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Development of various modules of environment friendly furnaces concerning melting and castings of iron, brass and bell metal products

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Abstract : Since over a decade there is a worldwide trend towards using fuel alternative to coal/ coke concerning casting production due to the excessive emission undesirable level of suspended particulate material and toxic gases beyond acceptable limit with flue emitted from coal/coke based units. India is an important global player in the casting sector and the study on ferrous as well as non-ferrous casting reveals that : (i) there are above several thousand coke based foundries currently operating in different parts of India and (ii) there are numerous cottage based brass and bell metal industries in India which mainly use coal/coke/wood / wood charcoal as main fuel. Exhaust emission with flue from these coal/ coke based industries normally carries lots of Suspended Particulate Materials (SPM), Toxic gases such as SO_x, NO_x, etc. Normal emission of SPM and SO_x from these foundries/ melting and casting unit is about 1000-3000 mg / NM^3 and beyond 700 mg / NM^3 respectively. Stringent specifications set by not only Pollution Control Boards of various First & Second World countries but also by CPCB (Central Pollution Control Board of India) threaten the existence of most of the coke/coal based medium and small scale casting sectors as operation of these solid fuel based furnaces is reported extremely unhealthy because of the excessive presence of SPM and toxic gases.

Coke less cupola using sulfur-stripped hydrocarbon based oils (LDO, Kerosene Oil)/ Gases (LPG, LNG, NG) developed by M/s Richard Taft[1], Ducker[2], NML/CSIR[3], in Russia[4] as well as in Japan[5] is presently in the process of replacing coke based cupola concerning iron casting / foundries. Therefore, an attempt had been made in this work to carry out research and development of environment-friendly furnaces of various sizes for brass and bell metal melting and casting in connection with the production of thin section of not only traditional items/ utensils such as lota/small size pitcher, ghara/ big size pitcher, tumbler, thali/saucer/plate, flower vase, but also of artifact.

Number of visits to various clusters of Brass and Bell metal Industries of West Bengal, especially at places and around Bishnupur in Bankura district were made. Thorough discussion with practitioners as well as artisans and witnessing some of the present practice were carried out. State of precarious ambient condition due to excessive presence of SPM as well as toxic gas in and working places as a result of using highly ash content coke was noticed. Based on mutual agreement and self financing, an eco friendly furnace was envisaged to design and developed to deal with melting and casting of about 5 kg weighing standard Kalsi. Concept design of coke less furnaces using sulfur-stripped hydrocarbon based oils (LDO, HSD, Furnace Oil) / Gases (LPG, LNG, NG) was envisaged to be utilized as exhaust emission from these ensures SPM and toxic gases much less to the extent of about 10 ~ 25 mg/ Nm^3 from the limit of 150 mg/ Nm^3 set by any local Pollution Control Board [CPCB].

The developmental work of such a furnace [a module unit of melting and casting] envisaged to include a set of either oil or gas burners which are to be positioned/ placed spirally along the hearth portion of the furnace to provide necessary heat for heating and melting. Around the burners, there shall be some of refractory coated [heat insulated] grate bar to support entire load of permeable bed and mould containing desired raw materials for melting and casting of Kalsi/ pot. Desired quality permeable bed may be improvised to be made by using either by making highly insulated and un breakable quality ball made from cast able quality refractory ball [about 50 Ø mm.] or by breaking and shaping of granular size rejected graphite block [-55 + 50 mm] from used and rejected graphite electrode. Permeable bed is envisaged to extract and absorbed heat from flue and suitably transfer the heat to the mould. During the operation of the mentioned furnace, hot gases/flue from burners is expected to flow up through the permeable bed placed along the annulus space between furnace and the mould. Heated flue which is ejected out from the mentioned burners while passing along mould and permeable bed is expected to accomplish preheating, heating, maintaining temperature for complete melting of raw materials. Through permeable bed area, the proposed design is envisaged to control/ adjust the operating temperature of furnace, mould and raw materials. Molten metal with desired flow ability is expected to get into the cavities of investment mould to produce thin shell utensils/ Kalsi when it is tilted upside down after getting superheated in the stated furnace.

The desired furnace was designed and developed in the premises of an entrepreneur at Bishnupur locality in Bankura District of West Bengal. No. of successful campaigns then carried out which reveals not only the acceptability and validity of the developed Furnace based on using Sulfur stripped domestic fuel such as mainly LPG [Liquid Petroleum Gas] as well as Kerosene but also market acceptability of the product i.e. Kalsi/Ghara/Pot. In near future, the developed technology is expected to be utilized by the Practitioner as well as Artisan of the Brass and Bell metal product cluster with sulfur stripped either LPG from west coast or NG [Natural Gas] from Assam when these are expected to be supplied through National Piping Net Working.

Keywords : Environmental friendly furnace; Coke-based foundries; Castings; Iron; Brass industries; Bell metal indusries.

INTRODUCTION

In the developing countries, both poverty and economic growth pose serious environmental challenges. In their desperate attempt to service, people are forced to destroy ecology. More over in order to prosper, cheap and dirty technology is utilized. It is often not realized that uncontrolled economic growth, urbanization and industrialization may be achieved by destroying environment, forest , mines and land and excessive and uncontrolled overuse of raw materials from mines, ground water systems and industrial waste, water, air and soil are getting polluted.

The manufacturing process that currently are in practice in the rural districts not only in Bankura, West Bengal but also in other numerous parts elsewhere in India to produce traditional items/ utensils such as lota/ small pitcher, ghara/ big size pitcher, tumbler, thali/ plate/ saucer, flower vase, etc is unique in their own methodologies. However, meting furnaces used for mentioned melting and casing which use coal/ coke/ coke breeze / wood charcoal are environmentally excessively hazardous. Flue from coal/ coke firing contains excessive, uncontrolled and health injurious SPM and toxic gases [including unburned hydrocarbon] such as CO, CO_2, SO_X, NO_X, HF , etc. It is reported that people as well as other living beings exposed to fine particulate air pollution primarily by coal /coke fired furnaces face the risk of developing breath chocking/ suffocating as heart disease. Toxic gases such as SO_x, NO_x, CO, CO_2, the other main constituents of flue of coal/ coke fired furnaces result in increasing acid rain, green house effects and smog and Ozone depletion layers . As a result of which, there is an excessive formation of smog which affects presently smooth movement of Air traffic, Auto transportation as well as Railway Traffic suffers. Based on the said reason, there is a Government directive to use mainly CNG [Compressed Natural Gas based vehicles in Delhi and Mumbai. LPG is in use elsewhere. Gas cleaning Plant [GCP] is normally incorporated large scale coke/coal based plant. However, incorporation of any GCP is neither desirable due space constrain and nor economical in any small scale furnace unit.

The present work aims mainly to design develop and provide a less costly green technology/ eco friendly melting furnace concerning production brass metal items [utensils] considering combustion, heating to desired temperature of mould/ investment mould assembly with raw materials and melting of raw material having desired fluidity. The furnace is to consist of number of either oil or gas burners which are to be positioned approximately at the bottom portion of the furnace to provide necessary heat for heating and melting. There shall be some of grate bars/ conduit which may or may not be coated with refractory for insulation. Grate bars are to support entire load of permeable bed and investment mould along with raw materials. Desired quality permeable bed is planned to be created by using either quality refractory ball of 55 mm ø dia. or granular sized +55 -60 mm rejected graphite electrode pieces through breaking and shaping. During the operation of the mentioned furnace, hot gases/flue from burners will be made to flow up through grate bar, along investment mould surrounded suitably by permeable bed along the annular space of furnace. Heated flue which is ejected out from the mentioned burners while passing along mould and permeable bed is expected to accomplish preheating, heating, maintaining temperature for melting and complete melting of raw materials. The depth of permeable bed area is expected to control/ adjust the operating temperature of furnace, mould and raw materials. Molten metal with desired fluidity is expected to get into the cavities of investment mould to produce thin shell utensils when heated mould at desired temperature is taken out of the furnace and placed upside down in order get casting.

The present work aims at the following chronological order of events :

– Design and development of a conceptually designed green technology based furnace for rural based small scale industries / Artisans.
– To visit a number of clusters of rural based industries and artisan and discuss on :
  (i) their saleable product and concerned melting units,
  (ii) expected damage caused due to generation and inhaling of air pollution generated by the of coal/coke firing that is used in melting.
  (iii) demonstration of pollution measuring unit/system available in nearby available smoke testing centre
  (iv) witness and participation of existing coal/coke based melting units,
  (v) to finalize the design and development of a standard melting[4.0 kg ~ 5.0kg] unit based on consensus using of sulfur stripped available either oil or domestic LPG,
  (vi) to carry out tests and trials of the developed furnace to ascertain its validity.
– To utilize oil [mainly Kerosene(blow lamp type)]or gas [domestic LPG] burners (blow torch type). The oil burners are to be operated by compressed air that is pumped manually and gas burners are naturally aspirated. These burners are cheap and do not require electrically or D G set operated air supply system.
– To utilize either waste/scrap graphite chips or refractory chips or both to make permeable bed.

– To install and develop the furnace in the premises of M/S Bimal Shikary, Matukgunge, Bishnupur, Bankura - 722122. West Bengal.
– To provide furnace lining using clay as well as cast able Alumina refractory.
– To measure temperature Iron-Constantan thermocouple by using micro voltmeter.
– To make one such modules of furnaces in order to establish the scope of use in making not only smaller items but also artifacts. The scope also includes furnace iron melting in a crucible to items such as counter weights, agricultural implements, and domestic cutting tools.
– Expenditure/Budget was absolutely based on self-financing.

The furnace was made ready by the end of March, 2012. Initially a few trials were carried out to test its validity and subsequently, some successful trials were carried out in presence of M/S Bimal Shikary with his two sons and some other interested local brass and bell metal entrepreneurs. Results thus obtained by subsequent trials based on using LPG were extremely encouraging. Therefore, it can be hopefully predicted that the NG as well as LPG based Furnace is expected to be techno-economically viable option.

Background

Historically, precision casting dates back to 1600 BC (Shang Dynasty) when the lost wax process was first known to be used. However, it has been last 70 years that the greatest developments in technique of precision casting taken place worldwide. The late 1940 saw the introduction of Antioch plaster casting process, mainly for the purpose of producing tire-mould. At same time, keen interest was shown many others and investigated its possible application and found outlets for simple type air craft engine. More recently, investment casting have been introduced for producing precision casting light alloys (including magnesium and aluminum alloys) and steels (including alloy and tool steel, nickel chrome, cobalt chrome, copper base alloys, etc.). Before going any further, perhaps one ought to attempt to define misleading term "precision casting". It is not claimed to be precise in comparison with machine shop interpretation. It is however, claimed to be precise compared with other casting processes, hence the name. A close tolerance is considered to be e.g. ± 0.08 mm, whereas an engineer considers it somewhat finer, perhaps a tenth of this, but a foundry man somewhat coarser e.g. ± 0.3 mm to + 1 mm. Techniques of precision casting have been applied to meet requirement of complexity and accuracy which would not have been possible using conventional methods. Possibility the greatest advantages offered by this process are that dimensions remain consistent from casting to casting, the metallurgical characteristics of the casting are good, and very intricate parts can be produced by semiskilled labour.

The major uses of bell metal are church bells, tower and cupola bells, victory bells, memorial bells large and small, rail road bells, fire bells and artifacts. For centuries, the basic process of making bells has not changed. The metal used has changed very little throughout the ages. It is composed of pure copper and tin in the approximate proportions of 13 to 4 and is very durable subject only to an initial surface corrosion which forms a protective coating against further oxidization.

Metal craft is perhaps the single most important craft in terms of the number of artisans engaged in its practice as in its close links with the daily lives of the people of the concerned State. The craft is practiced by the people of the Kansari caste who can be broadly described as metal smiths while a particular variety, dhokra, is practised mainly by sithulias. The largest concentration of the former is Kantilo and Balakati in Puri district although fairly substantial numbers are found in Cuttack, Ganjam and Sambalpur districts. The product obtained from these can also be broadly subdivided into two groups in terms of raw materials used, this is, brass and bell metal, the former being an alloy of copper and zinc and the latter of copper and tin. The workshop is called sala or shed and consists of a platform with a block of stone for the floor on which the beating is done, a heating furnace or bhati, a raised verandah with a local lathe for polishing. Tools used are hammers and anvils, pincers, hand drills, files and scrapers. The heating furnace with a crucible is fanned by a blower with leather bellows although of late the craftsmen have started using mechanical blowers.

The process consists of preparation of the material by melting the required materials in the crucible and then placing the molten metal into an earthenware container. After the molten metal sets, it is taken out and after repeated hammering and beating is given the desired shape. Sometimes for making a single item two or three pieces are separately made and joined mostly with rivets. The major items manufactured in the beating process are plates or 'thali', deep round containers called Kansa, small containers called 'gina' (tumblers), water containers called gara and buckets or 'baltis', large cooking utensils and storage vessels called 'handi', various types of pots and pans, ladles or chatu, perforated flat cooking spoons etc. While the above mentioned are items used in cooking and eating there are also a number of items used for puja or worship. Of these most important, of course, is the ghanta or the gong and thali for offering of the food to the deities. It may be mentioned here that in a few places the surface of the items are also engraved with various designs including floral and geometric patterns besides human and animal figures and occasionally they are also painted with enamel paints. The items produced by the beating process are many and the designs also vary from place to place.

As for casting one can make two broad groups that are brass castings and dhokra casting. Both follow the lost wax process. Brass casting is done by the Kansaris and items produced include icons-mainly Radha, Krishna, Laxmi, pot bellied Ganesha, Vishnu and crawling Krishna called Gurundi Gopal, bells or ghanti, lampstand or rukha and lamps or dipa. It is interesting to note that at present there is no bronze casting being done in Orissa although the craft seems to have reached great perfection centuries ago as evidenced for the discovery of a large number of bronze icons from Achutarajpur near Banapur in Puri District. Again no casting is done in bell metal although this is quite common in South India. The socio-cultural links of its handicraft are very strong.

According to well entrenched traditions the bride is presented with a set of brass and bell metal articles for starting off her new home, the quantity and quality varying according to the economic status of the family. While in the villages these are extensively used for eating and cooking, in the areas other materials like stainless steel, aluminium and ceramics have dislodged them. Nevertheless the brides, even in urban areas continue to get their set of brass and bell metal items in marriage. Of particular interest is the round deep bowl called Kansa in which 'pakhala' a typical dish of Orissa, that is rice soaked in water and curd or torani or fermented gruel, is eaten. In the villages and in terms of the rural economy the articles also serve another useful purpose as they can be easily pawned for borrowing money.

Besides, the old, broken and used items can always be exchanged at reduced rate for new items from itinerant metal ware vendors. As for metal icons, while in most orthodox families these are installed as deities of the home, frequently placed on a brass platform called Khatuli, these areas also used in some temples as the presiding deities. However, in all major temples almost invariably the moving image or the chalanti pratima of the presiding deities are brass icons. It is these icons which are taken out in various ritual processions and perform other mobile functions of the much larger and fixed principal.

Kenjakura is a village situated in Block Bankura-I in the district of Bankura, West Bengal. It is situated in the bank of river Darkeswar. This cluster is more than 150 years old. Presently 300 hundred families are engaged in this profession and around 2500 people are working in this cluster. The main products of this cluster are - traditional bell metal utensils mainly plates of different sizes, container, glass and other gift items mainly for regular uses and bell.

Fig. 1 : Utensils made in Bishnupur and Kenjakura

The heating and melting is currently accomplished in oven operated mainly by coal or coke and partly by wood or wood charcoal or any combination of these. Most of the mentioned unit is located as clusters in the various rural belts of the country. Oven operation based on coal/ coke/ wood combustion is not at all environment/ eco- friendly. Flue from coal/ coke contains excessive and uncontrolled suspended particulate material (SPM), health injurious toxic and green house gases such as CO, CO_2, SO_2, NO_x, are normally emitted to atmosphere. The SPM consists of mainly dust, smoke, fumes, fly ash, etc and these are mainly air borne. These air borne particles are capable of temporary suspended in air or other gases Fumes are mainly fine solid particles (often metallic oxides such as zinc and lead oxides) formed by the condensation of vapours of solid materials. Fumes may be formed from sublimation, distillation, calcinations, or molten metal transfer processes, and they range in size from 0.03 to 0.3 μm. Fly ash consists of finely divided, noncombustible particles contained in flue gases arising from combustion of coal/coke/ wood charcoal. Inherent in all coal/coke/ wood charcoal, mineral or metallic substances are released when the organic portion of these is burnt. Fly ash shares characteristics of all three of the other solid particulates discussed. Like dust, it has particles that range in size from 1.0 to 1000 μm. Smoke is the result from burning; and like fumes, it consists of inorganic metallic or mineral substances. The severity of SPM, from both ferrous and non ferrous melting unit using Indian coke/ coal [containing ash between 22 ± 6 percent] and through yearly production of melt is about 1800 tons considering 6 hrs daily operation and 100 working days, SPM or dust generation is about 3.78 tons yearly from one such unit. By adopting a dry gas cleaning facility in order to control dust load emission to the extent to less than 150 mg/Nm^3 in atmosphere, 0.405 ton of which is remained to the atmosphere yearly and 3.375 tons of dust is collected yearly in dust collecting chamber by operating one such unit and a cluster consist at least 20to 35 of such units.

Environmental Pollution Hazard : Flue from coal/ coke contains excessive and uncontrolled suspended particulate material (SPM), health injurious toxic and green house gases such as

CO, CO_2, SO_2, NO_x, are normally emitted to atmosphere. The following is a quantified list of the status of various components of the environment due to human interventions:

- Emissions of carbon dioxide and other gases into the atmosphere from fossil fuel burning and other human activities may raise the average temperature of the earth's lower atmosphere several degrees by 2050. This would disrupt food production and flood low-lying coastal cities and croplands.
- Today more than 10 million people worldwide have lost their homes and land because of environmental degradation. These people are now the world's single largest class of refugees - Environmental refugees.
- About 8.1 million square kilometers of once-productive land (crop land, forests, grasslands) have become desert in the last 50 years. Each year almost 61,000 square kilometers of new desert are formed.
- Topsoil is eroding faster than it forms on about 35% of world's cropland. Crop productivity on one-third of the earth's irrigated cropland has been reduced by salt buildup in top soil. Topsoil water logging has reduced productivity on at least one tenth of the cropland.
- Most of the wastes we dump into air, water and land eventually end up in the oceans. Oil slicks, floating plastic debris, polluted estuaries and beaches, and contaminated fish, and shellfish are visible signs that we are using the oceans as the world's largest trash damp.
- In addition to its effects on human health, air pollution affects the physiology of the plants and the integrity of minerals used in man-made structures.

The acidic gases SO_2, NO_X, CO_2, and HCL are emitted by sources of airborne pollution and are converted by oxidation in the atmosphere to secondary pollution such as sulfuric and nitric acids. This cause may leads to acid rain. *Acid rain* can wash away essential plant nutrients from the soil. In addition, it makes the soil acidic and aids the release of aluminum copper ions which are harmful to plants. Aquatic life is also affected when pH is less than 4.5, calcium metabolism in fresh water fish will be affected, leading to poor health. As a result, diversity and population of some fish species get reduced. Acid rain will cause damage to common building materials (such as lime stone and marble), in addition to damaging statues and monuments'.

The earth's atmosphere is composed of several layers. We live in the Troposphere where most of the weather occurs; such as rain, snow and clouds. Above the troposphere is the Stratosphere; an important region in which effects such as the Ozone Hole and Global Warming originate. Ozone forms a layer in the stratosphere, thinnest in the tropics (around the equator) and denser towards the poles. Ozone is formed in the atmosphere when ultraviolet radiation from the sun strikes the atmosphere, splitting oxygen molecules (O_2) into atomic oxygen (O). The atomic oxygen quickly combines with further oxygen molecules to form ozone. The mentioned toxic gas also contributes towards depletion of Ozone layer. Ultra Violet radiation from the Sun can cause a variety of health problems in humans, including skin cancers, eye cataracts and a reduction in our normal immunity towards many diseases. Furthermore, UV radiation can be damaging to microscopic life in the oceans which forms the basis of the world's food chain, certain varieties of vegetation including rice and soya crops, and polymers used in paints, clothing and other materials. Health disorders, damage to plant and aquatic life and degradation of materials will increase. Ozone depletion may even affect the global climate.

In addition to environment pollution concerning coke/ coal based furnaces, the following additional Problems were also noticed :

Less production : Most of the unit produces 400 kg to 600 kg per month.

Lack of modern technology : The unit holders are unable to adopt modern technology as they have capital constraint to procure plant & machineries.

Lack of technical skill : The producers are not technically skilled enough to create new design, improve the quality and diversify the product line.

Quality control : There is no quality control and testing facility.

Lack of management skill : Owners are reluctant to take any managerial training, so they are working on unorganized way and approaches are very informal.

Lack of marketing skill : Marketing skill is required for proper packaging, promotion, etc.

Inadequate working capital : This is the main constraint to purchase bulk raw materials.

Lack of storage space : Most of the units are operated from their home. There is an inadequate space to stock the raw materials and finished products.

Lack of guidance/ training : Lack of proper guidance/training forms no promotional institute in the area.

High Cost of capital : Cost of capital is very high as they are borrowing from local mahajans at an exorbitant rate of interest.

Some literature on coke less furnaces : From literature survey, it reveals that coke less furnace that works on sulfur stripped either LPG [Liquid Petroleum Gas] / NG [Natural Gas or Kerosene oil/ LDO [Low speed Diesel Oil] ensures environment friendly operation. The following are the important information on coke/coal less furnace concerning ferrous as well as nonferrous foundries :

(i) The model design development of super furnace as shown in the photograph [Fig. 2] has the following features :

Fig. 2 : Super furnaces [Liquid fuel fired]

Gas / liquid fuel fired miniature module furnace capable of operating at temperature between 1200^0C to 1650^0C. the said furnace shell is lined with low to high quality refractory depending on operating temperature. It is provided with flue handling dome cover and designed to accomplish small quantity batch production of ferrous and non- ferrous casting.

The Coke less Cupola is very similar to conventional coke fired cupola as in the following Fig. 3. The burners are located in approximately the same position as the tuyers and their actual height depend on how much metal the foundry requires to hold in the well. Above the burners is a water cooled grate consisting of steel tubes, which may be coated with refractory on smaller cupola for insulation purpose, and on larger ones these may remain uncoated. This water-cooled grate supports the specially developed refractory/ heat insulated-resistant spheres above them. These spheres act as a heat exchanger and are responsible for superheating the metal. Metallic charge is placed above the sphere with a small quantity of flux. As there is no coke added to the cupola, there is no carbon pickup during melting process; thus demands continuous injection of a suitable re carburizer into the well in order to achieve the required carbon content. The burners are operated with excess fuel in order to give partially reducing condition inside the cupola and hence reduce oxidation losses. During the operation the hot gases from the burners pass through the grate and permeable bed to maintained the bed at high temperature. They then pass up through the charge where they preheat the metallic. These melt just above the belt and trickling over the sphere are superheated. The depth of the bed is the main-governing factor of metal temperature. The maximum temperature is achieved with a bed height above 400 ~ 450 mm. The spheres are either 125 mm. diameter for smaller furnaces or 150 mm. for larger furnaces.

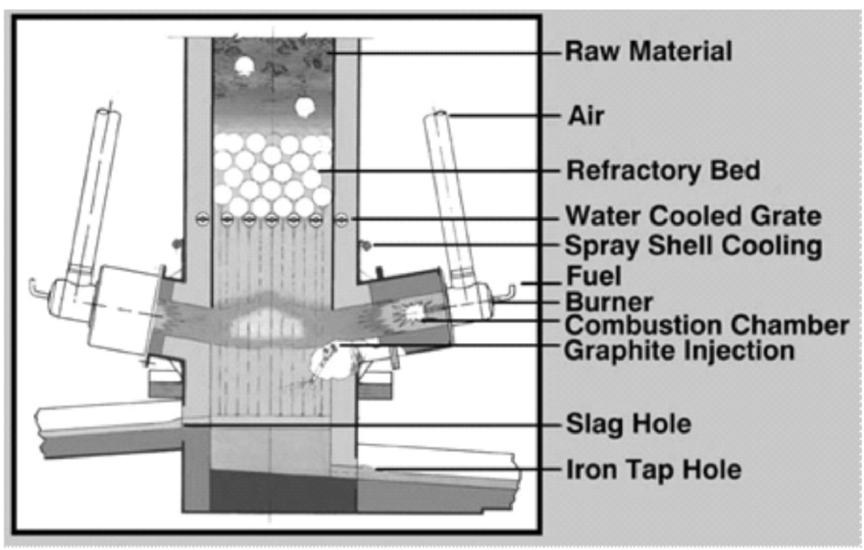


Fig. 3 : Schematic representation of Coke less Cupola

The metal then passes through the grate into the well where it can be tapped out either continuously or intermittently depending on the foundry requirement. The continual injection of re carburizer into the well is very effective and gives good control over composition with the added advantage of being able to achieve high carbon content should this be required.

At Duker in Germany a cokeless plant has been operating since 30 years. This furnace was originally fired with Diesel oil and then changed to Natural gas. There has been installation of coke less cupola plant in Spain, Korea and Austria. In Spain coke less cupola plant foundry is utilized for castings for automobile industries.

Conceived plan : An extensive and close interaction with an entrepreneur of Bishnupur under Bankura District of West Bengal, India enabled that a development of environment/eco-friendly, efficient and controlled temperature based melting furnaces unit for melting and casting weighing 1~2kg,3~5kg , 6~8kg brass/ bell metal as shown in Fig. 4 are very much needed for development. The process as mentioned is to produce thin traditional items/ utensils

Fig. 4 : Normal Utensil Product - Ghara / Kalsi (Pitcher)

such as lota/small size pitcher, ghara/big size pitcher, tumbler, thali/saucer/plate, flower vase, artifacts, etc may be considered under category of precision casting. In this case the pattern is metal made and in two halves. A fine sand layer is put on the concave surface of pattern initially and then a clay paste with binder of suitable thickness is pasted over this. Due to the presence of fine sand layer between pattern and mould, mould may be removed easily from pattern. The dried inner mould is then removed from pattern. The practice is repeated convex side also to obtain outer mould cover. The inner mould is then suitably placed on outer mould considering equal space thickness throughout. The same exercise is repeated on other pattern also. Thus prepared upper side assembly and lower side of the assembly is joined together to obtain entire mould assembly as shown in Fig. 3. This formed mould is then allowed to be baked for certain duration may be either by heating or natural sunlight curing. In the furnace for heating, melting and superheating, the mould assembly with raw material with flux mix is placed as shown Fig. 5.

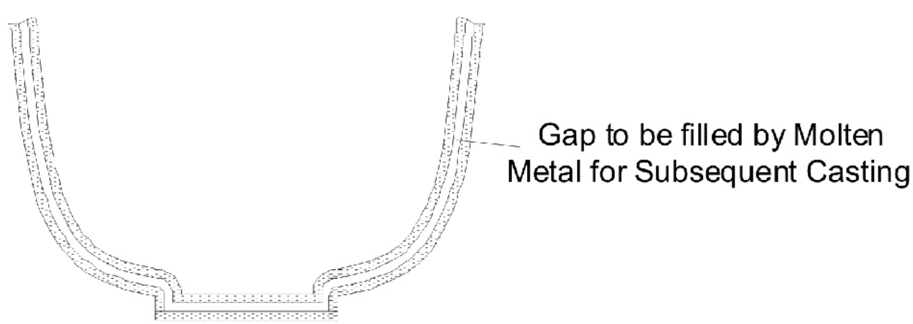


Fig. 5 : Mould Made of Local Clay Mixed with Binder

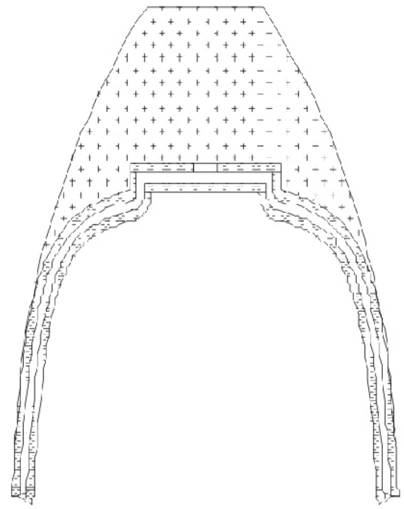


Fig. 6 : Heated mould with molten metal is placed upside down

While after desired heating [attending required temperature], the mould assembly is taken out from furnace and is placed upside down as shown in Fig. 6 out of furnace for letting liquid metal to flow and fill up space between moulds cavity and subsequently solidifies to produce desired thin casting.

PRESENT WORK

As already mentioned that, based on the visit to the places of artesian at Bishnupur and subsequent discussion and participation in presently practiced casting campaign using coke as fuel on making some pitchers, it is made to design and develop a coke/coal less furnace using domestic LPG in order to make similar size [4~5 kg] Kalshi/ pitcher. The data made available are as follows :

(I) Oven configuration : As shown in Figs. 7.1, 7.2 and 7.3

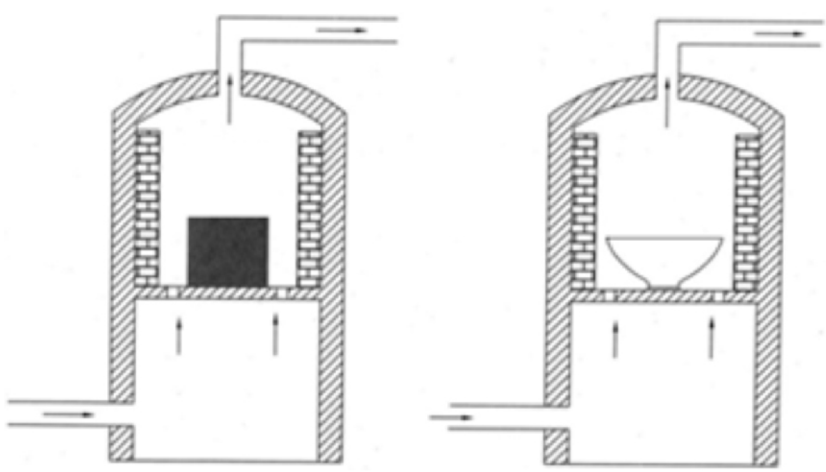


Fig. 7.1 : Present Practice of Heating & Melting

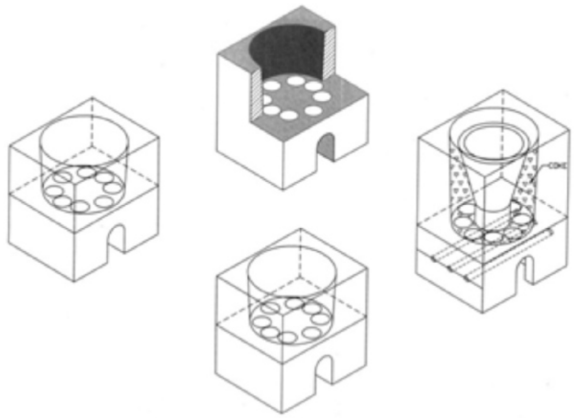


Fig. 7.2 : Various Views of Present Furnace

Fig. 7.3 : Photograph of the existing furnace

(II) Materials of furnace and sequence of operation :

Materials : Clay for Mould making, Pattern to make mould, Brass & bell metal chips for making product/ Kalshi, Coke as fuel, fire wood for initiating combustion.

Procedure : Mould assembly was placed upside up with raw material sink at the bottom in the appropriate place/ above grate bar level in the furnace. Annulus place between furnace void space and mould assembly was then filled with coke pieces. Firing was then initiated through burning wood from bottom space bellow grate bar of the furnace and most of the bottom portion is filled with coke. Combustion was accelerated with aid of table fan placed in front of Door openings suitably. Temperature rise was recorded in regular interval. Furnace temperature was found achieved to desirable extent within 2-1/2hrs. Furnace temperature was maintained for about an hour and mould was taken out and new green mould assembly was placed in the furnace, the void space was filled with fresh coke and the process was the repeated. Ripe heated mould assembly is take out of the furnace and kept suitably upside down in a suitable platform near the furnace. In this position, molten metal in the sink gets in to the void space in the mould to make a desired portion of Kalsi. The mould with newly formed casting is allowed to cool down for achieving consolidation and strength. Subsequently after desired cooling, clay portion over newly formed casting is broken out to obtain product, i.e. Kalshi.

Data obtained :

(i) Product weighs- 4.6 kg.

(ii) Furnace operating temperature maximum : 950^0c.

(iii) Coke consumption 10 kg - for 1st product and , 8kg- for subsequent product- melt

(iv) 2- heats in summer, 3- heats in winter

(v) Working ambience was found encompassed with excessive smoke.

(vi) Lots of ash found collected in the furnace bottom pit.

III Conceptual Design : This is carried out based on consideration of exiting furnace and working space. Configuration [Fig. 7.4 & 7.5] : It includes the followings :

(i) Furnace internal working dimension:(i) diameter - 400mmϕ, (ii) height- 900mm.

(ii) Outer shell is to be made from available oil drum shell [3mm thick]

(iii) As coke provide three two basic functions i.e. : (i) supply necessary heat, (ii) accomplish the per pose of permeable bed and (ii) also take load/ burden of entire bed of furnace including that of mould, the design coke less furnace to accomplish: necessary heat supply by combustion of liquid fuel, refractory ball or graphite chips to accomplish functions of heat sink as well permeable bed and grate bar to take care if entire load/ burden.

(iv) There shall be at least 3 insulated grate bar [d=65 mm Ø] to be placed approximately 115mm ~ 125 mm above bottom level/ plate so that :

$D_i = 3d + 4g$ [Fig. 6]

Where D_i is the internal shell dia. of the furnace, g is equal gap [~ 40mm] between grates. Flue from burner [oil or gas] of the furnace is expected to pass through the gaps between grates. Deflection of a grate bar [middle one, whose length is maximum] is due to both static and dynamic load on it:

$$\delta = \delta_{st} + \sqrt{}(\delta_{st}^2 + 2h\delta_{st})$$

where δ_{st} = Mg/k, the static deflection, M is mass of mould and pieces of accumulated permeable bed, g is acceleration due to gravity & h, possible falling height of pieces of permeable bed [furnace top to gtate] and k is the deflection per unit load.

(v) Refractory lining of 100 mm thick to be made from mixture of 60% of Clay and 40% of Cast able fire clay [20% Alumina]. Refractory lining is fixed on shell through anchoring.

(vi) A conical hood with 75mm refractory lining with fume exit duct is to placed on the furnace top during operation.

(vii) 2 or 3 or 4 no's of Gas or Oil Burner based on suitability [based on design requirement] is envisaged to be provided and to be placed spirally and tangentially over grate space along furnace.

(viii) to use at least 2 no's of thermocouples to measures temperatures [up to 1250^0C] at suitable place [150 mm above grate and on the exit hood] of the furnace to be placed.

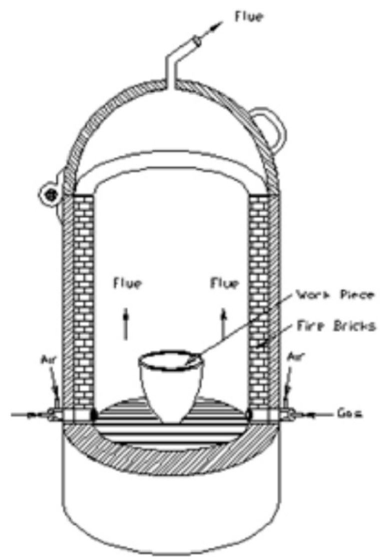


Fig. 7.4 : Placing of Mould in the Eco-friendly Furnace

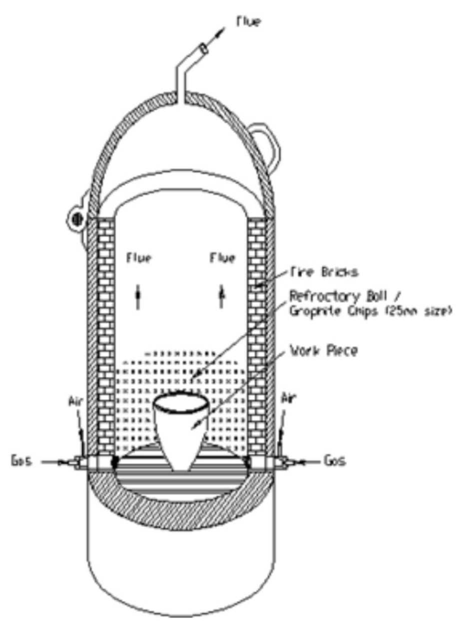


Fig. 7.5 : Proposed Eco-friendly Furnace in Operation

IV Mathematical Analyses :

This is necessary in order to estimate fuel consumption rate and also this estimation will be helpful for subsequently selecting suitable no of burners. Burners (oil based or gas based) may be selected based on Heat Balance. The mentioned analysis is based on:

(i) Based on theoretical analyses and

(ii) Based on Data analyses of presently used coal/coke consumption. Equivalent oil/gas may be estimated by comparing respective calorific values.

Heat balance based on theoretical analyses :

Heat of combustion = (i) Heat loss through furnace wall, hood and base, (ii) Heat [loss] carried out by the flue, (iii) Heat gained by the furnace wall, (iv) Heating of metal to melting temperature + Latent heat for melting + Superheating of metal for its flow ability within mould cavity, and also (v) Heating of mould, and permeable bed.

Heating and melting procedure is carried out through the following steps: (i) Heating of furnace with permeable bed is from ambient state to stabilize operational [at temperature of about 800^0C] stage. (ii) Placing of mould (containing metal pieces) within the heated furnace. (iii) Heating of furnace with mould to the desired temperature and duration. (iv) Taking out of mould for subsequent casting procedure outside the furnace. (v) Replacement of new green mould (containing metal pieces) within the vacant/identified space of the heating furnace. (vi) Continuation of heating of mould. (vii) Taking out of mould from the furnace. (viii) Continuation of casting and subsequent mould heating procedure till campaign is over. And (ix) Cooling of furnace after the campaign.

Mathematical modeling of furnace during heating up period when temperatures of various parts within furnace changes with time [unsteady] is very complex and is, therefore, not considered in this work. Heat transfer/balance during stage wise in quasi-steady stabilized period is considered in this work.

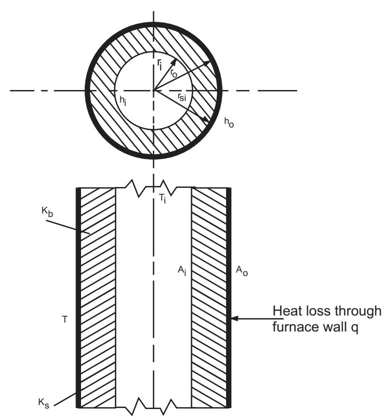


Fig. 7.6 : Sketch of Furnace shell with refractory lining [sectional views (plan & elevation)]

(I) Heat losses through furnace wall.

$$Q_{lk} = \frac{(T_i - T_\alpha)}{\frac{1}{h_i A_i} + \frac{1}{2\pi L k_b}.\ln\frac{r_{si}}{r_i} + \frac{1}{2\pi k_s L}.\ln\frac{r_o}{r_{si}} + \frac{1}{h_o A_o}}$$

Where, T_i is the inside temperature of the furnace = 1000^0C, T_α is the ambient temperature $\approx 50^0C$ h_i is the inside heat transfer coefficient ($W/m^2\ {}^0C$), ho is the outside heat transfer coefficient ($W/m^2\ {}^0C$), A_i is the effective inside area of furnace-m^2, A_o is the effective outside area of furnace - m^2, r_{si} is the inside radius of steel shell - 0.35m, r_i is the inside furnace radius- 0.25 m, r_o is the outside shell radius- 0.353m, K_s conductivity of carbon steel of shell =54 W/m^2, L= 0.8 m, h_o is based on natural convection & $h_o = 1.31(\Delta T)^{1/3}$ for turbulent region $G_{rf}P_{rf} > 10^9$, = $1.42(\Delta T/L)^{1/4}$ for laminar flow $10^4 < G_{rf}\,P_{rf} < 10^9$, Concerning vertical plane or cylinder, let ambient temperature = $30^0 \approx 50^0$, shell average temperature = 270^0 C (assumed), T_f or film temperature = $\frac{270 + 30 -}{2}\frac{300}{2}$ = 150^0C = 428^0K, $\beta = 1/T_f = \frac{1}{420}$ = 2.38×10^{-3} k^{-1}, μ at 420^0 K = 2.38×10^{-5} kg/m.s, $\rho = 0.88$ kg/m^3, $k_a = 0.3400$ w/m^{0}k, $Gr.Pr = \frac{g\beta(T_\omega - T_\alpha)}{\vartheta}.L^3.P_r$, where $T - T_s$ assumed to 270^0C, $Gr.Pr = \frac{(9.8[2.38\times10^{-3}]\,[270 - 30]0.8^3\times0.68)}{(27\times10^{-6})^2} = \frac{9.8\times[2.38\times10^{-3}]\times240)}{729\times10^{-12}}\times0.68\times0.8^3$ = 2.67×10^9, $Gr.Pr > 10^9$.

Therefore, $h_o = 1.31(\Delta T)^{1/3} = 1.3\times 6.20 = 8.06$ W/m^{2}K

It is now required to find the value of h_i - heat transfer coefficient along the inside the furnace. It is also to be noted due to expected combustion of burner, the flue from gas as well as oil burner is envisaged to enter the combustion chamber tangentially [Fig.7.7] to produce circulation as well as upward draft not equal with axial velocity. It is assumed that draft/axial velocity of flow to be ≤ 10 m/s.

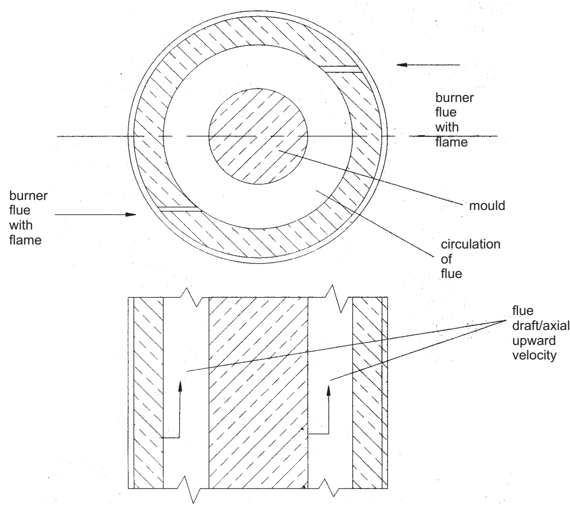


Fig. 7.7 : Sketch of furnace with mould [sectional views (plan & elevation)]

Now $Re = \frac{\rho v d}{\mu}$ and the average temperature of the flue (1900^0C flame temperature + 600^0C exit expected temperature)/2= 1250^0C $\cong$ 150^0C, & from Table 5, properties of air/flue : K= 0.946 W/m°k P= 0.2355 kg/m^3, μ=5.40 ×10^{-5} kg/m.s, D = 0.5 m, v=10m/s & Pr = 0.705 or, $Re = \frac{.2355\times10\times.5}{5.45\times10^{-5}} = \frac{.2355\times10\times0.5}{5.45}$ x10^5=0.216 ×10^5. Therefore, $Nud = 0.023\,Re^{0.8}Pr^n$.

Condition ; fully developed turbulent flow n=0.4 , for heating [n=0.3 for cooling may be considered for estimating cooling phase rate]

$0.6 < Pr < 100$, $2500 < Re < 1.25\times10^5$, $N_ud = hd/k$ or $N_ud = 0.023\,Re^{0.8}Pr^{0.4}$,

$Nud = 0.023\times[0.216\times10^5]^{0.8}\times[0.705]^{0.4}$, $= 0.023\times2934.7\times0.87 = 58.7$

$$\text{or, } h_i = \frac{Nud\times k}{d} = \frac{58.7\times0.0946}{0.5} = 11\,W/m^{2\circ}K$$

$$q_w \text{ or, } q_{wl} \text{ loss through wall} = \frac{T_i - T_\alpha}{\frac{1}{h_iA_i} + \frac{1}{2\pi Lk_b}.\ln\frac{r_{si}}{r_i} + \frac{1}{2\pi k_sL}.\ln\frac{r_o}{r_{si}} + \frac{1}{h_oA_o}}$$

$$= \frac{1250 - 30}{\frac{1}{11x\pi xdxL} + \frac{1}{2\pi Lx0.69}.In\frac{0.35}{0.25} + \frac{1}{2\pi k_sx54}.In\frac{0.353}{0.35} + \frac{1}{8.06x\pi xDxL}}$$

$$= \frac{1230}{\frac{1}{11x\pi x.5x8} + \frac{10.336}{3.46} + \frac{.00851}{271.43} + \frac{1}{8.06xpx.706x.8}}$$

$$= \frac{1230}{0.23} = 5347.8 \text{ W or, } q_{wl} = 5.34 \text{ kW........} \qquad ...(1)$$

Considering 20 % extra due to heat loss through cover & bottom portion, actual heat loss actual q_{wL} = 6.4 kw.

(ii) Heat loss with the flue :

Heat is carried out with flue when it leaves through gas duct placed on the hood of the furnace.

Let m_f kg per hr of LPG [as this fuel selected for the present work] be assumed to be consumed concerning combustion and melting. Stoichiometric Air-fuel ratio of LPG is about 16:1. However,from burner catalogue, it is found that blowtorch burner burns with blue flame and consumes 25% to 30 % [20 to 20.8 by parts] excess air.

Therefore, 1 unit of LPG normally consumes 20 units of air to produce (1 + 20) = 21 units of Flue & it is assumed that C_p of flue is equal to C_p of air.

or, Heat loss with flue = 21 m_f Kg × C_p × ΔT / hr where $\Delta T = T_{exit} - T_\alpha$

The flue leaves the furnace between 750^0C to730^0C and $T_\alpha = 30^0$C

Or, $\Delta T = 700^0$C

C_p at 700^0C = C_p at 973^0 K = 1.14 KJ / Kg ^{0}K

Or, q_f, the heat loss with flue = 21 m × 1.14 × 700 = 16758 KJ / hr × m

Or, 16758 / 3600 × m_f KJ / sec = 4.655m_f kW = m_f 4.655 kW ...(2)

(iii) H_f = Heating of Furnace wall and maintaining its temperature, $t_i = 1500^0C$

Let , t_s(shell temperature) = 200^0C, m_w be mass of Furnace wall = π/ 4 (d_{si}^2 x d_l^2) × L × ρ, C_p = 0.86 KJ / Kg ^{0}K [assuming furnace lining is made by using 50% of brick material + 50% of cinder stone…..C_{Pb} = 0.84 KJ / Kg ^{0}K, C_{Pc} = 0.88 KJ / Kg ^{0}K, ρ = 1550 Kg / m^3…..[ρ_o = 1500 Kg / m^3, ρ_c = 1600 Kg / m^3]

Therefore, $H_f = m_w C_p \times \Delta T$ = [π x 4 (0.7^2 x 0.5^2) × 0.8 × 1550] × 0.86 × {(1500 + 200) / 2 x 30^0 }]

H_f = 236.6 × 0.86 [850 x 30] = 166850 KJ

The heating of furnace takes place normally for 2 hrs. and subsequent operational (melting stage) takes place for 1 hr.

Therefore, the amountof heat requirement h_f = 166850.32 / (3600 × 3) = 15.44 KJ / sec.

= 15.5 kW ... (3)

(iv) H_m = Heating , melting and superheating of metal :

H_m = Heating to melting temperature (630^0C approx.) + Latent heat concerning melting of entire metal pieces + superheating to 1000^0C of molten metal with respect to very good flow ability of molten metal within mould cavity in order to obtain desired shape during subsequent cooling.

$\therefore H_m = m_m C_{Pm} (630^0C \text{ x } 30^0C) + m_m L_m$ [L of 66 % Copper + 33% Zinc ≈ 172 KJ / Kg from Google search] $+ m_m C_p (1000^0C \text{ x } 630^0C)$ $m_m = 5.0$ Kg, $C_p = 0.385$ KJ / Kg ^{0}C [Table A - 2 page 639, HOLMAN]

$\therefore H_m = 5 \times 0.385 (630 \text{ x } 30) + 5 \times 172 + 5 \times 0.385 [1000 \text{ x } 630]$

$= 5 \times 0.385 (1000 \text{ x } 30) + 5 \times 172$

$= 2727.25$ KJ

Heating of metal inside mould is carried out once the furnace reaches the stabilized condition and heating of metal takes place in about one and half hours. Therefore, time duration of 1 hr. is considered for the analyses.

$$h_m = \frac{H_m}{60 \times 60 \times 1} = \frac{2727}{3600 \times 1.5)} = 0.75 \text{ KJ / sec} = 0.5 \text{ kW} \quad ...(4)$$

(v) Heating of mould containing metal for subsequent casting :

Clay mould with appropriate cavity suitable for desired shape casting is filled with scrap metal piecesis first heated for desired duration and then cooled to obtain desired shaped casting. Permeable bed / chips also get heated.

Approximate mass of the mould is about 5(five) times that of metal $\approx 5 \times 5 = 25$ Kg (m_{mo})

$H_{mo} = m_{mo} \times C_p \times \Delta t, C_p = 0.86$ KJ / Kg and $\Delta t = (1000 \text{ x } 30)^0C = 970^0C$

Or, $H_{mo} = 25 \times 0.86 \times 970 = 20855$ KJ.

Heating of mould along with metal is carried out once the furnace reaches the stabilized condition. Mould is placed within the furnace. The mould heating cycle is then initiated and continued for 1.5 hrs. The mould with molten metal is taken out for subsequent natural cooling to obtain desired casting.

$$\therefore h_{mo} = \frac{Hmo}{1 \text{ hr})} = \frac{Hmo}{3600 \times 1.5} = \frac{20855}{3600 \times 1.5} = 3.86 \text{ KJ / sec} \approx 3.86 \text{ kW} \quad ...(5)$$

(vi) Heating of permeable bed / mixture :

Permeable bed/fixture made pieces [~30mmX~ 30mmX~30mm size] of refractory or rejected electrode/graphite or both in numbers are placed within void space between furnace and mould in connection with extracting and retaining heat from in order to maintain the temperature.

Approximate mass of the permeable bed is about same that of metal ≈ 5 Kg (m_p)

$H_p = m_p \times C_p \times \Delta t, C_p = 0.86$ KJ / Kg (assumed) and $\Delta t = (1000 \text{ x } 30)^0C = 970^0C$

Or, $H_p = 5 \times 0.86 \times 970 = 4171$KJ.

Heating of mould along with metal is carried out once the furnace reaches the stabilized condition. Mould is placed within the furnace. The mould heating cycle is then initiated and continued for 1.5 hrs. The mould with molten metal is taken out for subsequent natural cooling to obtain desired casting.

$$\therefore h_p = \frac{Hp}{1\ hr} = \frac{Hp}{3600 \times 1.5} = \frac{4171}{3600 \times 1.5} = 0.75\ KJ/sec \approx 0.75\ kW \quad ...(6)$$

$\therefore$ Total heat requirement, $q_T = q_{LW} + q_f + h_f + h_m + h_{mo} + h_p$

[Eq. (1) + Eq.(2) + Eq. (3) + Eq. (4) + Eq. (5) + Eq. (6)]

$$= 6.4\ kW + m_f 4.655\ kW + 15.5\ kW + 0.5\ kW + 3.86\ kW + 0.75Kw$$

$$= 27.01\ kW + m_f 4.655\ kW \quad ...(7)$$

(vii) Fuel requirement :

Now equating Eq. (6) and Eq. (7) we have, $q_{TC} = q_T$

Or, $m_f 25.8\ kW = 27.01\ kW + m_f 4.655\ kW$

Or, $m_f (25.8 \square 4.655) = 27.01\ kW$

$\therefore m_f = \frac{27.01}{21.145}$ = 1.259 Kg/hr ~ 1.26kg/hr of LPG LPG/ (50% Butane + 50% Propane) is chosen as fuel in this work. Heating is planned based on the utilization of suitable LPG/ NG (Natural gas) Burners. In order to choose/ select type of burner, it is necessary to estimate fuel/ LPG consumption.

Therefore, more than q_{Tc} is to make available through combustion of LPG.

Expected heat generation through combustion of

(a) m_{fuel} [mass fuel per hour] $= \frac{mf}{1.14} \times \frac{106 \times 1000000}{1000}$ kJ/ hr

$$= \frac{mf}{1.14 \times 3600} \times \frac{106 \times 1000000}{1000}\ kJ/sec$$

$$= \frac{mf}{1.14 \times 3600} \times \frac{106 \times 1000000}{1000}\ W \quad ...(8)$$

Where m_f, mass of fuel Kg/hr, [ρ =1.14 Kg/m^3 and caloric value = 106 MJ/m^3, for Butane from Google search] Or, $q_{TC} = m_f\ 25.8\ kW$ is required ...(9)

Estimation of fuel consumption based on coal /coke consumption rate :

As caloric value of general purpose is 32 to 42 MJ/Kg and coal consumption rate in the present furnaces [similarcapacity] is 10 Kg for the first mould/melt is 8 Kg for period of 1.5 hrs.]

Table 3.1 : Total heat developed during operation using coal/coke

Sl. No.	Coal/Coke Consumption	Duration Hour	Rate of consumption	Caloric value MJ/ Kg	Total Heat Value MJ/ hr
1	10 Kg	3	3.3Kg/hr	32×10^6	105.5
2.	08 Kg	2	4.0Kg/hr	32×10^6	128.0
		2.5 (average)		3.65Kg/hr(average)	116.75(average)

Therefore, in order to obtain this amount of heat value i. e 116.75 MJ/ hr., (a) 116.75 MJ/106 m^3/hr. or, $\frac{116.75}{106} \times 1.14$ Kg./ hr. = 1.25 Kg./hr. of LPG is necessary. Equation (8) indicates 1.26 Kg./hr. of LPG is required. Thereby it speaks of the validity of the mathematical modeling of the said work.

V Design and Development of a module furnace :

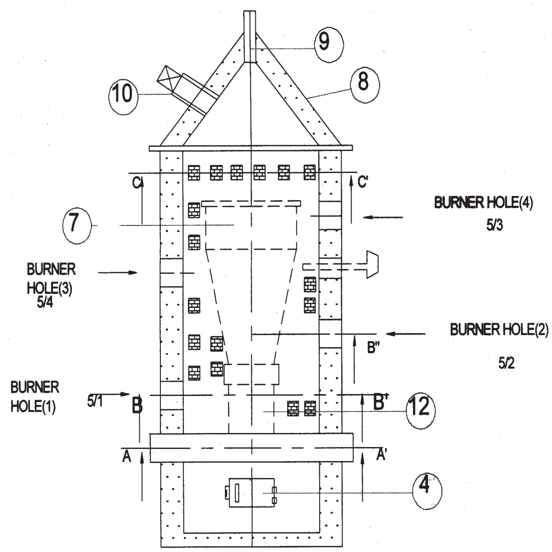
The proposed development (with reference to Figures.7.4 to 7.7) is as follows :

– Design development of eco friendly furnace for the treatment of 1-5 kg iron, brass and bell metal including selection and incorporation of suitable sizes high velocity short flame (75-100 mm long) burner , suitable refractory material, grate bars and flue guiding duct.

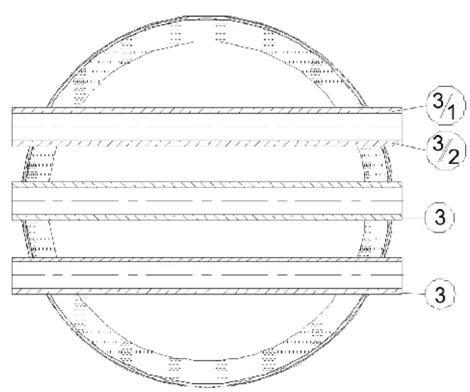
- Making of refractory (25-40mm size) ball and graphite (25mm-40mm) granular chips.
- Fabrication, making, refractory lining, grate bar fixing and incorporation of burner.
- Incorporation of peripheral facilities such as gas bottle, gas conduit with safety measures and air supply unit.
- Commissioning trial of the oven.
- Experimental trials in association with some indentified present Artisan of brass and bell metal.
- Data analyses.
- Techno economic analyses.
- On the concluding out come.

Final design :

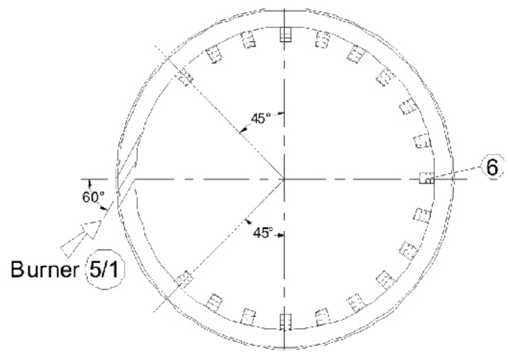
Details of the conceptual design was shown to the concerned entrepreneur and based on discussion & consideration, the following design was finalized and shown in Fig. 8.



A Elevation View

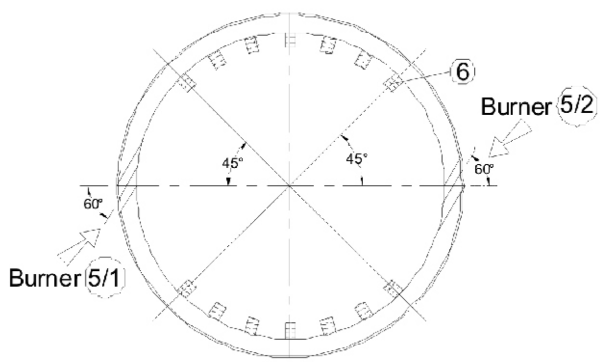


B Sectional View at grate bar location



Section B - B'

C Furnace cross section at lower burner location



Section B - B''

D Furnace cross section at higher burner location

Fig. 8 : Schematic of Developed Furnace

VI Burner selection :

The Selection of burners is the most important criterion in the design and development of eco-friendly furnace. Thermal radiation, convection and conduction taking place within the enclosure of furnace are the factors for the thermal performance of the system. Non- luminous gaseous radiation is usually the dominant mode of heat transfer from flame to combustion product. In order to achieve a high thermal efficiency within a compact design of furnace, combustion chamber should be incorporated with a number of either high velocity or controlled flame burners. Medium temperature controlled flame burner which provides heat transfer mainly by convection whereas high velocity burner provides heat transfer not only by radiation to a less extent but also by convective mode of heat transfer

Based on survey, blow lamp type burner which does not require additional compressed unit is selected and schematic of such type LPG burner is shown in Fig. 9.1.

a) Approximate Burner Details : Estimated rate of fuel burning

$C = a = \text{sonic velocity} = \sqrt{(K.R.T)} = 330 \sim 340$ m/s

$Q = c_d.A.v[\text{or } a] \times \rho_f$

Where c_d =, coefficient of discharge $\simeq$ 0.5

$A = \frac{\pi d^2}{4} = \frac{\pi}{4} \left(\frac{0.75}{1000}\right)^2$

V = 340 m/s

ρ_f = fuel density [fuel is 50% balance +50 % propane & sp. Gr. Of butane = 2.05; sp. Gr. Of propane = 1.05 & density of air = 1.22 & therefore ?f= 1.89 kg/m^3.

Therefore, $q = 0.5 \times 0.785 \times (0.75)^{2\times} \times (10^{-3})^2 \times 340 \times 3600 \times 1.89$

$= 0.510$ kg/hr

b) Burner Sectional view :

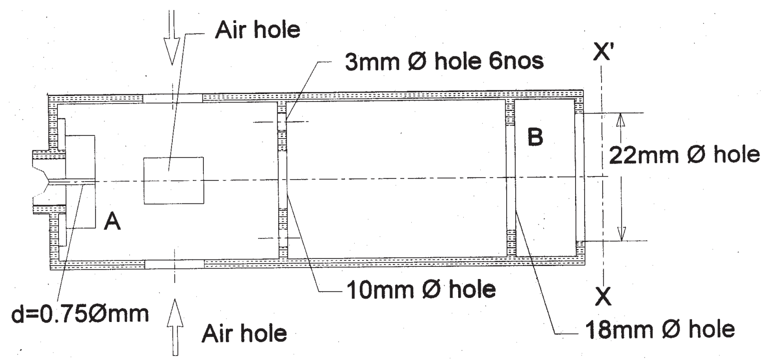


Fig. 9.1 : Schematic representation of a Burner

c) Fluid Dynamics Analysis : Flow analysis of flue emitted from fluid flow burner is very much desirable in order to visualize its flow pattern within the furnace which contributes to heat transfer. The estimation begins with free jet flow / free flow of fluid from burner hole :

Free jet of Fuel & Air mixing :

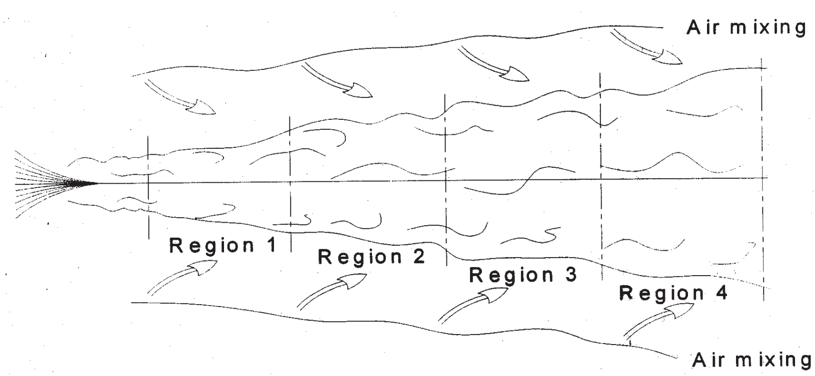


Fig. 9.2 : Expected Configuration of nearly Turbulent Free Jet

Total air and fuel are expected to mix and diffuse between Region -1 to region -4 as shown in 9.2.

The chosen short flame LPG burner with 20 to 30 % excess air with blue and diffusion flame characteristic provides flame length about 25 mm to 125 mm [turn down with turn down ratio is approximately 1:5]. As 1 kg/ hr. fuel [LPG] produce 20 kg/ hr combustible mix product with N_2. The maximum exit flow rate [V] of flue from burner exit = 20/1.22 = 16.4 m^3/hr [assuming flue density = 1.22 kg/m^3 at NTP]. Adiabatic flue temperature is about 1900^0C & PV=RT or,

$$V \alpha T, \text{ or, } V_1 = \frac{V}{T.} T_1 = \frac{16.4 \times [273+1900]}{[273+30]} = \frac{16.4 \times 2173}{303} = 117.6 \text{ m}^3\text{/hr.}$$

∴ Velocity of flue/flame, $v_e = V_1$ / Exit area of burner [for 2.2 mm dia.]

$$= \frac{117.6}{\frac{\pi}{4}\left(\frac{2.2}{100}\right)\left(\frac{2.2}{100}\right) \times 3600} \text{ m/sec}$$

$$= \frac{117.6 \times 10000}{0.785 \times 2.2 \times 2.2 \times 3600} \text{ m/sec} = 85.97 \text{ m/sec}$$

Note : C or a, the sonic velocity at, $= \sqrt{\gamma RT} \approx \sqrt{\{1.4 \times 287 \times (1900+273)\}}$, as R for air/flue = 287 (J/Kg) K or, $C = \sqrt{(1.4 \times 287 \times 2173)}$ = 934 m/sec., or, C_1 = based on average temperature of furnace $T_{av} = (T_f + T_\alpha)/2 = (2173 + 303)/2 = 1238$ K, or, $C_1 = \sqrt{(1.4 \times 287 \times 1238)}$ =750m/sec.

Therefore, Mach number, M of exit flue from burner varies from $\frac{85.97}{934}$ to $\frac{85.97}{750}$

$$= 0.092 \text{ to } 0.114 \leq 0.2$$

As this $M \leq 0.15$ and pressure in this furnace is nearly equal to ambient pressure, flow may be easily considered as just compressible flow. However, incompressible flow analyses may be applicable.

The schematic of burner placement in the furnace burner jet characteristies are shown in Fig. [10.1 to 10.6] :

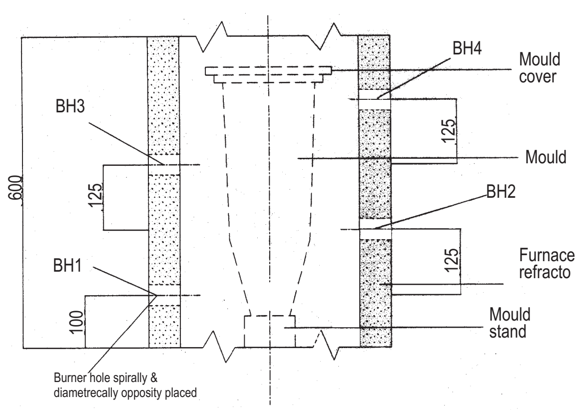


Fig. 10.1 : Schematic for Fluid Dynamic [F. D] Analysis of the Furnace
[Where- BH 1: burner hole 1]

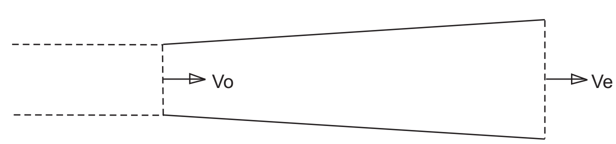


Fig. 10.2 : F.D. Analysis of Free Jet

From free jet analysis, we have $\frac{v_e}{v_o} = 1.41\, R_e^{0.135} [\frac{D_o}{x}]$, Where $v_o = 85.97$ m/sec, $D_o = 22$ mm, $\chi = d = 283$ mm, $\mu = 0.2 \times 10^{-4}$ N.S m^{-2} for air and flue at temperature more than 500^0C

$$\therefore Re = \frac{\rho_t v_o D}{\mu} \;\&\; \rho_t = \rho_o \times \frac{303}{2173} = 1.22 \times \frac{303}{2173} \approx 0.17$$

$$R_e = \frac{\rho_t v_o D}{\mu} = \frac{0.17 \times 85.97 \times 22/1000}{0.2 \times 10^{-4}} = 16076.39., \text{ or, } v_e = v_o [1.41 \times R_e^{0.135} \times \frac{22}{283}]$$

$$= 85.97 \times [1.41 \times (16076.39)^{0.135} \times \frac{22}{283}] = 34.8 \text{ m/sec}$$

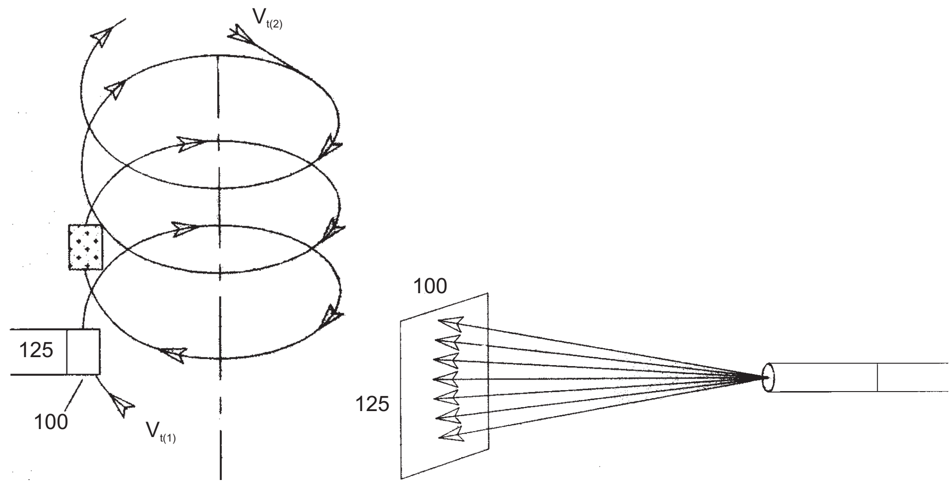


Fig. 10.3 : (i) & (ii). Schematic representations of F D analysis of spiral flow

U_e = the exit velocity of flue at Pitch circle Diameter [PCD] between inside wall and mould and U_e is at 45° to PCD. $\therefore$ v_t isthe tangential component = ϑ_e cos45° = 34.8×0.70=24.60 m/sec.

Due to v_t, the fuel will rotate along the channel.

However, v_t is reduced to average tangential velocity section wise v_{ts} and this can be estimated as follows :

At the bottom most zone $v_{ts} = \dfrac{\frac{V_1}{2}}{\frac{100}{1000} \times \frac{125}{1000}}$

And $v_1/2$ because ½ of the discharge will cause rotation/spiralling and ½ of the discharge will move radially as entry is assumed to be at 45° to PCD.

or, $U_{ts} = \frac{117.6}{2} \times \frac{1}{3600 \times [0.1 \times 125]} = 1.360$ m/s

The said discharge of flue will spirally go up due to furnace draft. v_{ts} will be increased to $1.360 \times 2 = 2.72$ m/sec.

Moreover, rotation considering rigid body rotation reads as below, $v_{ts} = \omega \Upsilon_{av}$ [Where r_{av} = 400 mm = 0.4 m] or, $\omega = \frac{1.36}{0.4}$ or, $\frac{2.72}{0.4}$ = 3.4 rad/sor, 6.8 rad/s, or, vorticity = 2ω or, 2× 6.8 rad/s or, 13.6 rad/s

The circulation is, $\Gamma = 2\omega A$ where A is the area, = $6.8 \times [0.1 \times 0.125]$ and $13.6 \times [0.1 \times 0.125]$

= 0.085 or, 0.175

Therefore,

Table 3.4 : Position of the Burner

Sl. no.	zone	v_{ts}	ω	Vorticity	Circulation
1	1 (bottom most)	1.36 m/s	3.4 rad/s	6.8	0.085
2	2 above bottom most	1.36+1.36=2.72 m/s	6.8 rad/s	13.6	0.175
3	3 above zone (2)	2.72+1.36=4.08 m/s	10.2 rad/s	20.4	0.255
4	4 above zone (3)	4.08+1.36=5.44 m/s	10.88 rad/s	27.2	0.34

ν_{r1} = the radial velocity $= v_e \sin 45° = 34.8 \times 0.707 = 24.8$

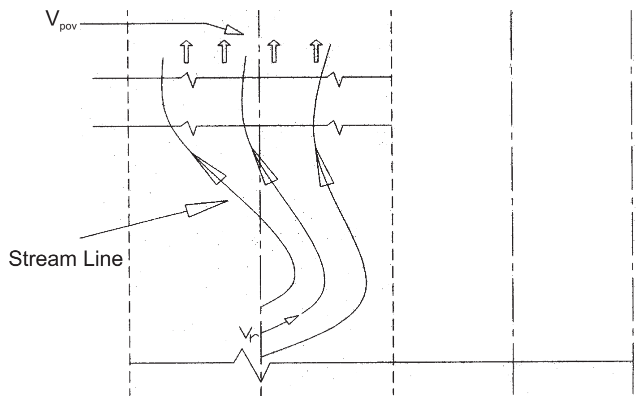


Fig. 10.4 : F.D. Analysis on Streamline flow

With radial component of exit velocity is expected to strike mould surface and due to hot draught it will move up [Fig. 5 and Fig. 6 F D analysis] finally it will have v_{pav} (upward average velocity). The stream line will assume a shape as shown in Fig. 6. v_r will contribute v_{pav} based on remain discharge from burner exit, i.e. $V_1/2 = \frac{117.6}{2}$ $m^3/hr = 58\ m^3/hr$

Thus, $v_{pav} = \frac{q}{\frac{\pi}{4}\left[\left(\frac{500}{1000}\right)^2 - \left(\frac{300}{1000}\right)^2\right]} = \frac{58}{3600\times0.785[0.25\text{-}0.09]} = \frac{58}{3600\times0.1256} = 0.128$ m/secMore over,

ν_{pav}, along zone-2 due to additional burner 2 is 0.256 m/s,

ν_{pav}, along zone-3 due to additional burner 3 is 0.38 m/s,

ν_{pav}, along zone-4due to additional burner 4 is 0.512 m/s

It is thus indicative that by providing additional burner, more heat as well as more draught and circulation may be made available.

Based on the above stated analyses, Furnace design and development had been completed and Blow lamp/ torch type burners following specifications were selected and procured:

(i) Blow torch : @ 0.5~ 0.6 kg/hr LPG

(ii) Blow lamps : 2litres capacity to dispense and @0.075 ~ 0.09 litres/hr of Oil [Kerosene]

(iii) Blow lamps : 8~10 liters capacity to @ 0.25~ 0.4 kg/hr Oil [Kerosene]

Table 1 : Expected fuel [LPG] consumption

Sl. No.	Burner use	Rate fuel	Expected fuel consumption With respect to operational hours				
			1	2	3	4	5
1	1	0.51 kg/hr.	0.51	1.02	1.53	2.04	2.55
2	2	0.51+0.51	1.02	2.04	3.06	4.08	5.1
3	3	1.02+0.51	1.53	3.06	4.59	6.12	7.65
4	4	1.53+0.51	2.04	4.08	6.12	8.16	10.2

Fig. 10.5 : Photograph of a Blow Lamp

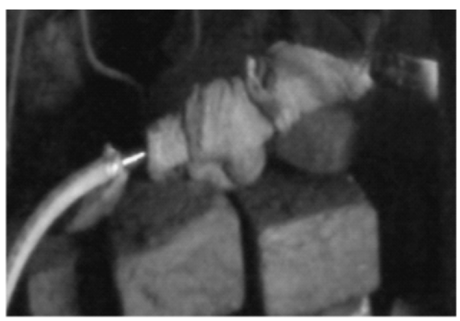


Fig. 10.6 : Photograph of a Blow torch

a) Operation of the developed furnace : The following operational views [Fig. 10.7 & Fig. 10.8] of the furnace during melting operation : In order to prove the validity of the mentioned design and development, number of the trials was planned and described in the following parts :

Fig. 10.7 : Photograph of the Developed Furnace during taking out of heated mould

Fig. 10.8 : Photograph of the Developed Furnace indicating burner in action

EXPERIMENTAL TRAILS

Numbers of different sets of experimental trials mainly based on using LPG were conducted during March- April 2012. Some sets of trials were also carried out with Kerosene and LDO. Smooth pollution free furnace operation was found possible with LPG and products were also acceptable quality. The following are the recorded observation:

A Operation with Kerosene :

(i) 2No's of 2lits capacity Blow lamps were used for trials Table 1 [only furnace with permeable bed heating without mould] conducted on 26-2 -2012 and 4-3 -12]. Maximum temperature achieved was about 570^{0}C after 2-1/2 hrs heating [against desirable ~950^{0}C]. However smooth trouble free combustion could be obtained. Trials were then abandoned for further subsequent trials.

ii) Similar trials Table 2 conducted on 11-3-2012 and 18-3-2017 with using 2No's of 2lits capacity Blow lamp based on using LDO. Smooth combustion could not be obtained and after 3 hrs effort, trials were abandoned.

It is then finally concluded that LDO would not be tried further and trials with Kerosene would be conducted with either 4- No's 4 lits or 2 No's 8lits capacity Blow Lamp

B Operation with LPG :

iii) Trial [Table 3] operation was carried out with Gas blow torch [0.2 to .08 hr/ hr capacity] using LPG on 25-3-2012. Higher temperature unto 620^{0}C against desirable ~950^{0}C obtained with 2 hrs of operation. Exercise was stopped for subsequent modification. It was decided to place/ locate burners-one near/ around bottom support near grate bar and place other one diametrically opposite at higher level [325 mm above the lower one/ grate bar] and to relocate graphite restrictor/ permeable bed [diamond pitch order] to obtain desirable temperature of bed and around mould.

iv) After the afore mentioned modification, trials [Table 4] carried out on 1-4-2014, within 2hrs of operation desirable temperature [~950^{0}C] was achieved. The trial was the switched off for carrying out subsequent melting and casting operation.

v) Successful trials carried out on Table 6 8/4, 15/4, /22/4 -2012 which revealed that the design developed modular furnace may be used LPG and NG without any hassle and sailable production of ghara/kalsi may be carried out. LPG consumption were recorded as : 1.2kg/hr from burner set of (2), ~ 4.8kg consumption during 4 hrs operation, furnace temperature recorded ~1150^0C , Maximum exit flue temperature ~4500C. Trials were witnessed 6 similar product manufacturers.

C Some miscellaneous trials (Table 5 & 7) :

vi) Some more successful trial concerning melting of iron in graphite crucible, and 4.6 kg bell metal melting using 4no's, 8 lits capacity kerosene blow lamp revealed its acceptable usability of developed green technology.

The following are tabulated trials data :

Table 1 [Experimental Trial - 1]

Experimental trials : i) were conducted at the premises of M/s Bimal Sikari, Dilip Sikari & Pradip Sikari, Matukganja, near Bishnupur P.O. ii) All equipments, tools & tackles, instrumentation and furnace were arranged and subsequently developed by the researcher.

(I) Burner selection & Performance

A. Kerosene

Burner											
Sl. No.	Date	Type	Capacity of the container	No. of use	Duration of operation	Remaining	Consumption		Temperature		
							Rate	Total	(i) at the hearth level	(ii) Exit	Time
1	26.02.2012 & 04.03.2012	Blow lamp	1 Lit each	4	4 Hrs.	1.2 Lit average	0.2 lit/hr	3.2 lit (4 unit toge-ther)	35°C	35°C	0
									150°C	80°C	1/2 hr
									225°C	125°C	1 hr
									310°C	150°C	1.5 hr
									430°C	160°C	2 hr
									450°C	180°C	2.5 hr
									510°C	200°C	3 hr
									550°C	210°C	3.5 hr
									570°C	220°C	4 hr

Remarks : i) Maximum temperature achieved = 570° C, ii) Frequent stoppages combustion record, iii) Conclusion : 2 lit capacity Blow lamp is not suitable with Kerosene.

Table 2 [Experimental Trial 2]

B. Diesel

Burner											
Sl. No.	Date	Type	Capacity of the container	No. of use	Duration of operation	Remaining	Consumption		Temperature		
							Rate	Total	(i) at the hearth level	(ii) Exit	Time
2	11.03.2012 & 18.03.2012	Blow lamp	1 Lit each	4	4 Hrs.	1.4 lit average	0.15 lit/hr	2.4 lit (4 unit toge-ther)			
									30°C	35°C	0
									120°C	70°C	½ hr
									180°C	100°C	1 hr

Contd.

									240°C	120°C	1.5 hr
									290°C	140°C	2 hr
									330°C	155° C	2.5 hr
									370°C	165°C	3 hr
									400°C	175°C	3.5 hr
									420°C	180°C	4 hr

Remarks: i) Maximum temperature achieved = 420°C at hearth level ii) Shorter flame with frequent stoppages record. iii) Conclusion: 2 At least a set of 4 no's 4 lit or 2 No's of 8 Lits capacity Blow lamp is required. The burner to be preferably used for Kerosene.[However trials with LDO would be tried].

Table 3 [Experimental Trial 3]

C. L P G. (Liquid Petroleum Gas)

Burner											
Sl. No.	Date	Type	Capacity of the container	No of use	Duration of operation	Consumption			Temp.		Time
						Initial weight cylinder with gas	Final weight cylinder with gas	Rate	(i) at the hearth level	(ii) Exit	
3	25.03.2012	Blow torch	0.2 to .08 Kg/hr	2	3	30.5 Kg	27.7 Kg	I) 0.41 Kg/hr through each	35°C	35°C	0
									180°C	100°C	1/2 hr
								ii) 0.93 Kg/hr for both	360°C	180°C	1 hr
									420°C	260°C	1.5 hr
								iii) 2.8 Kg total	480°C	340°C	2 hr
									540°C	400°C	2.5 hr
									620°C	450°C	3 hr

Remarks: i) Operation was carried out with all safety precaution. ii) Both the torches were operated through suitably Bottom (Below grate). iii) Rate of increase of furnace temperature found encouraging. iv) Exercise was stopped with the view to incorporate the following: a) To used burners suitably over grate- one near/ around bottom support, other to be placed diametrically opposite and higher level [300-350 mm above the grate level]. b) To put graphite / refractory restrictor in order to reduce exit temperature and increase furnace temp.

Table 4 [Experimental Trial 4]

D. L P G. (Liquid Petroleum Gas)

Burner											
Sl. No.	Date	Type	Capacity of the container	No of use	Duration of operation	Consumption			Temp.		Time
						Initial weight cylinder with gas	Final weight cylinder with gas	Rate	(i) at the hearth level	(ii) Exit	
4	01.04.2012	Blow torch	0.2 to .08 Kg/hr	2	3	27.7 Kg	24.8 Kg	I) 0.48 Kg/hr through each	35°C	35°C	0
									190°C	80°C	1/2 hr
								ii) 0.96 Kg/hr for both	380°C	160°C	1 hr
									550°C	230°C	1.5 hr
								iii) 2.9 Kg total	720°C	300°C	2 hr
									850°C	350°C	2.5 hr
									980°C	390°C	3 hr

Remarks: i) Operation was carried out with all safety precaution. ii) One torch was suitably placed around support above grate, and other was placed at 350 mm above and at diametrically opposite location. iii) Rate of increase and temperature record after 2 hrs. of operation was found very encouraging and suitable for melting and superheating. iv) To incorporate more restrictor suitable along furnace wall surface to increase and maintain higher temperature and lower exit temperature. v) Operation was abandoned after 3 hrs and decided to carryout melting operation in subsequent heating.

Table 5 [Experimental Trial 5&6]

Kerosene for 5 Kg brass & metal melting.

Sl. No.	Date	Burner Type	Capacity of the container	No of use	Duration of operation	Consumption			Temp.		
						Initial weight jar with kerosene	Final weight jar with kerosene	Rate con-sump tion	(i) at the hearth level	(ii) Exit	Time
5&6	20.05.2012 & 27.05.2012	Blow Lamp	4 Litre	4	4.5 Hrs	28 Kg	20.8 Kg	1.8 Kg/hr	35°C	35°C	0
									180°C	60°C	1/2 hr
									330°C	120°C	1 hr
									540°C	180°C	1.5 hr
									680°C	260°C	2 hr
										300°C	2.5 hr
										360°C	3 hr
									950°C	410°C	3.5 hr
									1000°C	430°C	4 hr
									1020°C	440°C	4.5 hr

Remarks: i) Operation was carried out with safety precaution. ii) Mould with metal incorporated. iii) Two in identical repeated trials carried out. iv) Records were average of noted reading. v) After 4.5 hrs .of operation, burners were switched off. Subsequent mould lifting, reversing in case of pouring in mould cavity cooling and taking out casting. vi) Good and acceptable casting products were obtained.

Table 6 [Experimental Trial 7,8,9]

E. L P G. (Liquid Petroleum Gas) for melting & casting Brass and Bell metal products

Sl. No.	Date	Burner Type	Capacity of the container	No of use	Duration of operation	Consumption			Temp.		
						Initial weight cylinder with gas	Final weight cylinder with gas	Rate	(i) at the hearth level	(ii) Exit	Time
7	08.04.2012	Blow torch	0.2 to .08 Kg/hr	2	4	24.8 Kg	20.0 Kg	I) 0.6 Kg/hr through each	35°C	35°C	0
									200°C	75°C	1/2 hr
								ii) 1.2 Kg/hr for both	390°C	150°C	1 hr
									580°C	210°C	1.5 hr
									750°C	280°C	2 hr
								iii) 4 Kg total	870°C	340°C	2.5 hr
									1000°C	390°C	3 hr
8	15.04.2012	DO	DO	DO	DO	20 Kg	15 Kg	Do	1100°C	420°C	3.5 hr
9	22.04.2012	DO	DO	DO	DO	30Kg	25.2 Kg	Do	1150°C	450°C	4 hr

Remarks : i) Operation was carried out with all safety precaution. ii) Mould with metal was incorporated. iii) Three identically / repeated trials were carried out. iv) Records were average to note readings. v) After 4 hrs. of operation, burners were suitable off mould was taken out for subsequent tilting, pouring is mould cavity, cooling and taking out casting. vi) Good and acceptable casting product was obtained. vii) The trials were witnessed by about 5 to 6 similar product manufacturers of Bishnupur.

Table 7 [Experimental Trial 10]

F. L P G. (Liquid Petroleum Gas) for melting cast iron.

Sl. No.	Date	Burner				Consumption			Temp.		
		Type	Capacity of the container	No of use	Duration of operation	Initial weight cylinder with gas	Final weight cylinder with gas	Rate	(i) at the hearth level	(ii) Exit	Time
10	29.04.2012	Blow torch	0.2 to .08 Kg/hr	3	3	25.2 Kg	20.4 Kg	0.53 Kg/hr	35°C	35°C	0
								through each	350°C	125°C	½ hr
								ii)1.6 Kg/hr	700°C	275°C	1 hr
								through 3 burner	810°C	380°C	1.5 hr
								iii) 4.8 Kg	1180°C	450°C	2 hr
								total	1280°C	510°C	2.5 hr
									1330°C	555°C	3 hr

Remarks: i) 3 burners were spirally around crucible heat in area with furnace. ii) Mould was replaced by crucible containing about 7 Kg of iron. iii) Operation was carried with all safety precaution. iv) After operation of 3 hrs., lid was opened and melting of iron piece with good super heat were noticed. v) Melting of cast iron ensured veracity of the furnace. Cast iron melting may be utilized for making rural based cast iron spares.

The following are parts produced during afore mentioned trials

Fig. 11.1 : Photograph of bottom half of Ghara[Bishnupur -type] produced by trial

Fig. 11.2 : Photograph of Upper half of Ghara[Bishnupur -type] produced by trial

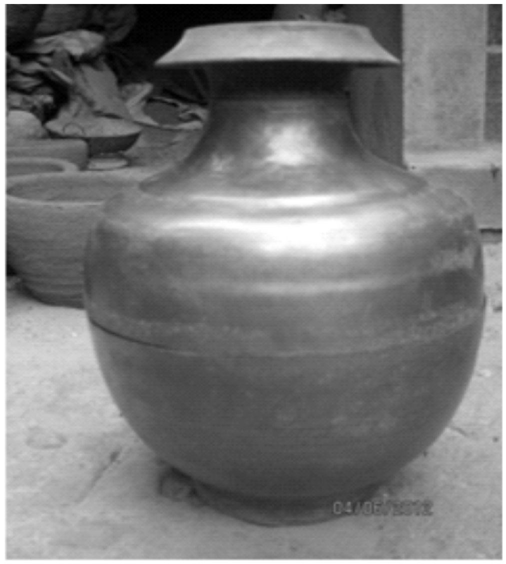


Fig. 11.3 : Photograph of Upper half of Ghara [Bishnupur -type] produced by trial

CONCLUSION

The present work concerning LPG/ NG based furnace for brass, bell metal and iron melting and casting is successful, acceptable and is also directed towards new second generation various modules melting furnaces. Incorporation of these type of furnaces is expected to ensure not only production of cheaper product but also clean ambience for subsequent expected health improvement of rural population, live stock and crops.

The benefits are derived from high thermal efficiency, reduced SPM as well as CO2 and SO2 emissions. In addition, it is aimed to improve furnace operation melting. It is hoped that the research can be continued, with further improvement and refinements in operating studies, to produce an even more efficient melting furnace. The establishment of the system and its widespread introduction to the casting industry on a large-scale will contribute to the industry's progress and to environmental conservation The following benefits are envisaged:

(i) Due to the fact that coke is not used in furnace, operation is pollution free. The coke less furnace, itself has a refining well controlled melting system self cleaning melting ability to give the foundry good flexibility of operation at low cost and affords molten metal with excellent properties. During operation strict vigil and observation is not required to a large extent.

(ii) More operational trials with cavity (between mould and furnace) of variable sizes of permeable media are required. It is sure that some suitable matching data will be arrived at which will ensure less LPG consumption with more efficiency.

(iii) Only one module was designed and presented in this work is suitable for 5 kg Utensils. Development of various modules depending on requirement may be tried following the procedure mentioned in this work. Therefore, there is a scope for further work in this regard.

(iv) Incorporation of the mentioned type of furnace in the rural sector will ensure clean ambience for subsequent expected health improvement of rural population, especially for the children.

(v) Available Blow torch type burner based on using either LPG or NG is safe, suitable and acceptable for the immediate use in rural base melting furnaces.

– Kerosene burner provides better ambience but that is inferior to that is provided by NG/LPG. However soot formation some were noticed.

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