Chapter 14
Developments to Overcome Problems in Traditional Process of Making Glass Bangles

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1 Introduction

Glass bangles are manufactured by skilled artisans in several clusters in Northern India. Bharatpur in Rajasthan has several artisans engaged in this activity traditionally. Considered very auspicious for weddings across the state of Rajasthan, these bangles are intended to be made jointless. This makes the crafting process different from their counterparts of Firozabad where jointed bangles are produced. Bharatpur is house to 14 of these bangle-making furnaces operated on loose biomass. The artisans in Bharatpur have been facing several difficulties in the use of traditional furnace and tools. In the village Unch, in Nadbai block of Bharatpur district, LUPIN Foundation, an NGO has been working for the betterment of the artisans. At the request of LUPIN Foundation The Rural Technology Action Group (RuTAG) IIT Delhi has taken the initiative for finding solutions to the problems faced by the artisans engaged in manufacturing glass bangles. The present paper presents the solutions proposed and their implementation in the field.

2 Traditional Bangle-Making Process

The bangle-making process involves heating of glass to a semi-molten (jelly-like) state in a furnace, drawing desired quantities of glass from the melting tray and forming it into the desired shape and size by hand tools. The furnace is fired using cheaply available biomass like sawdust, husk and agricultural residues as fuel.

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Fig. 1 Traditional furnace

A traditional furnace used in the area for making bangles is shown in Fig. 1. It has a diameter of about 1 m with 16 small window-like openings to enable 15 artisans to work simultaneously on one furnace. The sixteenth opening, which is larger than the other windows, is used for the manual feeding of loose biomass into the furnace (Fig. 2). The temperature inside the furnace is around 1200–1300 °C. Temperature of semi-molten glass kept inside the furnace is around 1100 °C. The raw glass is melted in small earthen trays kept in the furnace one near every working window (Fig. 3). A desired amount of the semi-molten glass is drawn from the tray kept inside the furnace using the tip of a long pointed iron rod. A small hammering tool is used to tap this rod to create a small hole in the collected glass blob. Then the iron rod is shaken such that this hole enlarges and the glass takes the shape of a small ring. This small ring is then transferred to the sizing mould (locally known as kalbhoot), which is rotated manually. As the spinning continues, the red-hot loop of semi-molten glass is pushed back to expand along the cone to a ring of the desired diameter. This process takes place within 5–10 s, during which the glass cools down and solidifies, and a bangle is ready [1].

3 Problems Faced by Artisans

The artisans perceived several problems in using this process. These problems were categorized into three parts: problems related to (i) The furnace (ii) the posture of artisans during their work and (iii) the tools used. These are discussed below.

(i) Problems related to the furnace.

- The smoky environment in the working area leading to respiratory disorders.
- The high temperature in the working area making the working conditions very difficult particularly in summer.

Fig. 2 Large opening for fuel feeding

Fig. 3 Working window of furnace

- Low furnace efficiency is leading to high fuel consumption. The artisans never imagined that it was possible to reduce the fuel consumption, and hence, this problem was actually identified by the RuTAG, IITD team.

(ii) Problems of uncomfortable posture: The artisans did not have any back-rest while working. As shown in Fig. 30, they had to use a rope or cloth to tie their knees together to enable them to sit stably in a crammed space for long hours. Consequently, they had a backache and other health problems.
(iii) The artisans also faced the problem of bruising/blistering of hands while spinning the rod of the mould.

Due to the various problems faced by them, the artisans had to take frequent breaks leading to a reduction in productivity. The following sections of the paper address the solutions to the above three categories of problems faced by the artisans.

4 Modifications in Furnace Design

Philosophy of design changes: For any biomass-based furnace to have high efficiency and low emissions, combustion quality must be high, and heat losses must be low. To achieve this, it was necessary to make the following major changes in the furnace design:

- Need for insulation: The traditional furnace was not insulated, resulting in loss of a large amount of heat to the environment, thus leading to poor efficiency and increased consumption of fuel.
- Need for better combustion of fuel: The fuel was being fed into the furnace in powdery form. For proper combustion of the fuel in powdery form, a fluidized bed or an entrained flow configuration is employed. Both of these require forced flow of combustion air, which will necessitate the use of a fan or a blower for the operation of the furnace. This was not advisable due to dependence on the availability of electricity, which can be uncertain in villages. For this reason, it was decided to use natural convection for supplying combustion air to the furnace.
- Due to the poor quality of combustion of loose biomass, it was considered desirable to use pelletized/briquetted biomass with a grate.
- Need for a suitably designed chimney: In the traditional furnace, the flue gases were being let out into the workplace. There was one furnace in Unch village which was modified by LUPIN foundation which had a chimney to vent out the flue gases (Fig. 4). The need was felt to design the chimney more scientifically such that it not only exhausts the flue gases from the working area but also provides the right amount of draught for the operation of the furnace. A very large chimney would lead to excessive draught reducing the temperatures inside the furnace, and a small chimney would cause insufficient supply of air and hence excessive pollution.

Fig. 4 Traditional furnace with chimney

4.1 Preliminary Designs

Trials with compacted fuel:

Single-block Sawdust Stove: The first prototype considered for the furnace was a large powdery biomass stove envisaged to be used by a single artisan to melt glass in one crucible. Sawdust was rammed into an annular cylinder with an L-shaped opening (Fig. 5). The crucible with glass was kept on the stove, and the entire unit was kept in an enclosure having a chimney (Fig. 6). The enclosure was insulated as shown in (Fig. 7). This prototype resulted in better combustion of the fuel as indicated by exhaust gases. However, before the temperature of the entire chamber could reach

Fig. 5 Sawdust stove

Fig. 6 Encloser for stove

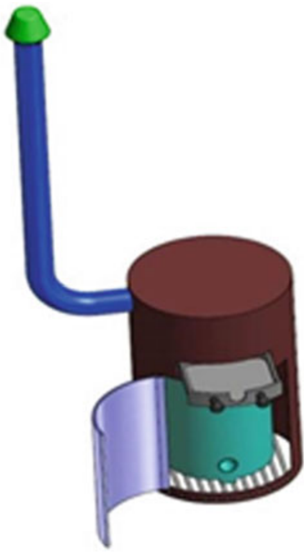

Fig. 7 Insulated encloser

Fig. 8 Multi-hole briquettes die

Fig. 9 Students making briquettes

Table 1 Firing of sawdust stove and briquettes

Sl. no.	Hr./Min	Flame temp.	Glass temp.
1.	0.0	930	575
2.	0.08	908	720
3.	0.16	952	800
4.	0.32	930	820

the desired levels, the sawdust got consumed. There was no provision for adding more fuel in this mode.

Multi-hole briquettes: Subsequently, the design was modified to burn multiple briquettes of smaller size with some small holes as shown in (Fig. 8). These briquettes were made of sawdust with binders of cattle dung or used motor oil and were placed on a grate inside an insulated enclosure (Fig. 9). Table 1 shows the temperature of the fire in the stove and the glass at different times during the firing. The temperature of about 940oC was reached in 40 min. However, these briquettes also had a limitation. They were difficult to handle and feed into the furnace without breaking (Fig. 10). Since the fuel had to be repeatedly fed into the furnace to attain high temperatures and sustain them for a long period, this idea also had to be abandoned.

Pellets in a Small Furnace: Following up on the above experiences, it was decided to use compacted fuel in the form of biomass pellets on a grate in a furnace with a similar configuration as the traditional furnace but of a smaller size with insulation and a chimney. It was decided to make this prototype for only seven artisans to work simultaneously in place of 15 in the traditional furnace. It was envisaged that the heat losses in a smaller furnace would be lower and hence the efficiency would be better than the traditional furnace.

This furnace was designed to ensure that despite a smaller size of the furnace, the following details are kept unchanged from those in the traditional furnace: (a) distance between the two artisans (b) distance of the artisans from the furnace. This was done to keep the current working method of the artisans reasonably unchanged

Fig. 10 Multi-hole briquettes

Fig. 11 New model CAD

so that they do not suffer from any loss of production owing to need to retrain themselves.

Figure 11 shows the CAD model of the new furnace while (Fig. 12) shows the CAD model of the traditional furnace for comparison.

Fabrication of the furnace was carried out with the following main features:

1. Furnace body was moulded with castable material so that desired shape could be obtained.

Fig. 12 Traditional furnace CAD

Fig. 13 Flat bottom crucible

2. The grating was provided to supply enough primary air for proper burning of the palletized fuel.
3. A high-density insulation blanket was provided to reduce heat losses.
4. A chimney was provided along with a damper to regulate the draft.

It was also decided to have a single flat bottom crucible (Figs. 13 and 14) in the centre of the furnace so that short-circuiting of the flue gases to the chimney can be avoided. The furnace was operated using sawdust pellets of 16 mm diameter and about 25 mm length. The details of the experiments with this furnace are reported in Singh et al. [1] During several trials on this furnace, the following problems were encountered:

Fig. 14 Crucible in the middle

- The single crucible in the centre had high thermal inertia and also prevented the flame from reaching the upper part of the dome leading to very long preheat time.
- Material with which the furnace had also been made had high thermal inertia.
- The primary air was found to be insufficient, but an excess of secondary air was entering the furnace thereby increasing the preheat time.

To rectify these problems, the single crucible was replaced by individual crucibles made of alumina bricks positioned near each opening in the same manner as in the traditional furnace (Fig. 15). This helped the flame reach the entire dome. Two alumina bricks were made to hang to form a baffle just below the top opening of the furnace to avoid short-circuiting of the flue gases (Fig. 16). The primary air openings below the grate were increased. The furnace was preheated by closing most of the working windows to restrict the secondary air entry during preheating. With these changes, glass temperature up to 916 °C was attained, and glass could be melted in all the crucibles.

This furnace consumed much less fuel for preheating as compared to the traditional furnace. However, the required temperature was achieved only when all the working windows were closed. Thus, it was not possible to maintain the desired glass temperature with open working window and hence even this trial was not successful.

Fig. 15 Single crucible inside furnace

Fig. 16 Baffle hanging up upon cricible

4.2 Preliminary Mathematical Modelling of the Furnace

From the above experiences, it became clear that the furnace design required a delicate balance between the furnace surface area and its volume. Thus, a simple mathematical model was used for simulation of the furnace to find out the steady-state temperatures that could be attained in the traditional and the experimental furnace [2]. In this model, for a given rate of heat release, the air induced into the furnace due to natural convection was computed, and hence the steady-state temperature inside the furnace could be obtained. The simulation showed that the ratio of the surface area and volume seemed to be important for obtaining the desired temperature. For the small-sized furnace discussed above, this ratio was higher than that for the larger traditional furnace. Consequently, for the volume available for fuel combustion, the secondary air entry was much higher than required leading to low temperatures in the furnace. The simulation also showed that the traditional furnace size which was the result of hit and trials by the artisans over a long time indeed provided the desirable temperature.

4.3 Development and Testing of a Full-Scale Prototype

After the above experiences, it was considered desirable to design the furnace for powdery biomass first to provide a solution to the artisans in a shorter period. The main focus of the new design was (i) to reduce the fuel consumption and (ii) reduce the emissions and the temperature in the working environment.

The above experiments and modelling provided the following guidelines for the next prototype:

- The desirability of retaining the configuration as well as internal dimensions of the traditional furnace for the new prototype.
- Use of construction material and insulation with low thermal inertia.
- Use of a suitably sized chimney with a damper to remove the flue gases from the working area as well as for providing the right amount of combustion air to the furnace.
- Use of a baffle in the top region of the furnace to prevent short-circuiting of the flue gases directly through the chimney.

The new furnace henceforth referred to as the "modified traditional furnace" (Fig. 17) was fabricated by a *tandoor* manufacturer in Delhi using clay (Fig. 18) with an outer casing made of mild steel (MS) sheet to ensure structural integrity.

Alumina blankets [3] suitable for withstanding high temperature were used as the inner lining of the furnace (Fig. 19). The same insulation was also used in the space between the clay and the outer MS casing (Fig. 20). The floor of the furnace was made of Alumina board. The chimney height was determined from the simulations. A damper was provided in the chimney to control the draft.

The new prototype was fabricated and installed in IIT Delhi. Artisans from Bharatpur tested the furnace at IIT Delhi for three days (Fig. 21). Table 2 gives the results of fuel consumption in the new furnace as compared to the traditional one in Bharatpur.

The following observations were made during the testing at IIT Delhi.

1. The new design drastically reduced the pollution level and temperature around the furnace thus improving the working environment.
2. The furnace attained a temperature of 1000 °C within 10 min of firing.
3. The percentage reduction in fuel consumption in the complete operation (for 8 h) was found to be about 74% compared to that of the traditional furnace.

Fig. 17 Modified traditional furnace

Fig. 18 Clay core of furnace

Subsequently, another furnace of the same design was installed in Unch village with the help of LUPIN Foundation (Fig. 22). The construction of a shed and a raised platform was taken up by LUPIN Foundation. The furnace is currently in use. The support for the baffle is a weak component of the present design and is found to fail first. During operation at Unch, one such failure happened, and it has been repaired. However, this issue needs to be taken care of in the design of the next version of the furnace.

Fig. 19 Inner lining of furnace

Fig. 20 Outer insulation

Table 2 Results of fuel consumption of testing at IIT Delhi

Fuel consumption	Conventional furnace	New furnace	Savings
Preheating (kg/h)	55–60	12	43–48
Firing (kg/h)	37–42	10	27–32
Overall, 2 h (kg)	92–102	23	69–79
Overall, 8 h (kg)	314	82	232
Fuel savings (%)			74

Fig. 21 Artisans at IIT Delhi

Fig. 22 The furnace at Unch village

5 Seating Arrangement

In a traditional furnace, 15 artisans sit around the furnace facing small windows to withdraw semi-molten glass. The gap between each window is about 15 cm. Each man sits 35–45 cm away from the outer wall of the furnace and takes 70 cm × 50 cm workspace. They bind their legs together with a cloth or rope as shown in (Fig. 23) for the stability of posture while working and to minimize workspace. They also sit on a pillow for cushioning. The feedback provided by the artisans highlighted that this working posture was not comfortable for them and led to frequent pain in the back and abdomen. Due to difficulty in sitting in this position for a long time, they had to take frequent breaks.

To improve the comfort while working, they were provided with two numbers of a commercially available ground chair (Fig. 24) to try out while at work in the village for about 2 months. They found the ground chair comfortable. The possibility of making such a chair locally using jute was also considered (Fig. 25).

Also, while installing the modified furnace, a raised platform was constructed (Figs. 26, 27 and 28). In this arrangement, the artisans have the option of sitting on the platform traditionally. They would also have the option of sitting in a posture similar to a normal chair, with legs resting on the floor, during their work.

Thus, the artisans have two alternatives to the traditional uncomfortable posture. They need to be encouraged to adopt these alternatives, which is proposed to be done in the near future.

Fig. 23 Artisans with legs tied

Fig. 24 Commercially available ground chair

Fig. 25 Ground chairs made at IIT Delhi

Fig. 26 Raised platform

Fig. 27 Detachable shelves of raised platform

Fig. 28 Artisans working at raised platform

6 Tool Design

Artisans use four different tools to make one complete bangle. They are as follows:

1. A long steel rod with conical edges on both sides (Fig. 29).
2. An arrow-shaped tool (Fig. 30).
3. A bicycle spoke (Fig. 31).
4. The bangle mould called the *kalbhoot* (Fig. 32).

Fig. 29 Artisan using long steel rod

Fig. 30 Artisan using arrow-shaped tool

Fig. 31 Artisan using tool made of bicycle spoke

Fig. 32 Kalbhoot with bearing arrangement

Fig. 33 Artisan using Kalbhoot

All these tools were made by the artisans themselves.

Problems related to the tools are given as follows:

- Rotation of kalbhoot causes blisters on their hands.
- Needle tip of long steel red gets blunt with every operation.

It has been observed during the field visit that kalbhoot is supported on the hand of the artisans causing blisters. Thus, a modified kalbhoot (Fig. 33) was designed and fabricated using bearing for support and to reduce friction in the rotation. A wooden handle was also provided to facilitate manual rotation. This modified kalbhoot was tested by the artisans at IITD, and the feedback was positive. Use of the modified tool in the village needs further promotion by the RuTAG, IITD team.

7 Conclusions

Three sets of problems faced by the artisans in Bharatpur have been addressed and solutions proposed. A modified furnace has been developed, installed in the village and is in use at the time of writing this paper. This furnace is shown to provide up to 74% saving of the fuel, reduction in emissions in the workspace due to the flue gases leaving through the chimney and reduction in workspace temperature due to the insulated furnace. Thus, the furnace has resulted in substantial improvement in their working environment. The solutions to the other two problems of uncomfortable sitting posture and blisters in the hands with the long-term use of tools have also been proposed, and these were appreciated by the artisans. Further effort is required for promoting their use in the village. It is hoped that the design improvements will help the villagers at the grassroots to have relatively more comfortable working environment resulting in higher productivity. Since the new furnace also saves fuel, the cost of production is reduced, and hence it can improve their economic status as well.

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