

## A biomass powered Ringbom-Stirling engine for developing countries: a low-budget solution for distributed electricity generation.

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**Abstract.** In many isolated settings electricity is not available or is supplied by fossil fuels, while biomass is used for cooking purposes, not exploiting all of its potential. We are building a prototype of a biomass powered 1kW<sub>e</sub> Ringbom-Stirling engine that doesn't require high technology, but nevertheless brings relevant innovations. This solution aims to generate electricity using the same source used for cooking. It is meant to be used and to be producible in developing countries, where distributed electricity generation, using locally available primary sources, can help reducing the dependence from foreign aids or suppliers. The system we are building is composed of a down-draft gasifier which supplies the syngas that is then burned to heat the Ringbom-Stirling engine, which produces electricity, while the remaining heat is available for cooking. We discuss here the general scheme of this solution with particular regard for some new applications that greatly simplify the operation of traditional Stirling engines, such as metal bellows, used instead of the typical cylinder-piston arrangement, to totally eliminate the friction due to sealing needs between moving parts.

### Key words

Biomass gasification, Ringbom-Stirling engine, metal bellows.

### 1. Introduction

Distributed electricity generation in developing countries requires a totally different approach with respect to analogous needs for developed countries [7]. Not only there are limitations on primary energy sources, but also operating problems can arise with the use of some high-end selected technologies and with maintenance.

For this kind of needs today's mainly used generators are internal combustion engines fed with fossil fuels, usually diesel or gasoline. This kind of engines are very reliable, but often the energy source may not be available with continuity, while it is almost always possible to find some residual biomass from local production.

For cooking purposes the typically used sources are coal and wood. The source that we want to exploit in this solution, as a single alternative to the simultaneous use of coal, wood and gasoline, are residuals which are often burned just for disposal (Fig. 1). The biomass we have focused on are rice husks because in developing countries this is one of the most widely available agricultural residue, that if burned directly does not produce flames but only black smoke. One of the best ways to exploit this source that cannot be usefully burned directly is gasification. This choice brings also other advantages, like the possibility to gasify the biomass somewhere and burn the produced syngas in a separate location (e.g. the engine's housing).

The Ringbom-Stirling engine is thought to be easy to understand and, along with ease of use, low maintenance [5] and low production costs, the possibility to reproduce this system in developing countries, with the locally available technology, is the main bond for this project. The innovations are due to simple solutions that do not require high production costs and technology. These solutions may not be the most efficient available today [4], but they are meant to be the most efficient that can be locally built and operated, using widely available production means and materials. In this project only the engineering part (which is mainly carried out in Brescia) is aligned with developed countries' standards; anything else must be as widespread as possible. This has excluded many possibilities, like the thermodynamic exploitation of solar energy in a low budget key, which certainly are very interesting, but not suitable for a quick spreading in developing countries.

High power is typically not necessary, 1kW is enough for a refrigerator in a remote medical settlement or for a small incubator in a village farm, however constant production may be required and this is a primary goal for this project, so we are developing a gasifier that can be fed continuously.

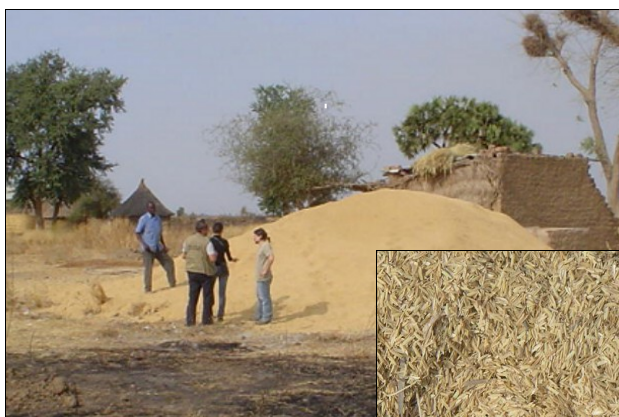


Fig. 1. Biomass residues from rice production near Bongor (Chad) and a detail of rice husks.

The final optimization and testing will be carried out in an African context, where the use of this machine and its local production will be contextualized. This part of the project will be carried out in collaboration with CeTAMB (Research center for appropriate technologies for environmental management in Developing Countries), which has many energetic-awareness programs already running, in various missions [15]. The social relevance of our project is strictly related to a context where biomass residues are perceived as a better alternative. It must be clear to local system developers and end-users that a biomass like wood obtained through deforestation is not a source that can be used sustainably, while the exploitation of biomass' residues can relieve the local ecosystem from a great part of its deployment.

## 2. System Layout

Gasifiers are starting to be used as cook-stoves in developing countries, for example in some rural Indian provinces [3]. This kind of stoves are very little and simple [1], [8], typically used only to cook small amounts of food, while big gasifiers (e.g. 200 kW<sub>th</sub>) are being used to heat (e.g. 35 kW<sub>el</sub>) Stirling engines in European co-generating installations like the one in Castel d'Aiano (Bologna) in Italy [6], with very different needs and costs. We have focused on a similar approach, but with an intermediate size and technology (Fig. 2.).

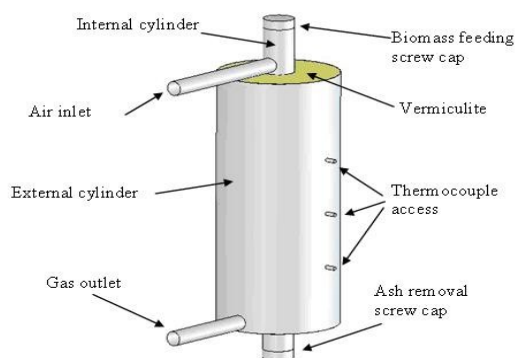


Fig. 2. The gasifier's scheme.

As fuel source for the engine we have chosen a down-draft gasifier, which is built up from very simple materials, an oil barrel used as the external shell and a chimney exhaust pipe used as the gasifier's body itself. Between them vermiculite is kept to insulate the internal heat which is necessary for the gasification process.

These gasifiers are capable of producing syngas via pyrolysis thanks to a small amount of forced air which flows through the stacked biomass from above [9]. In our solution a small fan, like those used for CPU's cooling, does the work and adjusting its induced air flow helps optimizing the system for different biomasses, while the production rate of the syngas, which exits from below, may not be so simple to master in this way. Ashes form in the lower part of the biomass stacked in the gasifier's tube so they are able to fall down, through a metal grill, and deposit on the very bottom of the tube. This allows the gasifier to be fed continuously from above, unscrewing the cap, while the ashes can be removed from the lower part. This gasification process has many advantages, like the possibility to use one single machine with distinct settings for many different agricultural residues, some of which can not be burnt directly like rice husks.

The heat obtained burning the syngas in a separate burner is then forced against the hot end of a simplified Ringbom-Stirling engine, while the remaining heat is available for various applications, such as cooking or dehydrating, during all the operating time.

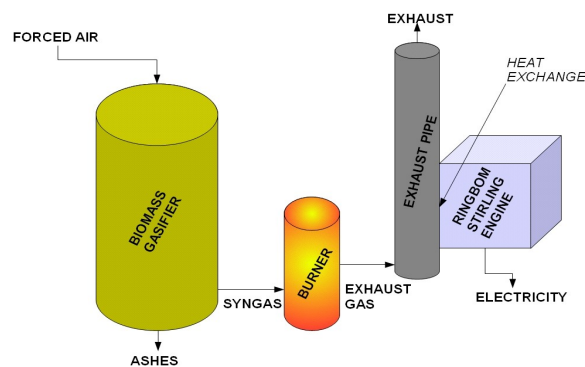


Fig. 3. The system's conceptual layout.

The external combustion engine, which contains air as the working fluid, is very simple. The Ringbom architecture is one of many variations of the Stirling engine, that eliminates all the external connection of the hot end displacer to the crankshaft, relying originally only on a pressure difference for the displacer's motion. For power requirements one major issue of hot-air engines is the need to pressurize the working fluid [12], which usually induces to enclose the entire engine in one big pressurized vessel, up to several thousands kPa for the most advanced engines. This generates two of the main hot-air engine's problems, sealing and friction. These problems usually lead to high-tech solutions which require expensive materials. For this project's purposes the mean internal pressure is not meant to be very high

and will be kept below 500 kPa, but this doesn't solve the problem, so we are developing metal bellows to be used instead of the typical cylinder-piston arrangement. This eliminates the need of sealing between moving parts, since there is no slit for the working fluid to pass through. This also removes most of the friction losses that are so crucial in a big dimension and low power engine. The bellows also work as a spring and this compensates, at least in part on the displacer side, the difference between the mean internal pressure and the external pressure that acts on the displacer's rod and that triggers its motion [13]. If it is not possible to completely compensate all the pressure difference with this effect, an auxiliary spring can be placed between the displacer's rod's end and the upper plate.

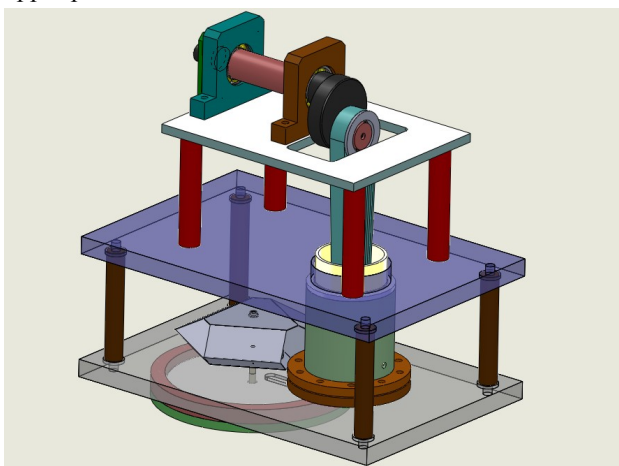


Fig. 4. 3D view of the engine with piston-cylinder arrangement on the cold side.

In the first prototype (Fig. 4) metal bellows will be used only on the displacer side, while a traditional piston-cylinder, with a jacketed water-cooling system, will be placed on the cold side of the engine. As soon as some experience is gathered through the development of the displacer's metal bellows (Fig. 6), also the power cylinder-piston will be substituted by metal bellows (Fig. 5), which are appealing also because their shape can help a lot to eliminate heat in the cold part of the engine, performing a finned cylinder's effect and hence eliminating the need for water-cooling.

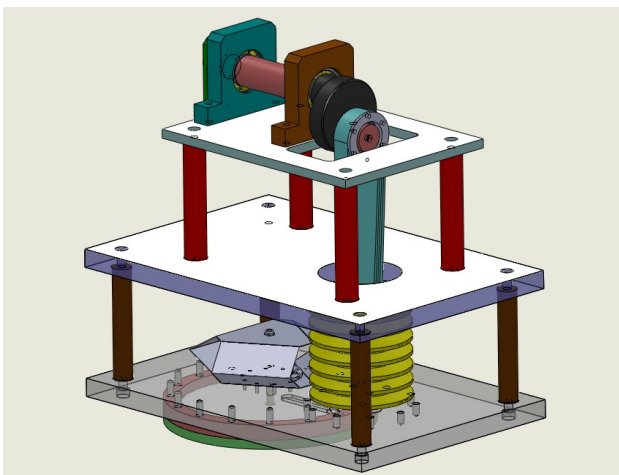


Fig. 5. 3D view of the engine with metal bellows on the cold side.

Efficiency is hard to determine at this development stage, especially because this type of engine doesn't have a standardized power model that can be considered trustworthy [2], [11]. The ideal engine has a Carnot efficiency, that for large temperature gaps can reach a very high value, but this doesn't mean that very high efficiencies can be reached with the present technology at a reasonable cost, not even in a developed country's point of view. The overall electrical efficiency we are aiming to with this project is, reasonably, below 10%, which is quite low on an absolute basis, but could be evaluated differently considering that the fuel is costless (economically and environmentally) and that production costs and technologies are quite low, facilitating a quick spreading. In any case the thermal efficiency of the gasifier will be quite high [10] with respect to the very low present-day thermal efficiencies that are associated with traditional cook-stoves.

### 3. Metal bellows

Metal bellows, used for such purposes, is a solution that has many advantages. Besides eliminating friction losses, due to the sealing contact between piston and cylinder, it simplifies many accessories parts in one single component. The shape of the bellows is a central issue that has to be investigated. The number of bends and their area, especially in relation to welding issues, are crucial for good performance and reliability. The main problem is the pressure that the weldings of the bellows have to withstand, commercial bellows are available for high pressure only if, while they're working, they do not move, whereas moving metal bellows usually work with 100 kPa pressure difference across the walls.

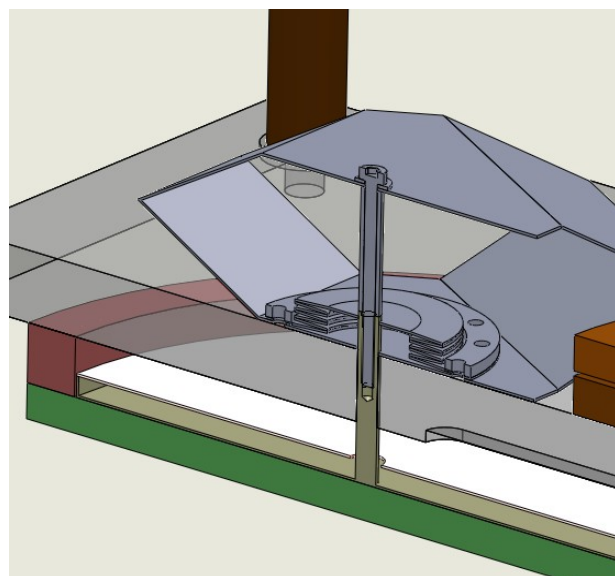


Fig. 6. Section detail of the metal bellows on the displacer side.

The thickness of the single plate that composes the bellows is also a very important detail that we are investigating experimentally. A high thickness plate leads to a good weldability, but also to a high rigidity and a lower heat exchange rate through the metal. The ideal

solution is a low thickness plate with many wide annular rings, so to lighten the structural stress induced on the single welding from the bellows motion and to favour heat exchange as much as possible, but all of this is bound by structural limits.

This kind of moving bellows appear to have never been used for this type of applications. The engineering problem that has to be solved is quite complex, there are metallurgical concerns, structural and technical ones. The solution of this experimental investigation is the main challenge of this project.

#### 4. Further improvements

During the present project's development, several improvements have been set temporarily aside, for a future implementation. These upgrades are very important for the final configuration, but they would introduce supplementary concerns, that should not interfere with the basic operations we are investigating at the present time.

First of all the gasifier can be built with crude clay bricks, but this can be made only after the optimal geometry has been identified. This kind of bricks can be produced locally [16] with simple skills and they appear to work quite well as stove building material.

A simple and little thermoelectric generator (few W), working thanks to the difference between the gasifier's internal and external temperatures, can be developed to power the little fan that forces air through the biomass. When the gasifier is lit up it must be kept 'open' for a while (allowing lots of air inside to start the combustion), until the necessary temperature is reached thanks to enough embers. Only at this point, the gasification process can take place, shutting the gasifier and starting to force air through the biomass.

An other possibility that we will investigate in the future is to re-design the engine in a 'beta configuration' keeping both the displacer and the power piston moving along the same axis. This not only will allow to save materials (and hence costs), but it will also reduce the dimensions of the engine. This step, although, will be possible only when some insight is achieved with metal bellows production and in the basic motion of this kind of engine.

#### 5. Conclusion

This solution brings many advantages like simplicity and low maintenance, besides using energy sources more efficiently. This kind of engines on the other hand are very big and are not capable of very high absolute efficiency or very high power either, but still they appear to be suitable for a steady installation in remote contexts where little amounts of electrical power are needed. The drastic simplifications in the mechanical parts of the engine and the use of low technologies make this a simple and low-budget alternative, with respect to internal combustion engines, a more appropriate solution for developing countries' energetic needs.

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