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REVIEWS

Development and Dissemination of Fuel-Efficient Biomass Burning Devices

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Abstract | Applying the principles of combustion and heat transfer, we have developed fuel-efficient, wood and other biomass burning stoves, furnaces and driers for a variety of operations carried out both in rural and urban areas. This paper highlights the concepts utilised for these and then summarises how the concepts have been used for developing the various devices. The dissemination strategy applied, the extent of dissemination, and the benefits accrued have been detailed.

1 Introduction

Wood and other biomass are major fuels for many operations carried out in rural areas and to some extent in urban areas. Examples are cooking, bath water heating, dairy-products making, post harvest operations, textile processing, Ayurvedic medicine manufacture, rubber band making, steam generation for a variety of operations, and drying. Traditional devices for these operations, not being energy- efficient, consume large quantities of biomass fuel, thereby contributing to the degradation of ecology and the environment. One way to arrest this is to develop and deploy fuel-efficient devices for these operations. We, at ASTRA, now renamed Centre for Sustainable Technologies (CST), Indian Institute of Science, Bangalore, have been developing and disseminating, for the past three decades, fuel efficient stoves, furnaces, and driers for such operations.

Cooking in over 90% of rural, half of peri-urban and a fifth of urban homes is generally done in smoky, soot-filled and often dark kitchens in simple stoves that burn fuel-wood incompletely and inefficiently causing a lot of smoke to be produced that spreads into the kitchen. Constant inhalation of smoke brings about various health issues and related drudgery. This smoke creates an environmental threat to sustainability in relation to health. Such a high dependence on fuel-wood as the main energy source for cooking (>200 Mt/yr in India) has often been considered as a threat to the green cover. This demand is expected to always be on the increase, threatening to create a rapid loss of tree cover. Fuel wood based cooking is the single largest need for energy in rural areas and accounts for about 30–40% of primary energy use at a country level and therefore at a national and regional level. This forms the single largest threat to the environmental segment of sustainability. During the 70's and the 80's the continued extraction of fuel wood at such rates was considered to threaten the sustainability of the tree cover over India and therefore science and technology alternatives that reduced this threat were urgently required. To overcome this potential threat and problems of sustainability we have attempted, multi-pronged solutions. The key approach has been to evolve and disseminate fuel-efficient cook stoves and stoves for other applications that burn wood. This paper discusses the concepts used for fuel efficiency, followed by the development and dissemination carried out so far, and the benefits that have resulted.

2 Concepts Utilised for Achieving Energy Efficiency

The two concepts utilised for developing fuel-efficient devices are:

- Carry out the total combustion of the fuel, with as little excess air as practicable, to generate the highest possible temperature of the flue gases.
- Maximise heat transfer to the job in hand, e.g., to the pans in cooking operations.

Combustion is carried out over a suitable grate in an enclosed firebox, with the requisite combustion

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chamber volume and ports of proper size, suitably located, for the controlled entry of primary and secondary air, and a chimney of adequate cross sectional area and height for creating the required draught and dispersing the smoke away from the device, to make it 'smokeless'. We then take recourse to the principles of heat transfer to maximise heat transfer for useful work, e.g., to the pans. Heat transfer takes place by conduction, convection, and radiation, according to the following equations:

$$\text{Conduction: } Q = k\,A\,(T_h - T_c)/L$$
$$\text{Convection: } Q = h\,A\,(T_h - T_c), \text{ and}$$
$$\text{Radiation: } Q = e\,\sigma\,A\,(T_h^4 - T_c^4),$$

where, (all in consistent units; for radiation the temperatures are in absolute units),

Q = heat transferred in unit time,
k = thermal conductivity,
A = area of heat transfer,
T_h = temperature of the hot medium,
T_c = temperature of the cold medium,
L = thickness of the conducting medium,
h = convective heat transfer coefficient,
e = emissivity, and
σ = Stefan-Boltzman constant

These equations indicate that the amount of heat transferred by all the mechanisms increases with the area of heat transfer, the temperature difference between the hot (flue gases) and cold (pans) media, and the coefficients (conductivity, convective heat transfer coefficient, emissivity). For conduction, it decreases with the thickness of the conducting medium (pan thickness). Thus, to maximise heat transfer, we must increase the area, temperature difference, and coefficients, wherever possible, and decrease the thickness of the pans. By carrying out the combustion in an enclosed firebox and by controlling the primary and secondary air entry with ports of proper size, suitably located, we have generated the maximum possible combustion temperature. Thus a higher temperature difference has been achieved. The area of heat transfer can be increased by adopting any or all of the following:

- Multiple pans,
- Having extended surfaces—fins—on the heat transfer areas,
- Using the maximum external area of the pan by 'dipping' it in the flue gases.

We have used all these techniques in our devices. Next we look into improving the coefficients. For radiation, this can be done by increasing the 'view factor'. We should make sure that the stove interiors such as the bottom and other surface of the pans, which constitute the heat transfer area, can 'see' the flames as much as is practicable. If possible, the emissivity of these surfaces could be improved. Normally, in a multi-pan stove, radiation plays a role in the first, and maybe, in the second pan. However, improvement in the convective heat transfer plays a major role in improving thermal efficiency.

The convective heat transfer coefficient increases with the velocity of the flue gases past the surface of the vessel. This velocity can be increased, for a given volumetric flow rate of the gases, by decreasing the cross-section of the flow. We achieve this, to the extent possible, by reducing the clearance between the stove interior wall and the pan surface. Another factor is the effective use of the heat transfer surface by bringing it into contact with the flue gases, by avoiding bypassing. Flow directors-baffles-are an effective way to achieve this.

Conduction plays a minor role, unless one is using a mud pot of higher thickness in so far as the heat transfer to the pan is concerned. Conduction is important in reducing the heat lost to the stove body and thus to the surroundings. As the stoves are made with brick masonry, this condition is partly met. The use of insulating material in the interior of the stove is very helpful. The use of insulation bricks, though expensive, is justified toward this end for 'industrial' stoves like those for making jaggery or for textile processing, where the stove is used for a long time, and the brick cost may be less in proportion to the total cost of the stove. For domestic applications, we use the less expensive alternative of mixing rice husk in the mortar used in the stove interior to give a porous, insulating layer.

Summarising what has been discussed so far, to have high thermal efficiency, we carry out the combustion of fire wood in an enclosed chamber over a suitable grate, with proper openings for primary and secondary air, suitably located, and a chimney, to generate the highest combustion temperature, and then maximise the heat transfer to pans by having:

- an interior compatible in shape to the pans for a higher radiation heat transfer,
- a flue gas passage below the pans such as to facilitate maximum gas-pan contact and as high a velocity of gases as is practical,
- multiple pans, extended surfaces (fins), and maximum immersion of the pan in the stove, to increase the area of heat transfer, and,
- a chimney of adequate height and diameter to create a draught and disperse the smoke away from the stove-zone.

In all the energy-efficient devices that we have developed, the points mentioned above are followed. The combustion zone, consisting of an enclosed fire box, grate, ash pit, and air inlet ports, is similar, except for size. The high area for heat transfer is taken care of by multiple pans in stoves for cooking, cottage-basin silk reeling, and areca processing. The immersion of the vessel in flue gases is done in stoves for *anganwadi,* bath water heating, areca processing, *charka* and Italian-basin silk reeling, while extended surfaces (fins) have been used in *tawas*, jaggery, and steam generation stoves. The maintenance of the high velocity of flue gases around the pan surface is brought about by the progressive reduction of the cross sectional area around successive pans in multi-pan stoves. In single pan stoves for bath water, areca, and in heat recovery vessels, where the vessel is surrounded by the flue gas, the passage is made narrower from the fire box side to the chimney side.

Boiling, evaporation, baking, frying, and drying are the operations that are mainly carried out in the stoves. Thus, depending on the duty of the device, the design of the stove is suitably modified. This will be discussed in the section detailing the different devices. A list of the energy efficient devices developed and disseminated by us as follows:

- Cook stoves, both domestic and large size, 3-pan, (2 + 1)-pan, (1 + 1)-pan, (+1 indicating a heat recovery vessel);
- Single pan large stove for ***anganwadis***, restaurants, two models;
- ***Tawa*** stove, for different sizes of *tawa,* for making *rotis, dosas*, *parathas,* with heat recovery arrangement, in the form of a hot case to keep the food warm or for providing hot water;
- Stoves for the Mid-Day Meal Project in Karnataka schools during 1988, capacity ranging for catering to 100 to 6,000 students;
- Bath water heating stoves, for various capacities, up to 1,000 litres;
- Areca processing stoves, single, two, and three pans;
- Stoves for dairy products like *paneer* and *khova,*
- Stoves for products from rice (puffed rice, beaten rice),
- Jaggery making furnaces, single, two, and three pans, some with fins on the pan bases;
- Stoves for candying papayas;
- Silk reeling stoves, different types, for *charka,* cottage basin, and Italian basin;
- Textile stoves, for both cotton and silk, yarn as well as fabric, for starching, bleaching, pre-dyeing, and dyeing;
- **Steam Generating** stoves, different types, for cashew processing; stifling of silk cocoons; sterilisation of substrates in mushroom production; vulcanisation of rubber in rubber-band manufacture; distillation of aromatic oil; cooking of *papad* dough and idlis; curing of lime-stabilised mud blocks;
- Small baking oven for bread, buns, and biscuits;
- **Driers—**a variety of types and capacities—**cabinet type** with trays, natural and forced convection, all metal or partly masonry, capacity 2 to 400 kg; **room type**, natural and forced convection, capacity 200 to 1,000 kg; **modified version** of the traditional drying units in **Sikkim** for large cardamom, and in **Kerala**, for processed areca, with suitable ducts, instead of direct fire, below the material being dried (placed on bamboo mats), capacity 250 to 400 kg;
- Flue curing barns for Virginia tobacco;
- Crematorium

The salient features of some of these are discussed in the following paragraphs, with isometric views and engineering drawings in some cases. While the routes applied for dissemination are discussed under the section for dissemination, the extent of dissemination and the saving achieved for the devices are indicated in the sections pertaining to them.

3 Cook Stoves

3.1 *Domestic cook stoves*

Extensive studies were carried out in 1981–82 to evaluate the effect of various parameters which affect the performance of a domestic stove. These included the fire box type, distances between stove interior at various positions in the stove and the pan base, the size and location of the primary and secondary air holes, leaks in the stove body, and baffles. The result of this was the emergence of the design of a three-pan stove yielding an efficiency of 40 per cent, for a burning rate of 1.2 kg firewood per hour, where normal food cooked in southern parts of Karnataka—rice, sambar, vegetable, and ragi balls—could be cooked for a family of five adult members in an hour, with a specific fuel consumption of 80 to 100 g fuel wood for 1 kg of cooked food, as against 250 g in the traditional 3-pan stove, which had a thermal efficiency of about 10 per cent. The clearances below I, II, and III pans were respectively, 11, 4, and 2.5 cm, with the pan-wise break-up of the total 40% efficiency being 20, 12, and 8. Since many families may cook only two dishes, or may find it difficult to cook three dishes simultaneously, other

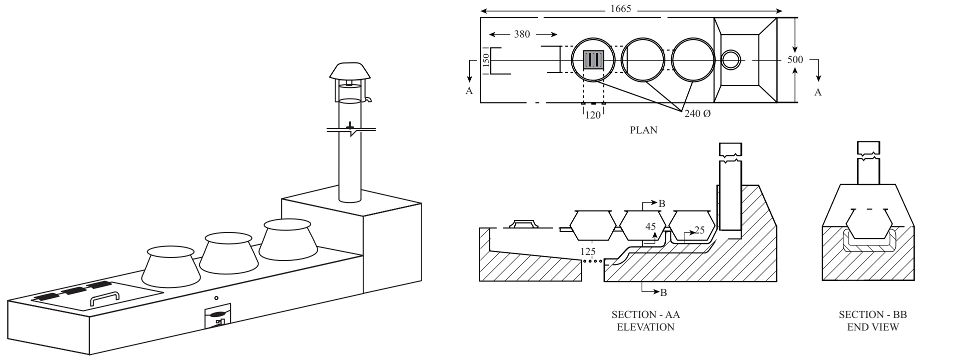

Figure 1: The three pan ASTRA OLE.

types of stoves—2-pan, (2 + 1) pan, and (1 + 1) pan—were developed, +1 indicating a heat recovery vessel for heating water. The 2-pan version has a lower heat transfer area and thus yields lower thermal efficiency (ca 30%). To correct this, we developed a version with a heat recovery vessel. In this, the third pan is completely immersed in the flue gases in which water is heated. This hot water can be used to speed up the next batch of cooking or for other domestic activities. The 3-pan model (Fig. 1), christened ***ASTRA OLE,*** was disseminated on a very large scale by the Government of Karnataka through the Karnataka State Council for Science and Technology (KSCST). From 1984 to 1997, about 1.5 million ***ASTRA OLES*** were built in the entire state of Karnataka. Many surveys carried out during this period indicated a survival rate of about 50%. At a very conservative estimate, the saving of fuel wood at the rate of just 1 kg per day per stove for 1 lakh stoves (about 7% of 1.5 million) for the ten-year period 1997 to 2007 works out to 3,65,000 metric tons. We can visualise this amount, when loaded at the rate of 10 tons per truck, with the trucks standing bumper to bumper. Such a line of trucks would extend from *Bangalore to Chennai*!

3.2 *Large cook stoves*

Cooking in hostels, hotels, canteens, community halls, a*nganwadis*, and for the mid-day meal schemes of Karnataka for schools, both in 1988 and at present, comes under this category. The stoves used are (2 + 1), (1 + 1), single-pan, and *tawa* types. Since flat bottom vessels are common for cooking on a large scale and since cooking more than two dishes simultaneously poses problems, the (2 + 1) version (Fig. 2) was developed for large-scale cooking. This gave the dual advantage of adequate area for heat transfer and providing hot water for subsequent cooking. Since large-scale cooking is done in a number of batches, the use of this hot water hastens the subsequent cooking. Thus the stove gives the multiple advantages of short cooking time, less fuel requirement, and results in a cooler, smoke-free environment. In the laboratory, this stove yields a thermal efficiency of 40–45%, for a burning rate of 4 kg fuel wood per hour, for a run of two hours. In the field it requires only 50% of the fuel used in conventional stoves.

In the mid-day meal scheme of Government of Karnataka during 1988–89, where a single dish, prepared out of Bulgar wheat and vegetables, was being made for about 7 lakh students in central, mini-central, and individual kitchens, the (1 + 1)

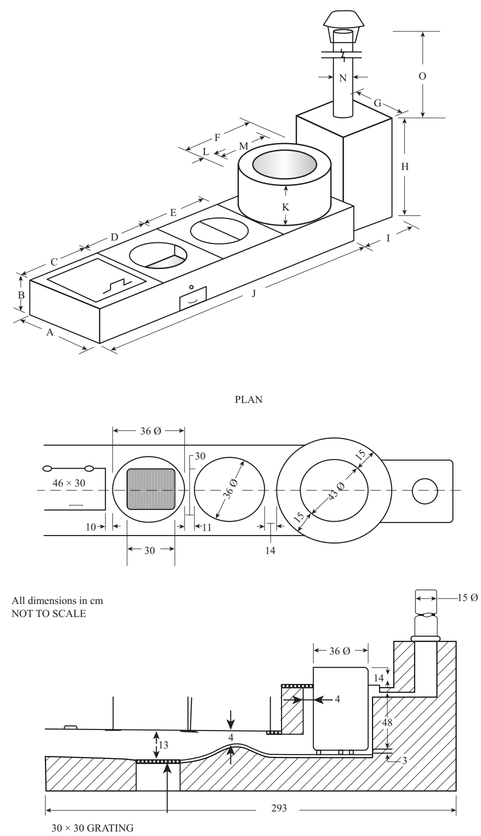

Figure 2: Large (2 + 1) Astra cook stove.

version was deployed in 14 locations. A saving of about 60% fuel wood was achieved in a central kitchen, when cooking for about 6,000 students in three batches. In the case of individual kitchens and *anganwadis,* a single pan stove was developed wherein the vessel is immersed up to 75% of its height in the flue path. The gradually-reducing clearance, a feature of the high-efficiency 3-pan stove, was introduced under the single pan used in this stove. The large diameter of the vessel facilitated this innovation. In the laboratory this kind of stove yielded a thermal efficiency of 40–45%. Recently, we made another innovation for a large, single-pan stove which facilitates the use of of vessels of different diameters; this model is being tried in *Anganwadis,* and restaurants. The standard (2 + 1) large stove is being used for the current mid-day meal programme in Karnataka in ten locations. We have recently made one such stove in Andhra Pradesh for the same purpose. Its successful use may result in more schools in that state adopting our design.

With the easy availability of LPG, many restaurants and large cooking establishments switched over to LPG as a fuel during the last two decades for their cooking needs, due to the ease of operation. With the increasing cost of LPG, and occasional non-availability of LPG in some areas, some of these establishments approached us for an alternative. We recommended the use of large (2 + 1) stoves for general cooking, and designed different-sized finned (cast or welded) *tawas* for making *dosas, parathas,* and *chapathis* for use in stoves with heat recovery vessels, either as a hot case for keeping the food hot or for heating water. Some restaurants in Bangalore, Belgaum, Puducherry have tried these stoves and found them useful on many counts—low fuel costs, cooler stove surroundings, and time saving. An additional benefit is the replacement of fossil fuel like LPG with biomass, a 'green' fuel. A pioneering restaurant in Bangalore, which replaced a boiler producing steam for some of its operations and some LPG with such stoves in 2006–07, saves around Rs. 1,200 per day in fuel cost. The fuel used in most of these stoves is biomass briquettes, an additional plus point vis-a-vis the use of fuel wood. A rough estimate of fire wood saving for about 2,000 large stoves in the field would be around 48,000 tons annually.

4 Bath Water Stoves

The use of hot water for bathing in all seasons is common in Karnataka. Conventionally, bath water is heated in a nearly spherical-shaped, narrow mouthed vessel (called '*Hande*' locally) which is permanently fixed in a masonry structure. Only the bottom surface of this vessel is heated by burning fire wood or waste biomass, without a grate. A chimney is used to disperse the smoke away from the room. A large excess of air gets sucked in, combustion is poor, and since only a small area is used for heat transfer, the thermal efficiency is low; at a guess one would put it around 15%. Often, the flue path gets blocked by char and tar, necessitating the dismantling of the stove, a cumbersome process requiring skilled help.

Utilising the concepts detailed above, we designed a fuel-efficient bath-water stove (Fig. 3A) which can be opened for cleaning, and reassembled easily and in a short time. Combustion is carried out similar to that described above for cook stoves. A larger area for heat transfer is made available by enclosing the *Hande* up to its neck in a cylindrical masonry structure, with an inside diameter 6–8 cm

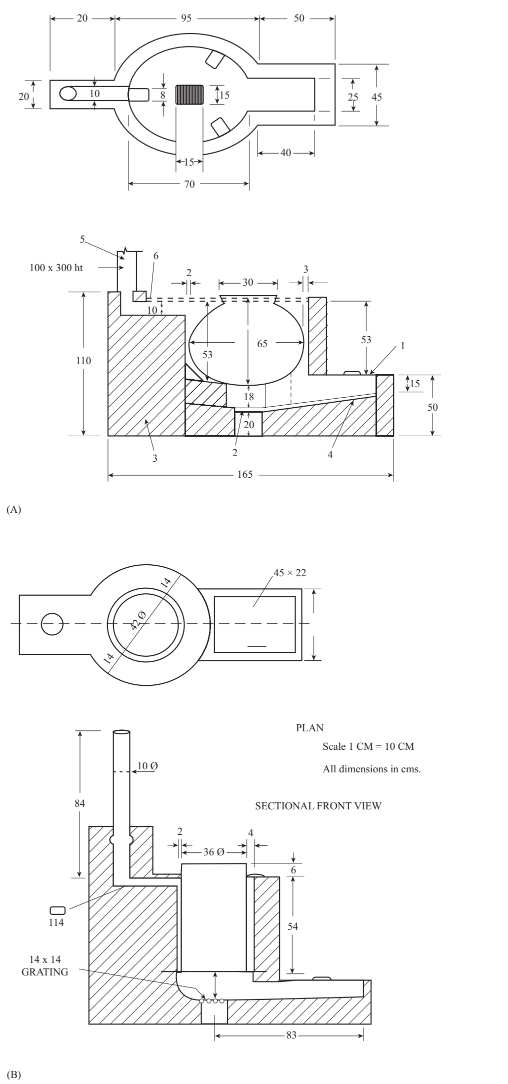

Figure 3: Bath water stove (A) *Hande* (B) Cylindrical vessel.

larger than the maximum outside diameter of the *Hande.* The annular gap between the vessel and the masonry can be changed by putting in or removing the mud plaster on the inside of the wall. The top opening between the vessel neck and the cylindrical masonry is closed by a ferrocement ring with a central hole slightly larger than the vessel mouth and a diameter slightly larger than the inner diameter of the cylindrical masonry structure, with mortar and brickbats for closing the gaps.

With this kind of design, the cross section of the flue gas path beyond the maximum diameter of the vessel increases, reducing the velocity, and increasing the possibility of the flue gases bypassing the surface of the vessel. The convective heat transfer would thus suffer, reducing the efficiency. Ideally, the top ferrocement cover should be made to correspond with the contours of the top half of the vessel, the shape being such as to gradually decrease the annular cross section toward the top. This would facilitate better gas-vessel contact and improve the heat pick up by the vessel. But since the vessels do not usually have a standard size or shape, and since making this kind of cover would be difficult, the ring of the type mentioned earlier has been used.

The ideal shape of the vessel to avoid the difficulties mentioned above would be cylindrical. By varying the thickness of the mud plaster on the inside of the cylindrical masonry structure, we can obtain a reducing cross section, and thus a proper velocity, to maximise convective heat transport (Fig. 3B). This idea was tested. Thermal efficiency in the range of 40–45% is obtained for the cylindrical vessel while it is around 35–40% for the *Hande*. To increase the effective surface area of the cylindrical vessel, we used the concept of extended surface (fins), using a cylindrical vessel in similar stoves for generating steam. This is discussed later. Since 2003, we have been using a different design for circulating the flue gases around the vertical walls of cylindrical or rectangular vessels, for many types of stoves and for the heat recovery vessel (+1 type). This involves the passage of the flue gases below the base of the vessel and after crossing the base, the gases are made to rise up the rear by a baffle touching one side of the vertical wall of the vessel and the stove wall beyond. The gases then go around the vertical wall, and at the end of the circle they enter a box-like structure over which the chimney is mounted. This facilitates a better gas-vessel surface contact, with lower bypassing. Admittedly, the construction is more complicated, but the advantage yielded outweighs this difficulty.

Between 1986 and 1997, more than a thousand bath water stoves were built, mainly in the Shimoga and Chikmagalur districts of Karnataka by masons trained by us. To date this number has gone up to about 2,000. We estimate a saving of about 2,500 tons of fuel wood due to this annually.

5 Stoves for Post-Harvest Operations

Jaggery making, areca processing, steam distillation of aromatic oils, rubber band manufacture, Ayurvedic medicine making, come under this category. Evaporation, boiling, and steaming are the tasks performed. We will discuss some of these operations.

5.1 *Areca processing*

Areca is grown and processed in some districts of Karnataka and Kerala. The processing depends on the type of areca. Basically, it involves boiling. In Kerala, however, some evaporation is also done. After this, drying is done which we will discuss under the section for drying. Boiling consists of heating the areca-nut pieces or whole nuts in a red astringent liquid till the desired product results. While in Karnataka *Hande*-shaped vessels are common, in Kerala wider, flat pans are used. For a raw material charge which ultimately yields 25–30 kg of processed areca-nuts, the fuel wood required by the traditional stove in Karnataka ranges anywhere between 50–100 kg. This stove, which uses neither a grate nor a chimney, emits a lot of smoke and cannot use any fuel except fire wood. The requirements of the areca stove in Karnataka are similar to bath water stoves, the only difference being the largeness of size. Using a larger grate and firebox and a wider chimney, we straightaway field-tested the *Hande* bath water stove design for areca-nut boiling. The results, in terms of ease of ignition and sustaining the combustion, coolness and smokelessness of the surroundings were remarkable. Of greater importance and relevance is the fuel and time saving. Against the earlier consumption of 50–100 kg of fire wood per batch, this design needs only 12–15 kg. Further, it can use waste biomass such as areca husk and waste from areca and coconut trees which the traditional stove could not. Now most of the areca processing in Karnataka is done with agro-wastes. More than 3,000 such stoves of varying capacities are operational now. A saving of more than 7,000 tons of fuel wood annually has thus resulted. In Kerala, as the processing involves both boiling and evaporation using different types of vessels, we deployed a (1 + 1) type stove in which boiling is done in the first pan and evaporation in the +1 pan. Here the saving in fuel and time is 50% compared to the traditional stove.

5.2 *Jaggery making*

Historically, this has been the starting point in c.1980–81 for the development of fuel efficient devices at ASTRA. The development of fuel efficient furnaces for making jaggery was taken up specifically to help the farmers of the village Unchagi, near Kumta, in the Uttara Kannada district of Karnataka. The making of liquid jaggery, an important source of cash income, was becoming uneconomical as the cost of fire wood, which was then used for making jaggery, was increasing every season. Sugarcane bagasse, obtained after the extraction of juice, was inadequate to make jaggery in the traditional single-pan furnace. Using the principles outlined earlier, we designed a 3-pan furnace, and tested it successfully to make jaggery with only 70 to 80% of the bagasse obtained. This success resulted in our research in 1981–83 (mentioned earlier) in the area of fuel efficient stoves. We designed 1- and 2-pan versions (Fig. 4) for jaggery making, as the 3-pan design was a bit difficult to use for the jaggery-making contractors who moved their equipment from place to place for making jaggery for farmers at different locations. In all, about 30 two-pan furnaces were made in the next few years, totally replacing fuel wood. At present, in the Mandya area, as perhaps in many areas in the country, bagasse is not saved. At best, the bagasse produced is just sufficient. But in the majority of the units, extra fuel is required.

Our many attempts to help the jaggery makers in the Mandya area of Karnataka were not very successful, as the jaggery makers are perhaps not prepared to change their technology, for whatever reasons. In 2005, we made a 2-pan furnace near Ungra (where our Institute's extension centre is located) using a 2-pan design in which the second pas has fins. This unit gave a specific fuel consumption (SFC) of 1.3 kg bagasse per kg of jaggery as against the average SFC of 1.9 to 2.0 in the Mandya area for a 2-pan unit. Now we are collaborating with the University of Agricultural Sciences, Bangalore, for making fuel-efficient, 2-pan furnaces in their ambitious national-level project on jaggery, which will go on stream in the next six months. We are using finned pans and anticipate a saving of 500 kg bagasse per ton of jaggery made. This project is bound to make an impact on the way jaggery is made in the country in future.

Some post harvest operations like Ayurvedic medicine making, silk reeling, rubber-band making, which can also fall under ***other*** categories, like 'textile' stoves, or 'cottage' industries will be dealt later.

6 Stoves for Other Operations

6.1 *Ayurvedic medicine making*

The making of Ayurvedic medicines involves boiling, evaporation, heating of leaves, roots, other plant materials in water and oils for the extraction of the active ingredients, and the heating of materials in a sand bath at high temperatures for making oxides. The vessels used for these are of different sizes and shapes like cylindrical vessels, shallow cauldrons, etc. Depending on the operation and the vessels used, we have employed single pan and two pan stoves of the type described above for different duties. The saving over the traditional stoves has been of the order of around 50%. In 1988, in Kumta (Karnataka) where we

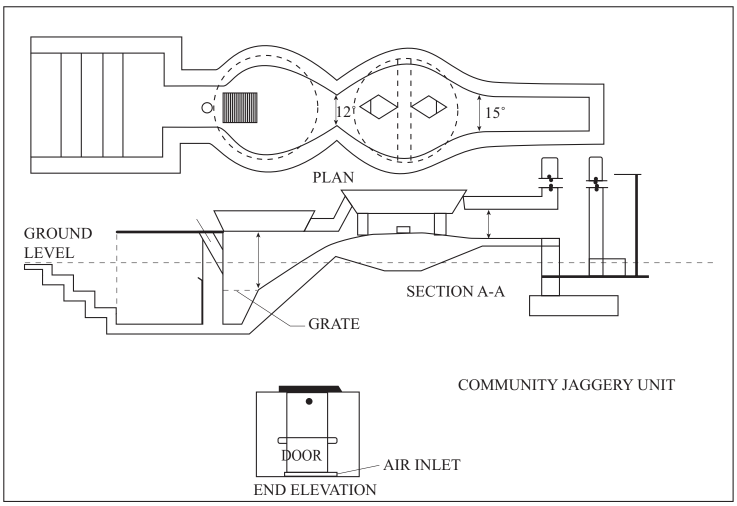

Figure 4: 2-pan jaggery furnace.

made the stoves of our design for Ayurvedic medicines for the first time, the saving in fuel wood compared to the traditional stoves for a year was Rs. 20,000 (equivalent to about 20 tons at the then prices). More than 90% of the stoves in the Ayurvedic medicine-making industry in Kerala have been changed to our design during 1998 to 2004 under a project by TIDE, an NGO from Bangalore. They estimate a saving of 11, 160 tons of fuel wood per year by the 900 stoves built in the project.

6.2 *Rubber band manufacture*

The vulcanisation of rubber tubes made from latex for rubber band manufacture is done either by steaming or by boiling in water. For boiling, rectangular tanks are used. Stoves similar to the bath water and areca stoves, where most of the vessel base and wall area are utilised for heat transfer, were designed. The saving in fuel wood is about 50% over the traditional stoves in which only the bottom surface is heated, without any chimney or grate. The additional benefit of a smokeless and cooler environment have resulted. Here also, most of the stoves (121) in the rubber-band industry in Kerala have been changed to stoves of our design by TIDE during 1998–2004, with an estimated annual saving of 2,335 tons of fuel wood.

6.3 *Silk reeling*

The reeling of silk thread from cocoons requires steam for stifling the pupae, boiling water to soften the sericin gum, and water at about 60°C to reel the filament. A variety of reeling equipment is utilised for this—*charka,* cottage basin, Italian basin, a multi-end reeling machine, and asophisticated filature. All, except the filature, where high pressure steam boilers are used, have different types of stoves in which the fuel is wood or other biomass. We have designed fuel-efficient stoves for all these, which have been disseminated by us, CSTRI, Bangalore, and the NGO TIDE. While the stoves for *charka* and the Italian basin are the completely 'immersed' type, the ones for the remaining two are the (4 + 1) type. TIDE has got 2,400 different kinds of silk reeling stoves of our design made till 2007, and the annual saving, as estimated by TIDE, is 9,000 tons.

6.4 *Textile stoves*

The processing of silk and cotton textiles, yarn as well as fibre, in the handloom and *Khadi* sectors, is done in biomass-fuelled stoves. The operations performed are sizing, bleaching, pre-dyeing treatment, and dyeing. Boiling of the textile material in water with additives is the main operation. This is done in rectangular tanks of various sizes. As only the base of the vessel is heated in conventional stoves, without any attention to the clearance for the passage of the flue gases, thermal efficiency is low. Using the techniques outlined above, particularly in the bath-water stove section, we have utilised the base and wall surface area for heat transfer, resulting in high energy efficiency, in some cases as high as 45%, which saves more than 50% fuel as compared to the traditional stoves. We have made 25 different-sized stoves under projects sponsored by KVIC and CAPART. TIDE has constructed 120 stoves. The estimated saving of fuel is 3,000 tons annually.

6.5 *Steam generation stoves*

Steam is required in the stifling of pupae in silk reeling, sterilization of substrate in mushroom growing, vulcanisation of rubber in rubber band manufacture, cooking *idlis* and the dough for *papads*, steam distillation of aromatic oils, and, recently, for curing lime-stabilised mud blocks. We have made fuel-efficient, biomass stoves which provide steam for these operations.

The same stove which is used for boiling cocoons in the *Charka* and Italian basins is used for stifling by keeping the basket holding the cocoons over the water-boiling vessel. However, when a separate stove is used for stifling, as in the cottage-basin silk reeling, the vessel where water is being boiled for generating steam is 'dipped' in the flue gases akin to the bath-water stove to have as much surface area as practicable. A Similar technique is followed for sterilisation of substrate for mushroom growing.

For steaming of *idlis*, both single-pan and three-pan stoves have been used, with the *idli* steaming vessel being dipped in the flue-gas path up to the water level. Similar design is followed for the 3-pan *papad*-dough steaming stove. These biomass-fuelled stoves were made as a replacement for LPG stoves. The single pan *Idli* stove has been saving Rs. 200 per day in fuel costs.

Steam generating stoves for steam distillation and curing of lime-stabilised mud blocks use finned boilers and chimney-cum-heat recovery flue-gas venting designs. Both stoves give 45% thermal efficiency for the required fuel-burning rate.

6.6 *Small baking oven*

We have recently commissioned a biomass-fuelled, small baking oven in an organisation which trains women's self-help groups for various operations. The oven has the capacity to bake 5, 400 g bread loaves and an equivalent (tray-area wise) quantity of buns and biscuits. One-third of the area of the base is heated by the burning fuel and all (five) sides, except the front door, are heated by the flue gases before they are vented through a chimney. Initial runs indicated low specific fuel consumption. More data are necessary to make an accurate statement regarding this.

7 Driers

During the dissemination of the areca processing stoves (1986–89), we became aware of the necessity of a drier for processed areca, especially during the rainy and cloudy days in the areca season. The absence of sun immediately after the areca is processed could cause fungal infection and thus a loss to the areca grower. The areca is dried by placing it on a bamboo mat, about 2 meters above the ground, and burning fire wood below to dry it. This would require a large quantity of wood. In the Malnad area of Karnataka, where areca is extensively cultivated, cardamom is also grown. The time of harvesting both these crops almost coincides. Cardamom, a high value crop, was being dried at that time in a room drier, recommended by the Spices Board. This also consumed a large amount of fuel wood. This encouraged us to develop a fuel-efficient drier. We developed the first model of a cabinet-type tray drier in 1990 and field-tested it. The results were very satisfactory for drying both processed areca and cardamom. Subsequently, we made this model at some 14 places during 1991, and the results were encouraging, from the fuel consumption, cost, convenience and space requirement points of view. The first design has since been modified.

Drying requires air at a suitably safe temperature to flow over the material being dried. The air has to be heated and made to pass over the material being dried. Wet material is placed on a tray or a net or a sheet of cloth, these being supported on a stand. The design of the drier allows the drying air to flow around (below and above) these, without bypassing it. The passage of hot drying air over the initial trays lowers its temperature and increases the humidity, thus reducing its capacity to absorb more moisture from the subsequent wet material it encounters. This requires reheating of this air. The drier has to have a facility of reheating the drying air during its passage in the drier.

The ASTRA natural convection cabinet drier (Fig. 5) developed by us, using trays to keep the wet material, follows the points made in the paragraph above. Fuel wood is burned in a combustion chamber similar to the ASTRA stoves at the bottom of the cabinet. The flue gases pass through a masonry duct of suitable thickness slightly above the base of the drier. At the back wall of the cabinet, this duct is connected to a metallic duct which rises up the back wall of the cabinet. At the roof level, the flue gases pass through a duct, below and parallel to the roof, and are then vented off through an asbestos-cement chimney. Dry air enters the bottom of the drier through air inlet holes of the proper size, suitably located, gets heated by its passage around the flue ducts, and passes in an ordered way below and above the

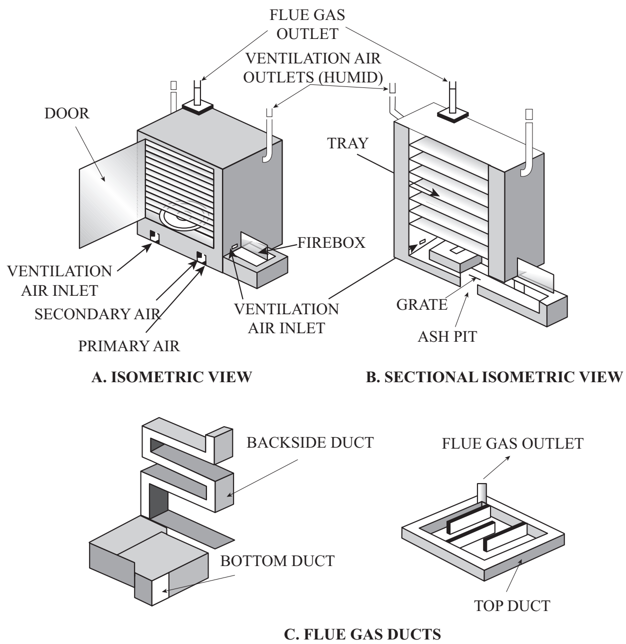

Figure 5: Astra cabinet drier.

trays up to the top of the topmost tray, where it is vented off through suitable pipes to the atmosphere. During its flow through the drier, this air passes over the metallic flue duct at the rear, and gets reheated. In the laboratory, this design could evaporate 3 to 4 kg of moisture from wet gunny bags per kg of fuel wood, with a controlled inlet rate of drying air. In the field, the specific fuel consumption varies between one kg to half kg fuel wood for the evaporation of one kg of moisture. Since there have been no biomass- based cabinet driers, to the best of our knowledge, except the ones mentioned earlier for the emergency drying of processed areca, and the Spice-Board recommended room drier for cardamom, we have no basis for comparison. But because of its low cost, convenience, and its capacity to dry a variety of material, our drier has found acceptance. About 1,000 ASTRA driers, with capacities varying from 5 kg to 400 kg of wet material, are in the field. They are being used to dry a variety of materials—fruits, vegetables, herbs, spices, papads, etc.

Room driers have both natural and forced convection for the drying air. For natural convection, the flue carrying air heating ducts are located in the same room where material being dried is kept. The wet material could be placed on trays which are placed on stands around the flue pipes, or placed over metal grills supported over the flue pipes. The only changes made in these were an increase in the area for heat transfer from the flue gases to the drying air, and in the material for the ducts. The wet material is piled up on this grill—this design has been used extensively (about 400 driers) by TIDE in Kerala to make copra out of broken coconuts. It has replaced the traditional one where broken coconut pieces are kept on a support, about 1 to 2 meters high, and fuel is burnt below this. Other examples of natural convection room driers are cardamom curing in Kerala and the flue curing barns for Virginia tobacco.

Research for tobacco barns was done by us in the UAS, Bangalore unit at Neville, Shimoga during 1994–97. The dissemination of our designs was done by the NGO TIDE in 1998–2003 under a project, in 15 tobacco curing barns. The SFC for curing tobacco has come down from about 8 kg earlier to between 3 to 4 kg fuel wood per kg of cured tobacco. About 30% saving in fire wood has resulted.

We have made only two forced convection room driers, one near Bangalore and the other in Sawantwadi (Maharashtra). For this design, the drying air is heated by suitable ducts extracting almost 90% of the energy generated by burning biomass in a separate room. The wet material is placed on trays on stands in another room and the heated air is circulated through the room by a blower. Most of this air (about 80%) is recycled through the 'air heating' room, where an equivalent amount of ambient fresh air makes up that quantity which has been vented off. This type of drier, made near Bangalore for a large farm, for drying herbs like chives, mint, basil, coriander leaves, wherein after successful operation with the first model built in 2005, the capacity was increased in 2007, from 250 kg wet herbs to 750 kg. This drier can evaporate 2 kg of moisture with 1 kg of fuel wood during continuous operation. This farm later acquired two sophisticated driers, namely an LPG-fuelled fluidised-bed drier and a freeze drier. While a comparison between these three methods of drying is certainly not proper, as the costs, capacities, and dried material quality varies, one is tempted to mention the cost of fuel per kg of dried chives, which varies from Rs. 15 for our biomass drier to Rs. 60 for the fluidised-bed drier, and Rs. 600 for the freeze drier.

8 Dissemination

The dissemination of the fuel-efficient devices has been accomplished through different routes—through government projects, NGO's, and individuals. It involves field testing, awareness campaign, training, and funds. The first device developed was the 3-pan liquid jaggery furnace in the Uttar Kannada district of Karnataka in December 1980. This was disseminated, during 1981–84, by trained individuals with Government support in the 2-pan version on a very small scale—about 30 units were made. The three pan domestic cook stove, which resulted as a consequence of research following the development of the jaggery furnace, and christened ***ASTRA OLE***, was disseminated on a very large scale by the Government of Karnataka, through the Karnataka State Council for Science and Technology (KSCST). This project was a consequence of the experience gained through a small project (December 1983 to February 1984) to train persons and build *ASTRA OLES* at three locations. The success of this project prompted KSCST to suggest to the State Government to train stove builders in each Taluk to spread the technology in the entire state. The government was quick to respond by sanctioning a project which involved the recruitment of 20 science graduates and engineering diploma holders who would be trained to be trainers for stove making. After training they would be placed, one per district (the state then had 19 districts), to organize a seven-day camp in one place in their district to give hands-on training to build ASTRA OLE. A small subsidy was given for each stove by the Government, and each district was given an yearly target. In this project, which lasted from 1984 to 1997, about 1.5 million *ASTRA OLES* were constructed. Many individuals, who were trained in the Government project, later started making the stoves in the commercial mode, either individually or through NGO's.

The dissemination for areca, bath, and large cook stoves followed a different pattern. During field testing, many masons were trained in making them, and later they made the devices for customers in the commercial mode.

The third major dissemination activity was through the Bangalore-NGO TIDE (Technology Initiative Design Endeavour) who, in a major project sponsored by ICEF (Indo-Canada Environmental Facility) during 1998–2004, made a variety of stoves and driers listed above, after training entrepreneurs to take up the stove-making activity on a commercial basis in the states of Karnataka and Kerala and to a small extent, in Uttarakhand and Chhatisgarh, with technical advice from me. Recently (2005 onward), some educational institutions and NGO's, requested us to participate in seminars and workshops organized by them for awareness and training in making these devices. Prominent among this class are the NIE, Mysore and CERD, Puducherry. Many persons were trained, and are active in making these fuel-efficient devices. The resulting dissemination from all these modes is summarised in the tables below.

Table 1: Devices built under projects of KSCST, 1983 to 1997.

No	Type of device	Number in field	Saving of fuel, %
1	Domestic Cooking, 3-pan	1.5 million	30 to 50
2	Domestic Cooking, (2 + 1) pan	100	50 to 70
3	Domestic Cooking, (1 + 1) pan	20	30 to 50
4	Large Scale Cooking, (2 + !) pan	100	30 to 50
5	Mid-day Meal, (1 + !) pan	14	40 to 70
6	Anganwadi, 1-pan	5	50 to 70
7	Bath Water Heating	1,000	40 to 60
8	Areca Processing	1,500	50 to 75
9	Jaggery Making, All Types	40	40 to 70
10	Silk Reeling, All Types	100	40 to 60
11	Candying of Papaya	3	50
12	Ayurvedic Medicine	5	40 to 60
13	Steam Generation	4	40 to 60
14	Driers + Tobacco Curing	150 + 2	30 to 60
15	Crematorium	2	50 to 60

Table 2: Devices built by TIDE, Bangalore.

No	Type of device	Number installed	Fuel saved annually, metric tons
1	Ayurvedic Stoves	900	11,160
2	Rubber Band Stoves	121	2,335
3	Hotel/Bakery Stoves	131	970
4	Textile Stoves	120	3,000
5	Areca Stoves	3,000	9,000
6	Sericulture Stoves	2,400	6,000
7	Tobacco Curing Barns	15	87
8	Water Heating & Miscellaneous	1,000	300
9	Community Cooking	1,098	6,588

Total annual saving: 39,440 metric tons.

Table 3: Devices made by entrepreneur trained by Astra (M/S Joshi & Co., SIRSI).

Type of device	Number installed
Domestic and Large Size Cooking Stoves Bath Water Heating Stoves Areca Processing Stoves	3,500
Driers	1,000

In addition to these, there are many other individual entrepreneurs who are making many types of stoves designed by us, after receiving training in the various training programmes conducted hitherto. While it is difficult to give the exact number and type of stoves and driers made by this group, we can safely conclude that the number exceeds 5,000 based on a meeting we had recently with some of them. Thus, with an extremely conservative estimate of fuel saving of 1 kg per day per device, the annual saving works out to 1,825 metric tons.

9 Conclusions

We thus conclude that the deployment of energy-efficient devices developed by us can:

1. Save a large quantity of biomass fuel and thus contribute to arresting deforestation, pollution;
2. We have just scratched the surface of the problem and a lot more is to be done;
3. There is need for larger dissemination;
4. N.G.O.s can play a significant role in future dissemination.

Acknowledgments

Most of the devices were developed and disseminated under various projects sponsored by the Karnataka State Council for Science and Technology, Bangalore. I am grateful to Ms. Svati Bhogle, CEO, TIDE, Bangalore, for providing the data pertaining to the devices of our design that have been disseminated by TIDE.

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Shridhar Sadashiv Lokras—retired from the faculty of Chemical Engineering at the Indian Institute of Science, Bangalore. He did his PhD from Indian Institute of Science, Bangalore in Chemical Engineering. He has also been an Associate Faculty at Centre for Sustainable Technologies (CST), Indian Institute of Science where he carried out much of his work on efficient wood burning stoves from the 80's. He was instrumental in evolving over 40 different types of wood burning stoves that have been used from simple activities such as domestic cook stoves to complex agro-product drying barns. Among the constructed wood stoves, the ASTRA-3 pan woodstoves have achieved the highest reported efficiencies under both laboratory and field conditions and is among the world's most efficient woodstoves. Over 1.5 million cook stoves have been disseminated in the state of Karnataka—these and 40 other stove designs stand testimony to this yeoman effort.