The Isomorph biomass gasifier

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We present a simple biomass gasifier with a high power density, based on a new principle of operation. It is able to process dry waste biomass. First results indicate, that it might be able in the future to also process humid biomass.

Physics against CO2

It has been known now for many years, that the CO2 concentration of the atmosphere is increasing continously, threatening our planet, and it is very clear, that existing technologies have not been able to stop this increase. Therefore either fundamentally new technologies or at least fundamental improvements of existing technologies are needed. Since physics is the most fundamental science, it should contribute to this quest.
Several years ago the accademic spin off company Isomorph srl has shown, that such improvements are possible when it presented the Linear Mirror – a very simple device, which concentrates sun light onto an absorber close to the ground in a fixed position. The Linear Mirror can be composed of any number of reflecting surfaces, moved concurrently by only three small electric motors (while instead heliostat fields need 2 motor for each reflector). The Linear Mirror is derived from a physics discussion of the problem of information processing, and it is likely to be similar to a device built already by Archimede (For the sake of demonstration, Isomorph has used the mirror also to burn a wooden ship).
In this article we want to present one more example of how a general physics discussion can be useful to create the kind of device needed for fighting the CO2 increase:

Biomass gasifiers

Wood gasifiers have already been used during the second world war in Italy and Germany in order to substitute fossil oil for driving cars or trucks. However, their operation was dirty and complex, and they needed very well defined high quality wood logs for their operation. So after the war they were abandonded. Since then the technology has not been improved substantially. Also nowadays wood gasifiers are either hobbyistic devices working in batch mode and not suited for the industrial application. Or they are very complex and therefore expensive systems, which usually can make use only of well defined kinds of combustible with a precisely given degree of humidity.

It is therefore the first objective of our study to create a very simple and small gasifier which is able to operate continuosly.
It is a second objective to achieve the ability of using different kinds of biomass, not only high quality wood, and to be less sensitive to the level of humidity.

The physics of gasification

In the engineering science, the gasification process is explained in terms of the air-fuel ratio. If there is precisely the amount of air available which is needed to burn the fuel (stoichiometric ratio), the fuel burns. If there is a lack of air, gasificiation is to occur: >>Gasification is a thermochemical conversion of a solid or liquid fuel into combustible gasesby understoichiometric addition of a gasification agent... << (Advanced biomass gassification, S,Heidenreich, M.Mueller, P.U.Foscolo, Academic Press, Elsevier, ISBN 978-0-12-804296-0)
Under this paradigma it is not possible to improve the performance of a gasifier by increasing the flow of primary air, because this would change the gasification reaction to a combustion reaction. Rather one has only the option to place additional inflows of primary air at a large distance, so that at each air inflow the reaction of the fuel with the air is independent of the reaction occuring at the other inflow(s). An example is shown in figure 1, where the reactions are not only indipendent from each other, but in fact are supposed to be of a different nature: first there is primary air to cause a pyrolysis reaction, then, separately, a primary air flow which is supposed to cause a gasification reaction. Note, that under the present engineering paradigm, this configuration is logical and even unavoidable.
In a real device constructed according to this figure, the distance between the air inlets is 47 cm (Bhattacharya SC., Hla SS., Pham H-L. A study on a multri-stagehybrid gasifier-enginesystem. Biomass Bioenergy 2001;21 : 445-460)

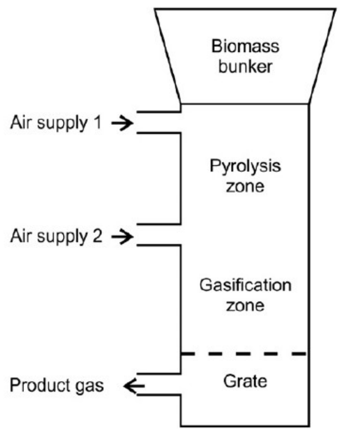

Figure 1: a state of the art gasifier with two primary air supply inlets

However, from a physics point of view, that paradigm is difficult to understand. For a combustion engine for instance, the amount of oxygen and fuel injected within the time interval of one motor cycle not only is well defined, so that for instance the term “stoichiometric” is defined, too. Moreover there is a cause-effect relation: the availabilty of sufficient air will cause the fuel to burn completely.
In a gasifier instead this way of reasing cannot be applied. Compared to the amount of oxygen injected in a short time interval, there is an abundance of fuel, very most of which will not react with the oxygen during this time interval. From a physics point of view one would expect, that the gasification reactions will occur primarily as a function of temperature: in the presence of C atoms and at sufficient temperature, CO_2 will not be stable, but instead there will be the formation of CO - due to the high temperature.
From a physics point of view one would therefore expect, that increasing the flow of primary air during gasifier operation should not transform the gasification process into a combustion process, but should rather increase the temperature of the gasification process. Here the limiting factor will be the maximum allowed temperature of the construction material only.
As a consequence, the problem of gasification now takes a different character: one would like to inject as much primary air as possible without overheating the device, and one would like to get an even temperature profile over a large volume in order to maximize the power and the power density of the device (minimizng its size).

From these requirements one can derive how our biomass gasifier should be constructed:

We assume a tube with biomass moving inside and along this tube. We consider a small hole in the wall of the tube, oxygen enters into the tube through this hole. If the biomass is ignited at this point, an oxidation zone will form with a certain temperature profile, we assume for the sake of discussion a very simple temperature profile, as shown in figure 2:
The biomass flowing through the tube will initially have ambient temperature, moving closer to the inflow of air, its temperature will increase, as shown in figure 2a , until it arrives at some maximum. This maximum should be sufficiently high in order to allow gasification. But it should not exceed the temperature which can be supported by the construction material.

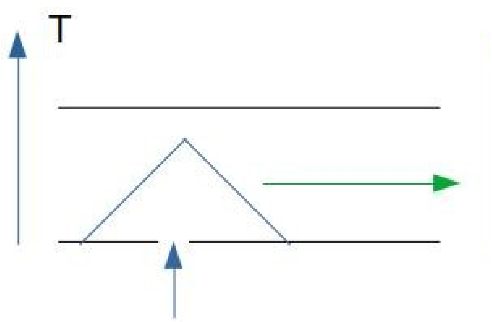

Figure 2a: biomass moves through a tube (horizontal arrow), air enters through an opening (vertical arrow), a temperature profile results.

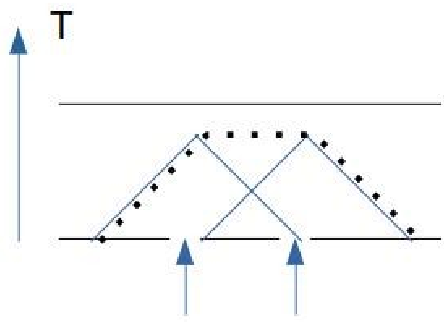

Figure 2b: if, in approximation, the temperature profile add, two openings will create a more even temperature profile over a finite length (dotted line)

We next assume a second hole in the tube through which flows primary oxygen. For the sake of argument the temperature profile created by this hole alone is assumed identical to the one of the first hole and we assume, that the temperature profile resulting from the operation of both holes be the sum of the sum of the two profiles, as shown in figure 2b.
We see, that the maximum allowed temperature is not reached only in 1 point, as in figure 2a, but over a finite length continuosly. With tow such holes, the power of the device has increased now by a factor of 2, and the volume where the maximum temperature is provided has increased by an even larger facctor.
Adding more openings along the tube, we can create a correspondingly long volume of constantly high temperature.
The characteristic freature of this construction is the distance between the holes: they must be close enough with respect to the length of their individual reaction zone.
This simple device should not only reach a high power density, but it should also produce rather clean gas, since the volatiles have to travel through a long zone of high temperature.

The Isomorph gasifier

Isomorph srl has developed this concept in the years 2015 to 2018. In 2020 it was first presented to the public at the occasion of ESOF2020. In this article we present results from an improved version constructed in 2021, a cross section of the device is shown in figure 3.

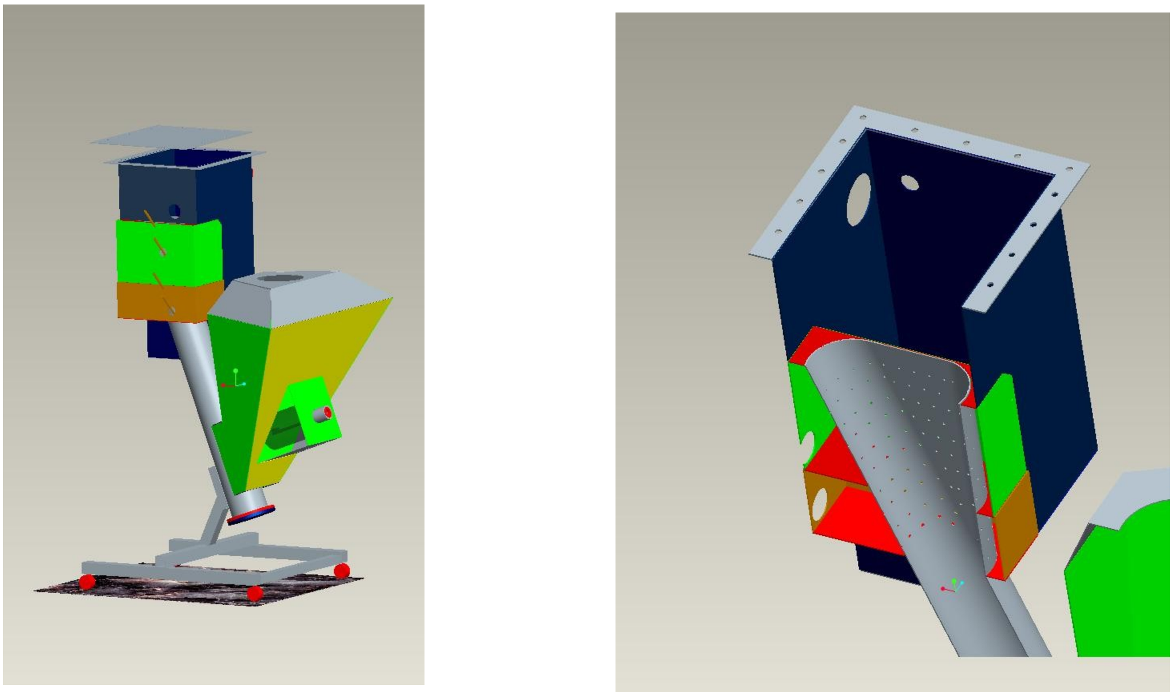

Figure 3: the Isomorph gasifier, state of 2021.

From a bunker for the biomass (yellow and green walls in figure 3) an Archimedes screw (the motor of the screw is omitted in the drawing) pushes the biomass upwards an inclined tube. In its upper part, the tube is surrounded by two chambers (green wall and brown wall), from where holes in the tube allow primary air to enter the tube – this forms the gasification reactor, it has a length of 30 cm and a volume of 5 liters.

The fact that there are two separate chambers allows to optimize the flow of primary air and also to perform stable running at low power. Ashes or dirt contained in the biomass will finally arrive at the top of the gasification volume and drop into a (blue) ash tray. The structure is only 150 cm high.

The primary air in the lower gasification volume is preheated.

Along the gasifier tube there are 4 temperature sensors (visible in figure 3) at distances of 15 cm from each other.

The primary air is provided by Micronel ventilators with a maximum pressure of 5 kPa, the system is controlled by a Siemens Logo plc.

The gas produced is combusted in a seconday flame outside the gasifier, an experimental heat exchanger heats a flow of water and allows therefore an estimate of the power of the device.

Technical details of gasifier:

height	150 cm
mass	about 60 kg
gasification volume	5 liters
motor of screw	150 W, 220 V
screw diameters	12 cm
mass in bunker	30 kg
material construction	stainless steel
control	Siemens Logo
ventilators	24 V

Figure 4: the gasifier, equipped with external burner (to the left) and preheating system for primary air.

Gasifier performance

For the first tests wood pellets have been used in order to have a calibrated standard material. Based on past experience we had expected this gasifier to arrive at a power of about 100 kW. However, already during the first test run temperatures reached 900 C°, so that the primary air had to be reduced in order to avoid excessive temperatures. The reduced power was about 50 kW.
This result is very promising for the future development: due to the high temperature, the gasifier can be expected tp produce a very clean gas and that also materials which are considered difficult to gasifiy can be handled. In order to limit the temperature, water vapor has to be added in the future.

The reactor of the gasifier has a volume of 5 liters. With a power of only 50 kW, the resulting power density is therefore 50 kW/5 l = 10 MW/m^3.
Nuclear reactors have power densities between 6 and 100 MW/m^3. Therefore the power density of our biomass gasifier can be compared to that of a nuclear reactor. This shows, that the new, physics based principle of construction does work as expected and that the major task of our development work has been met.

Several kinds of dried "waste" biomass were tried: alghe from the beach, green cut from gardening, pine needles. For quantities of up to about 20 kg no difference could be observed between the gasification of wood pellets and dry biomass.

The gasifier is also able to work for long periods of time autonomously: figure 5 shows the temperatures from the four sensors during 50 hours of continuos operation. During the night, combustible was provided to the bunker (capacity 30 kg) from a secondary biomass container which also had a capacity of 30 kg. In order to ensure, that the material was sufficient for at least 15 hours of operation (from 17.00 to 8.00), the gasifier was run at a reduced power of about 15 kW for this test.
During the night, the gasifier was running unattented. During daytime several tests were performed without stopping gasifier operation.

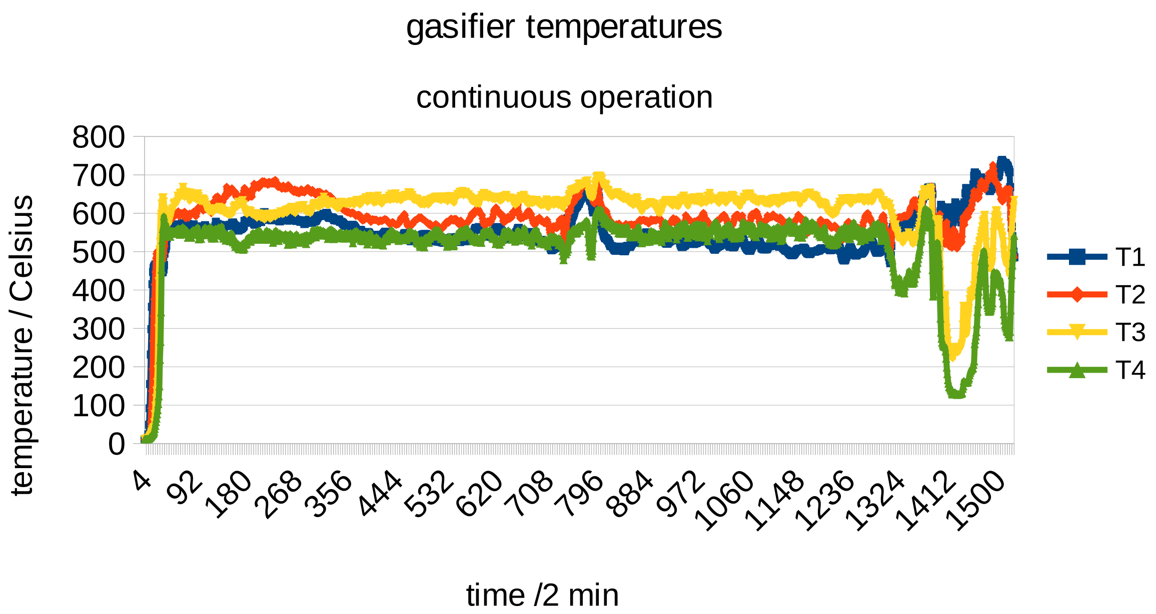

Figure 5: gasifier temperatures during continuous operation.

At about 800 minutes (in figure 5) and after 1230 minutes tests were performed and accordingly the temperatures changed at that time.
When no tests were performed, the temperatures were very stable. Even the temperature at the lowest measurement point (T4), positioned at the beginning of the gasifier, was always above 500 °C (as long as no tests were performed).

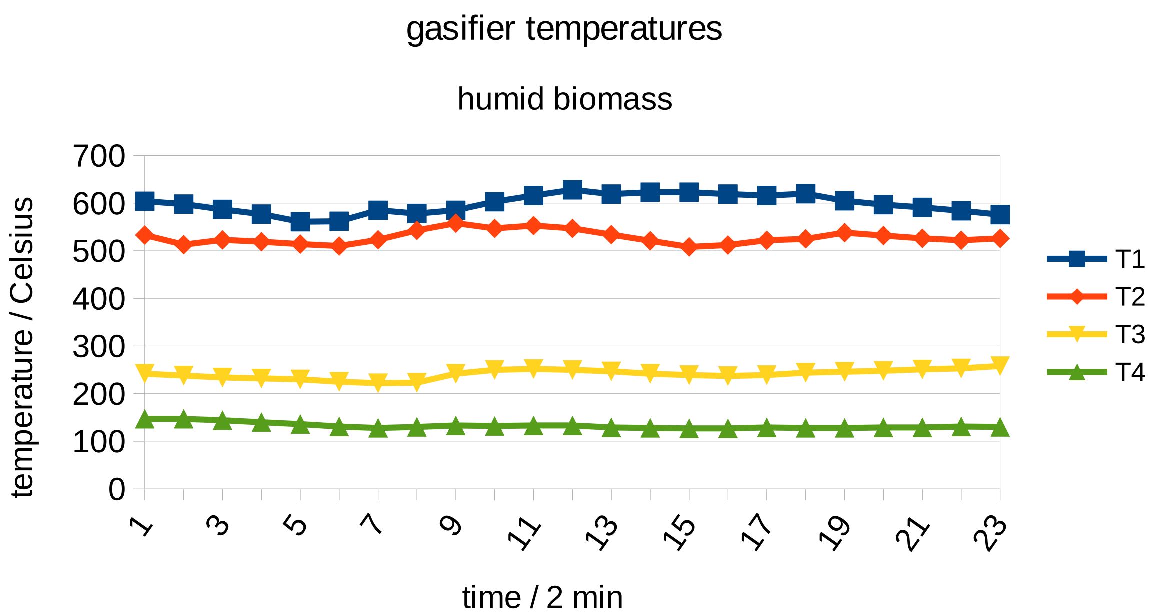

Figure 6 : temperatures during the gasification of humid biomass.

Towards the end of the run, after 1300 minutes, 7.4 kg of greencut were fed into the gasifier, the material had a humidity of 45 to 50%. The temperatures of the two lower sensors fell considerably, this is shown in more detail in figure 6, the lowest sensor measured 130 °C. However, the gasifier

continued operation. The temperatures of the lower sensors remained low and at a constant level for 45 minutes, which corresponds about to the time needed from gasifying 7.4 kg of humid biomass at low power operation.
After that period, the temperatures increased again (because dry biomass was provided to the gasifier).

Conclusion

We have reached our goal to create a very simple and compact biomass gasifier, which reaches a power density of 5 MW/m^3, comparable to that of a nuclear reactor. This device operates autonomously.
The gasification of humid waste biomass (green cut) succeded for about one hour of operation. It needs to be seen in the future whether also large quantities of humid biomass can be gasified.
It is clear from these results, that millions of tons of fossil gas (from Russia, for example) can be substituted with gas from waste biomass.