THE POWER OF SMALL GASIFIERS

By Paul Olivier

About three years ago, I received a set of drawings of a top-lit, updraft, rice hull gasifier from Alexis Belonio of the Philippines. After having built and tested this gasifier, I proceeded to make a few minor changes to enhance its performance and to increase its acceptability within Vietnam.

The size of the fan supplying primary air was reduced almost 10-fold. This significantly increased the holding capacity of the reactor. The small computer fan used here is guaranteed to operate continuously for 65,000 hours. The fan is situated within a perforated housing, shown on the right.

In the original Belonio design, the fan was permanently attached to the reactor. But now the fan can be detached from the reactor when it is being emptied of biochar. In this way, rising hot air does not damage the fan when the reactor is turned upside down.

A state-of-the-art electronic speed regulator is tucked away within the fan housing right above the fan. With an easy turn of a dial, the operator can control the flow of gas. This DC fan on loose rice hulls consumes no more than a watt or two of electricity.

Normally the fan is powered by an AC/DC adaptor. But if power from the mains is interrupted, any 12-volt battery can be used. Motorbikes can be inexpensively wired with a single outlet cord to provide electricity to the fan when power fails. In rural areas of developing countries with no access to power lines, small solar panels costing less than $20 US dollars become an exciting option for charging batteries.

The fan assembly slips smoothly into a curved pipe at the bottom of the reactor. This pipe serves four functions: an air pipe, a leg, a handle, and a means of evacuating any biomass that might fall through the reactor grate. This pipe, as well as the grab handle above it, always remains cool to the touch. The open area of the reactor grate was increased to allow for the easier entry of primary air into the reactor.

Next, the height of the reactor was reduced. Too much heat is lost when a tall reactor is employed. Insulating the reactor is problematic, since the use of insulation reduces the life of stainless steel. If a tall reactor is used, the temperature of the gas prior to combustion can drop toward the latter part of the burn by as much as 250 C. This represents a huge inefficiency that had to be eliminated. The burn time of this shortened reactor on loose rice hulls is about 35 minutes.

But no improvements could be made with respect to the Belonio burner itself. This burner was superbly engineered. Unlike many others before him, Belonio placed burner holes along the periphery of the burner. The number of holes, the diameter of holes, the spacing of the holes, and the staggering of two rings of holes – all remained the same. When any of these dimensions are changed in the slightest way, the burner does not function properly.

But a bare Belonio burner still produces a long diffusion flame. A burner housing is needed to force secondary air to mix properly with the gas exiting the burner holes. The gas that exits the burner holes does so under mild pressure, and at the same time, secondary air is introduced along a horizontal plane at the base of the burner holes. This secondary air is also under mild pressure created by the natural draft of the burner housing. As gas entrains air, and as air and gas forcefully come together, an intimate mixing takes place all along the periphery of the burner. The long diffusion flame is replaced by a series of small flames situated fully underneath the pot or pan, as is clearly seen in this video.

Many attempts were made to convert the Belonio burner into a true premix burner. This entails adding more burner holes and putting the gas under a lot more pressure so that it might entrain air. But putting gas under pressure causes the leakage of gas at the reactor/burner interface. To prevent leakage, a gasket is needed, and if ever this gasket should fail, deadly carbon monoxide would be released. So the idea of a premix burner was abandoned.

Determining the height of the pot above the burner involved a lot of trial and error. A small amount of tertiary air is needed to complete combustion under the pot. If the pot is too low, this tertiary air will not be able to enter under the pot to complete the combustion of the gas. And if the pot is too high, then the efficiency of the transfer of heat to the pot is compromised.

Once the pot is placed on the burner, the combustion dynamics of the gas as it exits the burner are changed, and surprisingly, what happens within the reactor is also changed. Once the pot is placed on the burner, open flames within the reactor are extinguished, provided, of course, that the speed of the fan is not too high. If the fan speed is just right, sometimes merely placing the burner on the reactor causes all open flames within the reactor to go out.

This elimination of open flames within the reactor is quite important, for it is this that distinguishes a gasifier stove from a direct combustion stove and all stoves in between. To the extent that gases are burned within the reactor, then the gasifier is no longer functioning as a gasifier but as a direct combustion unit. All direct combustion stoves release gas that burns at a distance above the biomass from which it was derived. But with a gasifier, this distance is controlled and maximized. The combustion of gases should take place outside the reactor and right under the pot. When this happens, the syngas exiting the burner is comprised mainly of CO and H_2, and contains little CO_2.

If a gasifier produces CO_2 in large quantities, this not only creates a considerable inefficiency in the transfer of heat to the pot, but it also involves a dangerous mixing of CO_2 with syngas. If syngas gets diluted, it might not burn properly, and this increases the risk of deadly carbon monoxide escaping the burner.

The Belonio burner has many advantages over most gasifier burners. If, at any stage in the gasification process, CO_2 should exit any of the burner holes, the operator can see burner holes that do not support a flame. If air should channel unevenly through the biomass, the operator sees burner holes that do not support a flame and can make necessary adjustments in order to maximize the transfer of heat to the pot. When channeling occurs, syngas is combusted within the reactor, and this can raise the temperature within the reactor at times to well over 1,000 C, severely damaging even the finest stainless steel.

Putting a housing around the reactor is not always a good idea. If the sides of the reactor begin to overheat and glow red hot, the operator cannot see what is going on, and the reactor can get badly damaged. Since a housing can be subjected to high heat, it too, like the reactor, should be made out of high-quality stainless steel. But this almost doubles the price of the gasifier. Putting a protective screen around the reactor is not necessary if the gasifier is set within an enclosure, as will soon be explained.

Many gasifiers on the market today have a burner with a single large hole in the middle. The burner does not serve as a reactor lid. This makes it hard to distinguish reactor from burner, and this makes it equally hard to spot the presence of CO_2 in the syngas. The intimate mixing of air with the gas exiting toward the center of such a large hole is difficult to achieve.

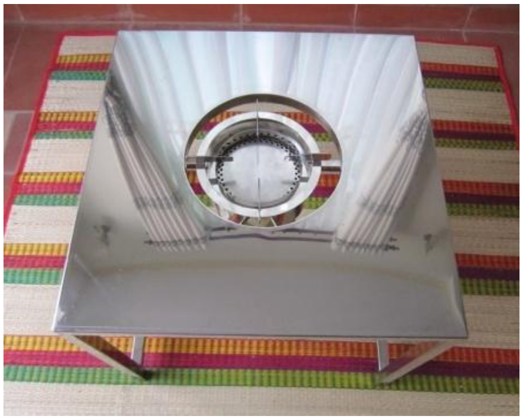
If such a gasifier is fueled with biomass that is not uniform, channeling will inevitably occur, and if this biomass is somewhat large, it is possible for hot char to drop down below the main gasification front, creating multiple gasification fronts. The process becomes so complex that such a unit, even though it might be top-lit and updraft, it should not be called a gasifier. It's at best an enhanced combustion unit.

So it is absolutely imperative that the fuel be uniform. Rice hulls, coffee husks, screened palm kernel shells and pecan shells are examples of biomass that are sufficiently uniform and can be gasified in their raw state. But biomass such as chunks of wood, sawdust, wood shavings and coconut coir are not uniform, and ideally they should be prepared into pellets or some other type of uniform fuel.

With pellets the bulk density of the biomass can increase, in some cases, by as much as ten times. This means that the height and diameter of the reactor can be reduced. A net reactor height of only 20 cm gives, for example, a burn time of over an hour. Since pellets offer much less resistance to the flow of air and gas through the reactor, the power consumption of the fan is no longer measured in watts but milliwatts. With a much shorter reactor and a much weaker fan, the cost of the gasifier is reduced by almost 50%. Pellet gasifiers are ideal in an urban setting where the transport and handling of loose biomass is not economical and practical. Two models of pellet gasifier have been designed and tested: one with a reactor of a diameter of 100 mm, and the other with a reactor of 150 mm. The smaller 100 pellet gasifier is all that is need for ordinary household cooking.

The moisture content of the biomass should be less than 12%. If the moisture content of the biomass is too high, then the process temperature within the reactor can drop below 700 C. In this case, the process resembles low-temperature pyrolysis in which tars and oils are formed. If some of these complex hydrocarbons exit in the gas and are improperly combusted, they escape the burner as particulate matter or soot. If they remain in the biochar, they degrade the quality of the biochar as a soil amendment or water filtration medium.

In the initial combustion reaction within a gasifier ($C + O_2 \rightarrow CO_2$), CO_2 is formed. In the case of true gasification, most of this CO_2 is converted into CO before it leaves the reactor. This conversion takes place by means of the Boudouard reaction ($C + CO_2 \rightarrow 2\ CO$). This reaction is endothermic and requires process temperatures greater than 700 C. If the Boudouard reaction does not take place, then the quality of the gas exiting the reactor is poor. Such gas burns in a very weak and ethereal manner.



But a gasifier stove must not only function properly, it must also look good, and it should be easy and safe to operate. Social acceptability is critical. If, after a few months of operation, the stove begins to rust and corrode, it will be viewed as a piece of junk. Even poor people who desperately need low-cost energy will shy away from buying it. Ideally a gasifier stove should look like any high-end kitchen appliance. It is important that it be fabricated out of the finest metal, such as bright annealed 304 stainless steel.

For safety reasons, this gasifier stove should not be operated as a stand-alone unit. It should be set within an enclosure. One simple type of enclosure is a stainless steel table with a hole through which the burner of the gasifier protrudes a little less than an inch. Once the gasifier is situated within the table, it is virtually impossible for someone to accidentally knock it over. If a pot or pan should slide off the burner, the chance of it falling down to the floor is minimized. If it slides off the burner onto the table, the change in elevation is less than one inch.

In this table concept, the wooden handle attached to the side of the burner housing has been replaced by a detachable stainless steel handle that fastens from above to two burner fingers. One can lift the burner from off the reactor, and slide the reactor under the table and just as easily remove it. Since the burner does not touch the table, the table is not discolored by the heat of the gasifier.

The top of the enclosure can be made out of terrazzo at a cost of about 10 US dollars. Or it can be made simply by cutting a hole in a large ceramic floor tile. Here the cost drops down to $2.50 US dollars. The small 100 pellet gasifier set within an enclosure with a ceramic table top looks like this. The 150 gasifier set with an enclosure with a ceramic table top looks like this.

In Vietnam and neighboring countries, these gasifier will be retailed only by women. The village retailer must make sure that the buyer knows how to operate the gasifier correctly (How to Operate the 150 Gasifier). This involves watching the buyer run through at least one complete gasification cycle in a flawless manner. The village retailer must make sure that the gasifier is never operated as a stand-alone unit and that it is set within an enclosure in a well ventilated space.

The 150 gasifier will retail at a price of about $60 US dollars. The 100 pellet gasifier will retail for about $40 US. The 150 gasifier on loose rice hulls puts out approximately 5.8 kW of heat and brings five liters of water to a boil in 12 minutes.

Since the biochar from this gasifier is produced at temperatures greater than 700 C and is thoroughly uniform, it has a much higher value than charcoal or biochar produced in dirty, low-temperature kilns that waste all of the gas. Each time someone uses this gasifier, this person can earn money through the sale of biochar.

Biochar routed to the soil has a life time measured in thousands of years and constitutes a wonderful way to sequester carbon. In study after study, rice hull biochar produced in this type of gasifier has been shown to greatly enhance the health and fertility of the soil. Arbuscular mycorrhizal fungi, vital for the growth of most plants, proliferate within biochar. With the addition of biochar into the soil, fertilizer consumption is greatly reduced, and plant growth can increase at times by as much as two or three hundred per cent.

Therefore burning biochar as a means of improving stove efficiency makes little sense. Heat is generated too far away from the pot. In many Asian countries there is no shortage of agricultural and forestry waste to fuel gasifier stoves. Through gasification, the useless burning of this waste, along with the smog and soot that this generates, can be eliminated. The useless burning of rice hulls, rice straw, coffee husks and pine forest debris constitutes a colossal environmental problem within Vietnam.

A biochar buy-back program could be set up to finance the sale or rental of gasifiers to the poor. The production of biochar becomes highly decentralized. Almost every household and small business requiring high-grade heat could potentially be a biochar production facility. A larger 250 gasifier has been designed and tested. It puts out about 16 kW of heat (see picture below).

Biochar produced from pellets retains its pelleted form. Biochar merchants could supply raw pellets free-of-charge in exchange for an equal volume of biochar pellets. If biochar merchants could sell to specialty markets where biochar fulfills many of the same functions as activated carbon, they might even supply gasifiers free-of-charge.

Alexis Belonio clearly understood the potential and power of small-scale gasification. His technology should be continually engineered and re-engineered for widespread use even in the developed world. To view this technology as primarily for poor people in developing countries is dreadfully short-sighted. Alongside microwaves and toaster ovens, there is definitely a place for gasifiers in modern kitchens. No one, rich or poor, either in developing or developed countries, should be relying exclusively on fossil fuels to cook a meal.

Of course one can do a lot more with gasifier heat than simply cook a meal. For example, in the highland areas of Vietnam where a lot of coffee is grown, gasifier heat can be used to dry coffee cherries and parchment beans (see 001, 002, 003, 004, 005, 006, 007, 008, 009, 010, 011). In the lowland areas where rice is grown, it can be used to dry paddy rice. Many Vietnamese exporters of rice use coal at a cost of $200 US per ton to dry paddy rice. They buy coal and dump rice hulls. It’s hard to imagine a more senseless use of fossil fuels.

Gasifier heat can even be used in the complex and precise process of roasting coffee. A roaster drum of a diameter of 20 cm has been designed and tested. It can handle up to 1.5 kg of coffee beans per batch.

Michael Wood and Cana Little of Philanthrope brought this first gasifier/roaster to Laos and presented it to a coffee co-operative there of 58 minority villages. It is hard to overstate the positive financial impact that this device has had on these minority people. Instead of selling green beans (Typica and Cantimor) for $3.00 US per kg, they can now sell roasted beans for $40 US per kg. The unit can roast as much as 8 kg of coffee beans per hour. It costs about $250 US, in sharp contrast to 1-kg roasters that typically sell for over $6,000 US. This gasifier/roaster paid for itself in the first hour or two of operation.

In this video Michael Wood is teaching a young minority man how to regulate the speed of the roaster drum and the speed of the gasifier fan in order to obtain a precision roast. This gasifier/roaster has been run batch after batch for as long as six hours. The gasifier puts out just the right amount of heat for the roaster, and it is fueled entirely by waste biomass. The total electrical power consumption per kg of coffee beans is less than one watt-hour. Surely nowhere in the world is coffee roasted in such an economical manner.

In sharp contrast to this minimal power requirement, on average, it takes about one US dollar of electricity and bottled gas to roast one kg of coffee beans. Since over 8 billion kg of coffee are roasted annually throughout the world, gasifier/roasters could represent an annual savings to the coffee industry of about $8 billion US.

The same coffee roaster can be used to roast cacao beans. We are designing a melanger to grind roasted cacao beans into a smooth chocolate. In this way cacao farmers will be able to sell chocolate.

This is just one example of the power of small gasifiers. Our primary objective at all times should be to eliminate the use of fossil fuels in the production of high-grade heat, while at the same time producing high-quality biochar.