 °C [20]. The operator's skill in initiating the fire, the size of the pit, and the number of cow dung cakes used are other parameters affecting the initial phase of the *pudam* process. The thermocouple, mounted to measure the inside temperature, was made of Inconel, and the fittings at the top of the *agal* were made of stainless steel. In the initial phase of the *pudam* process, the cow dung cakes on the top and near the top surface of the sealed *agal* were burning; the heat was supplied only to the top surface of the sealed *agal*. While the heat passes from the top side of the *agal* to the inside, the fittings made of metals would conduct the heat faster and make the thermocouple sense the higher temperature than the raw material's actual temperature. The observed temperature rise of the inside location during the initial phase is not valuable data. During the initial phase, the side and bottom thermocouples were away from the burning cow dung cakes; hence the fire took some time to reach these locations and raise the temperature, which is also observed in Fig. 8, where the bottom thermocouple readings are lagging behind the side and inside thermocouple readings.

At the end of the initial phase, rapid combustion of cow dung cakes occurs, which can be called the heating phase of the *pudam*. At the bottom thermocouple location, a heating rate as high as 30 °C/min was observed, and there is a maximum heating rate difference between the side location and bottom location, as shown in Fig. 8. These are due to the burning of cow dung cakes, which start from the top of the sealed *agal*, spread to the side of the seal *agal*, and then reach the bottom cow dung cakes. This phenomenon also causes two peaks in the temperature profile of the side thermocouple; the first peak was due to fuel burning near the side thermocouple, and the secondary peak was due to the burning of the bottom cow dung cakes. The reading at the bottom of the sealed *agal* is vital in capturing the temperature profile of the *pudam* for three reasons. The first reason is that 2/3rd of the cow dung cakes were kept beneath the sealed *agal*. During the heating phase of *pudam*, 1/3rd of the cow dung cakes covering the top surface of the sealed *agal* started to fire. These cow dung cakes are mostly exposed to the atmosphere, where it gets oxygen freely and fires quickly and unevenly; the heat generated in this process is partially given to the sealed *agal* from the top and partially lost to the atmosphere due to the open nature of the pit. Once the top cow dung cakes are entirely fired, the ash produced in this process completely covers the sealed *agal* and bottom cow dung cakes; this cover of ash act as a thermal insulator by which further heat loss is prevented from the system to the surrounding when the bottom cow dung cakes start to liberate the heat.

The second reason is that the raw material kept inside the sealed *agal* always touches the bottom surface inside the sealed *agal* rather than its sides; hence the maximum temperature reached by the raw material purely depends on the bottom temperature, as seen in Figs. 8 and 10. The third reason is that the shape of the *agal* used for medicine preparation has significant variations depending on the quantity of medicine prepared, and some *agals* do not have sufficient height or depth to mount a side thermocouple to measure the temperature of *pudam* for quantifying it. Hence it can be concluded that the bottom side of the *agal* is the optimum place for measuring the temperature of a *pudam*. The maximum temperature reached in the bottom thermocouple was 807 °C for 7 kg of cow dung cake; this temperature was captured at the outer surface of the agal. The inside surface temperature of the agal would be less than the outer surface temperature, which depends on the thickness of the agal. It is also observed that the temperature of raw material near the surface level captured by the inside location thermocouple, as shown in Fig. 3, does not reach the maximum temperature of the *pudam* process. The maximum temperature measured by the inside thermocouple was 453 °C for 7 kg cow dung cake. Hence it can be concluded that the raw material inside the sealed *agal* was not subjected to a uniform temperature inside the sealed *agal*, and there exists a temperature gradient between the raw material touching the inner surface of the sealed *agal* and the top surface level of the raw material due to insufficient holding time. The *agal*'s thermal conductivity and thermal diffusivity, reported in section 3.1, also play a significant role in this phenomenon. The value of thermal conductivity of the earthen enclosure, *agal* is 0.45 W/m°K which is significantly less compared to the standard stainless-steel grade having a value of 25 W/m°K [21] can conduct the heat from outside to inside very slowly. Thus, slow heating and cooling characteristics of the *pudam* process are captured by measuring the calorific value of fuel (cow dung) utilized and the thermal conductivity of the earthen enclosure.

The *pudam* heating process is not allowing a constant holding time at the maximum temperature; soon after the temperature reaches the maximum value, it starts to cool, as observed in Fig. 8. Hence the holding time at a particular temperature was calculated by noting the time duration of *pudam* process above that temperature. The holding time in the present case was found to be 66 min above 600 °C and 51 min above 700 °C. The maximum rate of cooling was found to be 8 °C/min. The *pudam* process was carried out in a pit with an open end at the top; the cooling was also fast but not at the same heating rate as observed in the temperature profiles. The cooling phase starts once the holding phase ends. The cooling phase starts once the heat required to maintain the maximum temperature reduces. Fig. 9 shows the product after the *pudam* process was over; the outer surface of the end product, which was in contact with the sealed *agal*, appears white, and the top surface appears in ash colour. The cross-section also shows the colour gradient, which might be due to the less holding time available, which might be the reason for repeating the *pudam* process several times for some of the preparation of the Siddha medicine. Different medicine manufacturing necessitates a different amount of cow dung cakes. The effect of the quantity of cow dung cakes in the *pudam* process was studied by increasing the number of cow dung cakes to double the initial amount with the same pit for the same medicine. Fig. 10 shows the temperature and pressure profile of the *pudam* process in the pit for the test with 14 kg cow dung cake. Similar to the test with 7 kg cow dung cakes, the temperature rises slowly at the start of the *pudam* ignition. A heating rate as high as 14 °C/min was observed, and the maximum temperature reached in the bottom thermocouple was 671 °C. The maximum temperature of the inside location for the test with 14 kg cow dung cake was 553 °C which is more than the temperature recorded in the test with 7 kg cow dung cakes; this was due to the slow burning of cow dung cakes which gives sufficient time for heat to penetrate from the bottom toward the top surface of the raw material kept inside. Thus, it is inferred that the fuel required decides the heat and the *pudam* process's heating rate.

3.3. Pressure development during the pudam in the pit

Fig. 11 shows the pressure developed inside the sealed *agal* for tests with 7 kg and 14 kg of cow dung cakes usage. It has been observed that the maximum pressure of 8.2 mbar and 11.3 mbar for tests with 7 kg and 14 kg of cow dung cakes, respectively. When the temperature of the *pudam* increases, the pressure builds inside the sealed *agal*; once the pressure reaches a threshold value, it starts to decline. It is also essential to consider the gases evolved by the raw material kept inside the sealed *agal* in the pit experiment during

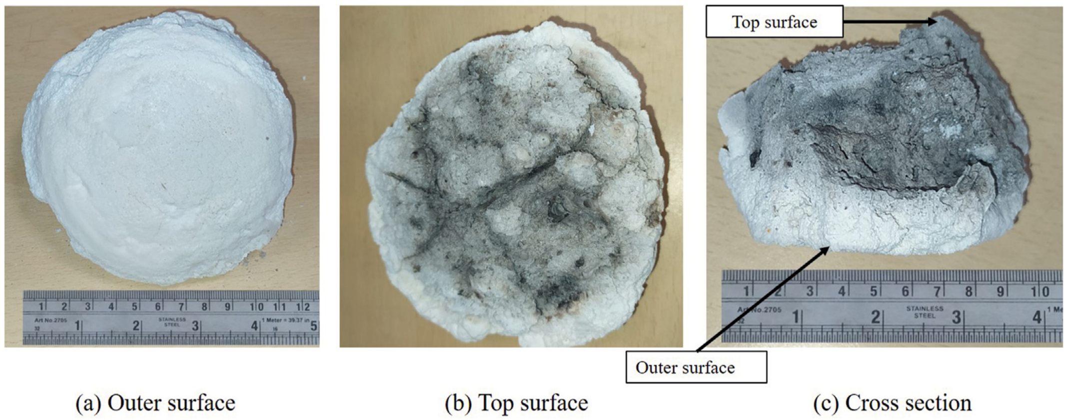

Fig. 9. The finished product after *pudam*.

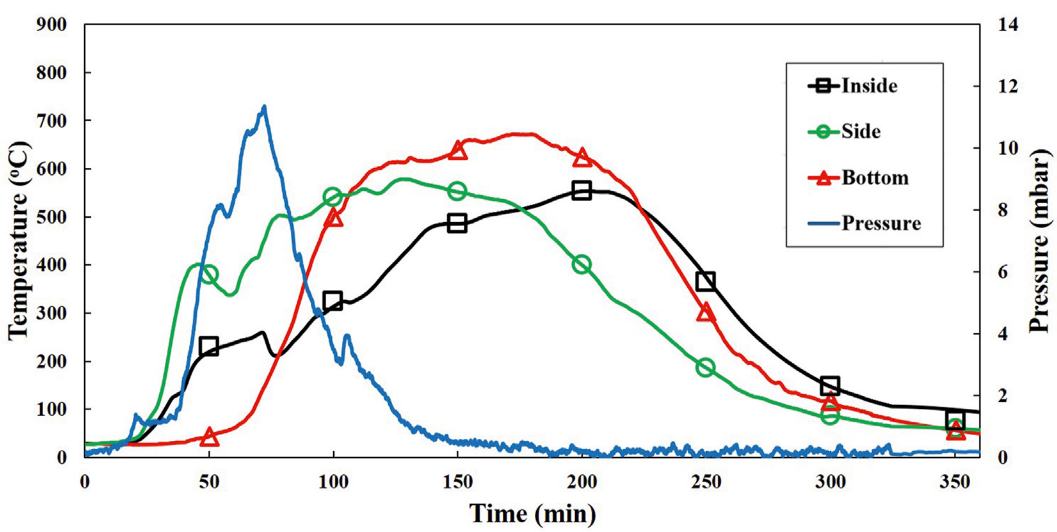

Fig. 10. Temperature and pressure profile of 14 kg cow dung cakes *pudam*.

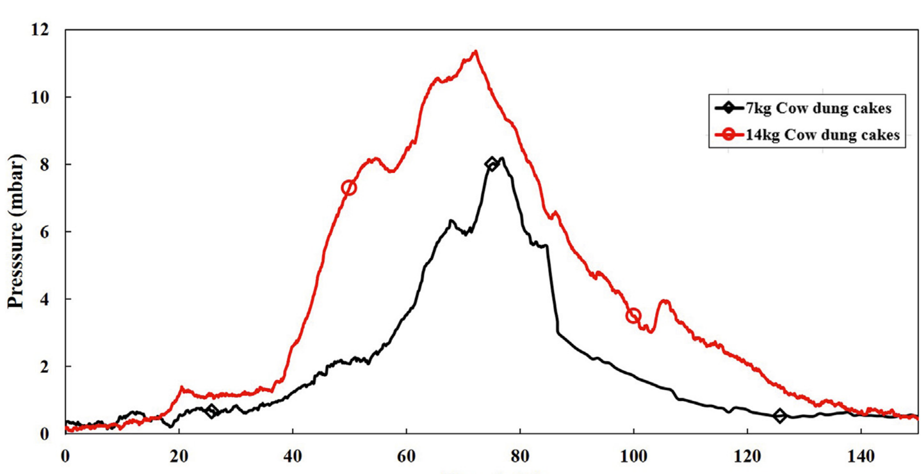

Fig. 11. Pressure development inside the sealed *agal* during the *Pudam*.

the heating process and the burning characteristics of cow dung cakes; these might be the reason for some of the secondary peaks in the pressure profile. The conclusion which can be arrived from the pressure profile is that the *pudam* process produces negligibly pressure depending on the strength of the *seelaimann*, porosity of *agal*, rate of heating, and raw material kept inside the *agal*, and it dies down well before the *pudam* process reaches the maximum temperature as seen from Figs. 8 and 10. Hence, the pressure built inside the sealed *agal* is negligible. The porous (33%) characteristics of the earthen closure were responsible for not building up pressure inside the closure. Thus, measuring the earthen closure's porosity and pressure developed inside the closure during heating helps scientifically understand the *pudam* process.

3.4. Pressure tests of empty agals

The pressure test was conducted with empty *agal*s sealed with the traditional *seelaimann* in the kiln with a constant heating rate of 360 °C/hr. The value 360 °C/hr heating rate is chosen for pressure development due to thermal expansion inside the empty sealed *agal* and is not specific to the *pudam* process. Thus, the pressure and temperature profiles captured are shown in Figs. 12 and 13, respectively. When the kiln temperature increases, the pressure begins to build inside the sealed *agal*; once the pressure reaches a threshold, it starts to decline to a low level, and its value oscillates near zero, as shown in Fig. 12. The maximum pressure reached in the test was 14.9 mbar for the kiln temperature of 189 °C. Assuming that the *seelaimann* perfectly seals the joint and the *agal* does not allow air to pass through it. Hence, neglecting the thermal expansion of the sealed *agal* during the heating process and considering only the air inside can be approximated to a constant volume thermodynamic process. The thermodynamic expression for the constant volume process is given by $(P_2/P_1) = (T_2/T_1)$, where P_1 and T_1 are initial pressure and temperature; P_2 and T_2 are final pressure and temperature. Assuming that the initial pressure of 1 bar and initial temperature of 300 K correspond to atmospheric pressure and room temperature, the above expression can be evaluated for the pressure P_2 for different final temperatures T_2. T_2 is the air

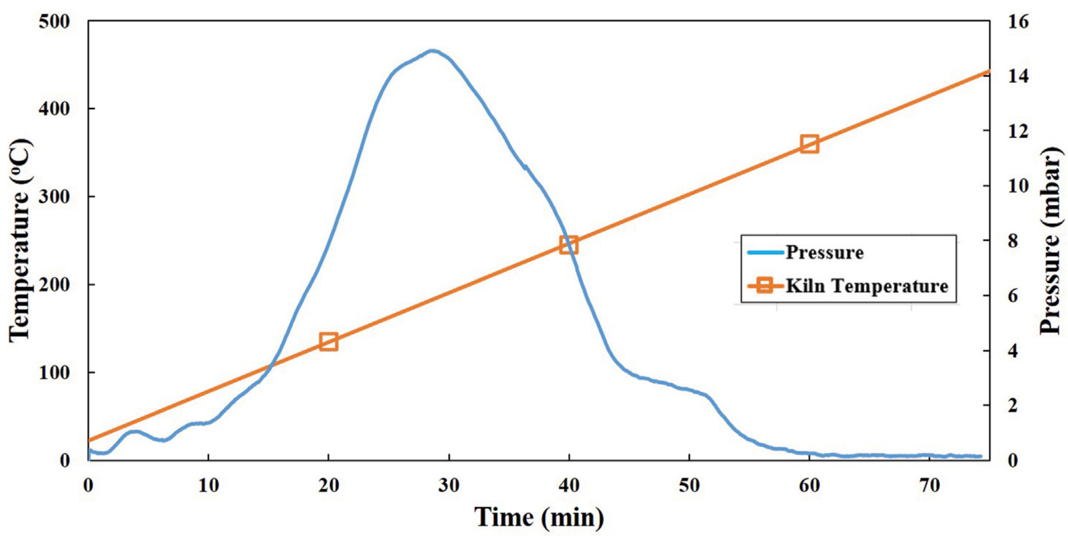

Fig. 12. Pressure developed inside empty sealed *agal* in kiln.

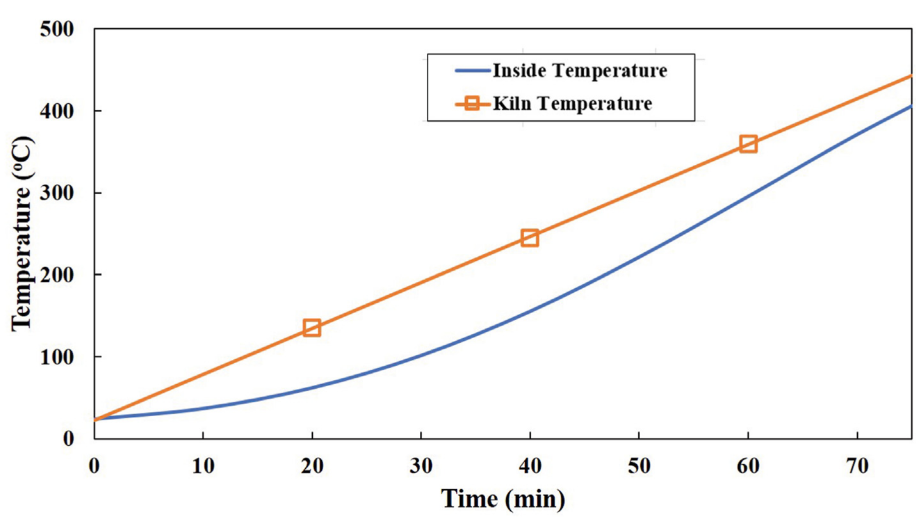

Fig. 13. Temperature developed inside empty sealed *agal* in kiln.

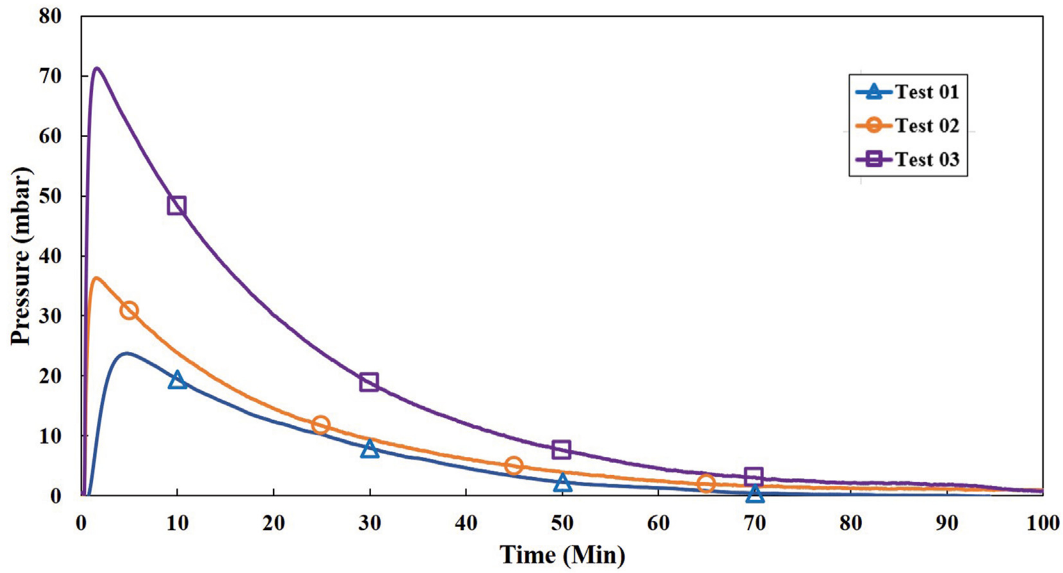

Fig. 14. Pressure profile of empty *agal* sealed with epoxy adhesive.

temperature inside the sealed *agal* measured by inside location, as shown in Fig. 13. By comparing the evaluated pressure P_2 from the above equation, the pressure built inside the empty *agal* in the test was found to be infinitesimally small. Thus, the air passes through the sealed *agal* during the heating process. It either passes through the *seelaimann* or pores in the *agal* or both. To verify this, a top and bottom *agal* sealed with an epoxy adhesive that perfectly seals the joint and does not allow any leakage was taken for study; it was fixed with the pressure transmitter, and a non-return valve for pumping air inside as shown in Fig. 6. Air was pumped into the sealed *agal* with a foot pump; once the pumping was over, the foot pump was disconnected. The pressure inside the sealed *agal* was captured with respect to time, and it is shown in Fig. 14. The test result shows that the empty *agal* sealed with epoxy adhesive permits the pressure to build compared to traditionally sealed *agal*, but it could not retain the pressure due to the porosity of the earthen enclosure. Hence, the *agal*'s porosity does not retain pressure built inside the sealed *agal*. From the above two experiments, it can be concluded that the *seelaimann* acted as a breathing medium by which hot air passes through it when the temperature increases; and the atmospheric air gets sucked in when the temperature decreases.

4. Conclusions

In the present work, the characterization of the *pudam* process in preparing the *Padigara parpam* was done by measuring the temperature and pressure profile by conducting the experiments in a *Kukku pudam* pit. The following conclusions have arrived from the current work.

1. The temperature profile of the *pudam* process should be captured at the bottom of the sealed *agal* for the case where 2/3rd of the total amount of cow dung cakes is kept beneath the sealed *agal* as in the current work.
2. The heating and cooling rates for different quantities of cow dung cakes were obtained. The slow heating and cooling characteristics of the *pudam* process were achieved with cow dung and with less thermal conductivity and thermal diffusivity of the earthen enclosure.
3. The pressure developed during the *pudam* was negligible, and it can be assumed that the *pudam* takes place in atmospheric pressure.
4. The porous nature of *agal* and *seelaimann* acted as a breathing medium, and it helps not to build up pressure inside the *agal* during the *pudam* process.
5. The *seelaimann* is a simple and effective temporary porous joint that helps in the easy assembly and disassembly of a pair of *agal*.
6. The effect of increasing the quantity of cow dung cakes is increasing the duration of *pudam* and the maximum temperature of the raw material and reducing the maximum heating rate; there is no change in the cooling rate, and the maximum temperature of the *pudam* has reduced, and more prolonged holding had been observed.
7. The temperature profiles obtained in the current work are valid for the *Kukku pudam* with the size and shape of the *agal* used the type & amount of raw material, and the number of cow dung cakes used. It should not be generalized for any other type of *pudam* because the size of the sealed *agal* and the type & amount of raw material kept in it, the amount of cow dung cakes used, and the size of the pit would change the fire dynamics.

Source of funding

This work was supported by Sanction No: 3-18/2015-TS-TS.1, IMPRINT, Ministry of Education, India.

Author contribution statement

A S Ganesh Kumar and Senthilvelan Selvaraj conceived the idea and devised a methodology. A S Ganesh Kumar contributed to testing, data analysis, and article drafting. Senthilvelan Selvaraj contributed to reviewing and editing the article. Senthilvelan Selvaraj contributed to supervising, project administration, and funding acquisition.

Conflict of interest

None.

Acknowledgement

The authors thank the Sophisticated Analytical Instrument Facility, Gauhati University, forsupporting XRF analysis.

References

[1] Shukla SS, Saraf S, Saraf S. Fundamental aspect and basic concept of siddha medicines. Sys Rev Pharm 2011;2(1):48–54. https://doi.org/10.4103/0975-8453.83439.

[2] Thiyagarajan R. Gunapadam (Tamil). vol. 2 & 3. 3rd ed. Chennai: Directorate of Indian Medicine and Homoeopathy; 1981.

[3] Pal D, Sahu CK, Haldar A. Bhasma: the ancient Indian nanomedicine. J Adv Pharm Technol Research (JAPTR) 2014;5(1):4–12. https://doi.org/10.4103/2231- 4040.126980.

[4] Sorna Mariyammal I. Siddha Marudhakiyal Vidhigalum Cheimuraigalum (Tamil). 1st ed. Chennai: Directorate of Indian Medicine and Homoeopathy; 2010.

[5] Angadi R. A Textbook of Rasassastra: Iatro-chemistry and Ayurvedic Pharmaceutics. 4th ed. Varanasi: Chaukhamba Surbharati Prakashan; 2021.

[6] Kumar A, Dubey S, Sharma A, Singh Thakur R, Parhate S. Importance of puta in rasa shas- tra: a review. Int J Res Ayurveda Pharm 2018;9(6):12–8. https://doi.org/10.7897/2277-4343.096164.

[7] Nisha B, Sudarshan TK. Effect of no of puta on particle size of Lauha bhasma. World journal of pharmaceutical and medical research 2018;4(12):149–54.

[8] Parmar D, Patgiri B, Prajapati P. Standardization of Gaja puta and Ardha Gaja puta in the prepa- ration of Vanga bhasma. AYU 2010;31(4):511–5. https://doi.org/10.4103/0974-8520.82028.

[9] Pathiraja PMYS, Herapathdeniya SKMKH, Sanja HPG. Investigation of temperature pat- tern of traditional puta in Ayurveda bhasma preparation. Sri Lanka Journal of Indigenous Medicine 2014;4(1):224–9.

[10] Chavan S, Tayade S, Gupta V, Deshmukh V, Sardeshmukh S. Pharmaceutical stan- dardisation and physicochemical characterization of traditional ayurvedic marine drug: Incinerated conch shell (Shankha Bhasma). Mar Drugs 2018;16(11):450. https://doi.org/10.3390/md16110450.

[11] Maggetti M, Neururer C, Ramseyer D. Temperature evolution inside a pot during experimen- tal surface (bonfire) firing. Appl Clay Sci 2011;53:500–8. https://doi.org/10.1016/j.clay.2010.09.013.

[12] Thér R. Identification of pottery firing structures using the thermal characteristics of firing. Archaeometry 2014;56(1):78–99. https://doi.org/10.1016/j.jaim.2015.08.003.

[13] Gupta KL v, Patgiri BJ. Standard manufacturing procedure of Lauha bhasma using triphala media and by employing electric muffle furnace heating. Annals of Ayurvedic Medicine 2012;1(3):87–94.

[14] Singh TR, Gupta LN, Kumar N. Standard manufacturing procedure of Teekshna lauha bhasma. J Ayurveda Integr Med 2016;7:100–8. https://doi.org/10.1016/j.jaim.2015.08.003.

[15] Kale B, Rajurkar N. Synthesis and characterization of Vanga bhasma. J Ayurveda Integr Med 2019;10:111–8. https://doi.org/10.1016/j.jaim.2017.05.003.

[16] Singh RK, Kumar S, Aman AK, Karim SM, Kumar S, Kar M. Study on physical properties of Ayurvedic nanocrystalline Tamra Bhasma by employing modern scientific tools. J Ayurveda Integr Med 2019;10:88–93. https://doi.org/10.1016/j.jaim.2017.06.012.

[17] Pathiraja PMYS, Ranatunga YMMK, Herapathdeniya SKMK, Gunawardena SHP. Swarna Makshika Bhasma preparation using an alternative heating method to tradi- tional Varaha Puta. J Ayurveda Integr Med 2020;11:206–12. https://doi.org/10.1016/j.jaim.2018.02.136.

[18] Samuel D. Marundhu sei Iyalum Kalaiyum (Tamil). 2nd ed. Chennai: Directorate of Indian Medicine and Homoeopathy; 2009.

[19] Krishnamachary B, Rajendran N, Pemiah B, Krishnaswamy S, Krishnan UM, Sethura- man S, et al. Scientific validation of the different purification steps involved in the prepa- ration of an Indian Ayurvedic medicine, Lauha bhasma. J Ethnopharmacol 2012;142:98–104. https://doi.org/10.1016/j.jep.2012.04.021.

[20] Jiang C, Lin Q, Wang C, Jiang C, Bi H, Bao L. Experimental study of the ignition and combustion characteristics of cattle manure under different environmental conditions. Energy 2020;197:117143. https://doi.org/10.1016/j.energy.2020.117143.

[21] James C. Mechanical engineer's data handbook. 1st ed. Butterworth-Heinemann; 1993.