Use of Biogas as Alternative Fuel for Tobacco Curing: Case for Zimbabwe

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Abstract
This research study investigated tobacco curing activities in the country. Historically tobacco related activities were responsible for over 15% of annual deforestation in Zimbabwe, due to the energy intensive tobacco curing process by the majority of small scale farmers who use firewood as they find coal expensive to procure. This practice is not sustainable hence need to consider the feasibility of biogas as an alternative fuel for tobacco curing. The study was undertaken on a sample of small scale tobacco farmers, and the feed stock was mainly from dung from cattle, goats and chicken droppings. A technical evaluation was done for an average farmer, and came up with a $12m^3$ fixed dome biogas digester to produce 2.6 m^3 of biogas on daily basis. A bulk tobacco curing barn of dimensions 3m x 4m x 8m was selected, and was calculated to require 1475,8 m^3 of gas produced by the biomass digester which would generate up to $949m^3$ per annum. This was found to save up to 65% in energy requirements for the average farmer during curing. A general “feasibility calculator” for individual farmers was generated which other functions could be used to check individual farm biogas potential and compare it with required biogas for curing a specific amount of tobacco and give costing results for implementation if the farmer intended to consider biogas tobacco curing.

Keywords: Sustainable, tobacco curing, biogas, feasibility, digester, calculator

1. Introduction
The most popular method of producing flue cured tobacco by small scale farmers is the use of firewood, coal or charcoal. The tobacco industry though lucrative is not sustainable in its current state, the use of firewood leads to deforestation and coal is a non-renewable resource. Tobacco curing is responsible for a considerable amount of environmental degradation (Deangelis, 2007). In Zimbabwe the use of biogas has been popularly common in schools, prisons and livestock farms. Hence the prospects of using it as an alternative renewable energy source in the curing of tobacco. There are many factors involved in the biogas production process and also the curing process hence more focus is required to determine whether the current technology could enableeffective curingof tobacco with biogas from an economic and technical perspective; as well as coming with optimized digester and barn combination.

2. Background
Tobacco is a product from curing leaves of the tobacco plant (Nicotiana tabacum). Its main uses are in the manufacture of cigarettes and also an additive in some medicine (Oppenoorth, 2014). The curing process is energy intensive and results in the drying, coloring and flavoring of the tobacco leaf. Tobacco farming is crucial to the Zimbabwean economy, as it is a major foreign currency earner.In 2016 alone total export proceeds amounted to $933.7 million at an average price of $5.67/kg (TIMB, 2016). However it is not without its own challenges according to the Forestry Commission, 15% of annual deforestation in Zimbabwe is due to tobacco related activities(Mwareya, 2014). To mitigate this production of biogas could be produced from anaerobic digestion of organic material through thebiological break down of organic matter in the absence of oxygen(Ndhlovu, 2017). Biogas is mainly composed of methane and carbon-dioxide. The use of biogas as an alternative energy sourcehas recently become popular with farmers and schools attempting the venture. Biogas is described as a low cost clean

energy option due to its many environmental benefits and the fact that it is produced from waste material(REA, 2017).

3.Literature of biogas use in tobacco curing barns

Biogas is produced from the breakdown of organic material in the absence of oxygen. The gas is mainly comprised of methane gas and carbon dioxide. The percentage of methane in biogas varies, 45-70% (Karlsson *et al.*, 2014) depending the type organic waste used to produce the gas and also temperature at which digestion occurs among other factors (Dobre Paul, Nicolae and Matei, 2014; Paramaguru *et al.*, 2017). Methane is the desired constituent of biogas andcalorific value of biogas is dependent of the methane content. Biogas has many uses from lighting, heating, electricity generation to refrigeration.

Figure1 Complete layout of tobacco curing using biogas

The main areas of usage are heating and production of domestic hot water and electricity. Other form of utilization is that the biogas, after cleaning and enrichment can be injected into natural gas network and supplement energy needs. Enriched biogas can also be usedto fuel motor vehicles and can be directly added into natural gas pipelines for household use (Svensson, 2013). The enriching process includes separating contaminants and removing non-combustible constituents. The end result is biogas ofmethane content in the range of 95-97% which is a very effective as a fuel(Nagy and Wopera, 2012).

3.1 The biogas production process

Biomass is biological material from living or recently living organisms. Biomass can be broken down by enzymes from bacteria and other micro-organisms. When this conversion occurs in the absence of oxygen methane gas among others is produced after a number of complex chemical processes which are hydrolysis, acidogenesis, acetogenesis and finally methane production.The hydrogen and carbon dioxide produced during acetogenesis and syntrophic acetate oxidization are subsequently converted into methane by hydrogenotrophic methanogens(Moestedt, Malmborg and Nordell, 2015) The process is illustrated below in Figure 2

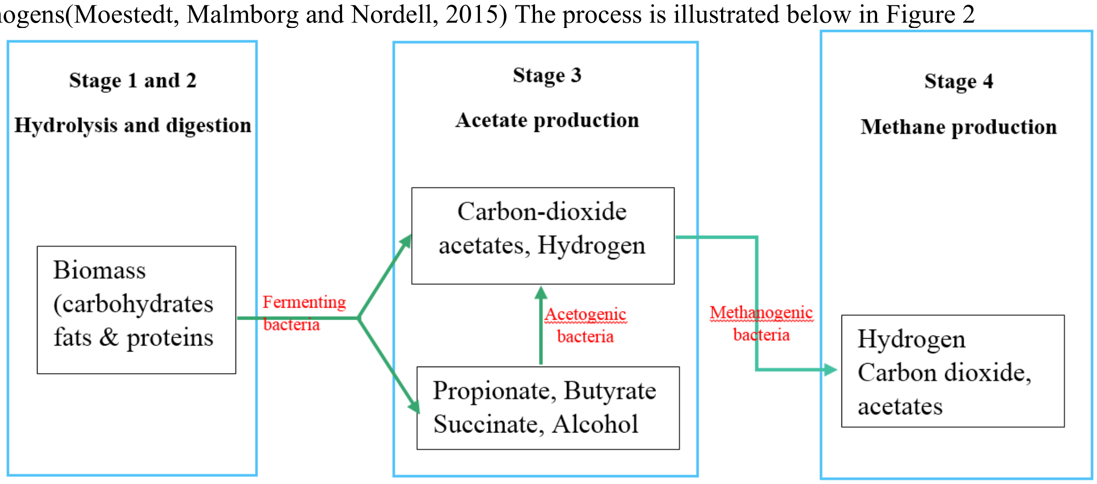

Figure 2 Methane production stages

3.1.1 Biogas digester

A methane biogas digester is basically a mechanical stomach that facilitates the breakdown of organic material in the absence of oxygen with the aim of producing biogas which is a flammable gas and another byproduct bio-slurry which can be used as a fertilizer. The fixed dome digester is most common type of digester (Den Liangwei, 2016) is characterized by the iconic dome or hemispheric shape at the top. This dome is to be made leak proof and seamless for effectiveness. Its four main components are combined thus the gas storage, fermentation tank, the inlet pit and the slurry pit. In practice, digesters are built partially underground to help maintain the warm temperatures required for anaerobic digestion with variations of ±2º (Samer, 2012). The fixed dome digester is simple in construction and operation as can be seen on the sectioned illustration in Figure 3.

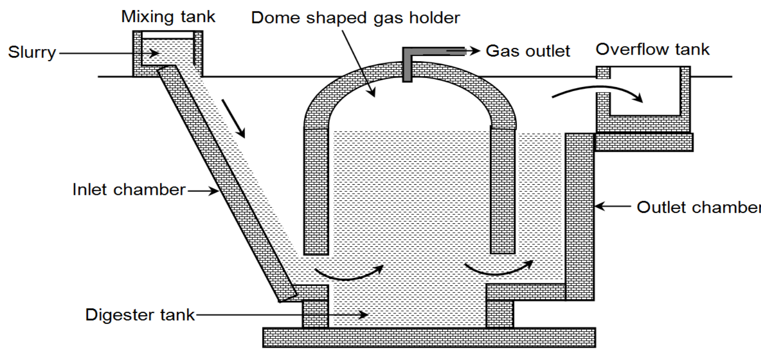

Figure 3 Fixed dome biogas digester schematic

The factors to be considered to improve the yield of biogas entail nutrients, pre-treatment and temperature:

*Nutrients:*The production of biogas depends on the growth of microorganisms which require certain nutrients to survive and therefore it is a necessity to supply these at the right time and in the correct amounts to get the most favorable growth of the bacteria to obtain efficient biogas production. There are nutrient dosing plans available from various suppliers to provide relevant substrates to maximize biogas output of biogas produced by increasing the growth metabolic activity of bacteria.

*Pre-treatment:*To be effective in a chemical process most solids require some preparation like grinding or cutting and dilution to make them before feeding into digester. Also wastewaters and different types of sludge from industries and municipalities might need pre-treatment before anaerobic digestion removing impurities that can harm useful bacteria. Types of pre-treatment include ultra-sonication, irradiation, sterilization, ozonolysis and pre-hydrolysis(Karlsson *et al.*, 2014).

*Temperature:*Anaerobic digestion is affected by operating temperature, can be worked in two phases, first mesophilic response temperature regularly kept up between 30-40°C and thermophilic response with operating temperatures ranging between 40-55°C. Thermophilic bacteria are able to create more biogas as compared to mesophilic ones but the temperatures required to sustain a thermophilic environment require an external energy source which affects the efficiency of the whole system therefore most texts recommend biogas digester operation in the mesophilic range.

3.2 Tobacco curing process

The ultimate goal of tobacco is to bring the leaf to a desired state without sacrificing its potential quality present at harvest. The curing process takes between 5 to 7 days (Sumner and Moore, 1993). Uniformity of the harvested crop is vital to ensure the whole batch of tobacco leaves are affected in the same way by the induced curing environment. There have been many advances in making barns more efficient through the use of insulation such as in bulk barns or more efficient firing methods and advanced air distribution techniques such as in the Rocket barns (Munanga *et al.*, 2014). Figure 3 shows the general principle of a tobacco barn and air flow system.The basic principle of the tobacco barn is to create a uniform environment with the recommended temperature and humidity to affect the tobacco in the desired way.

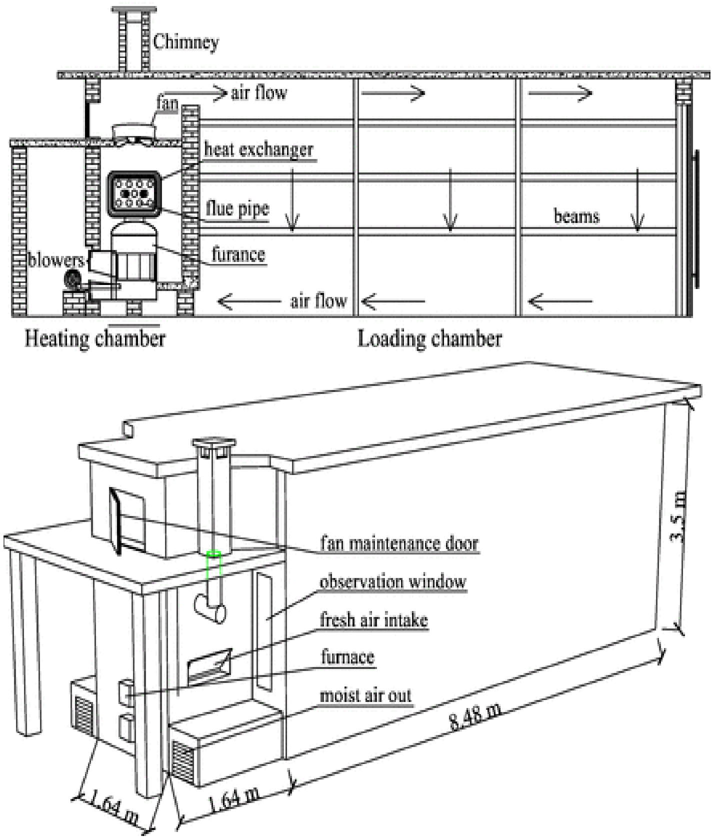

Figure 4 Schematic and isometric view of a tobacco bulk barn.

Tobacco curing can be divided into three distinct stages: yellowing, leaf drying, and stem drying.These stages are important and have to be followed meticulously to ensure the best quality cure. If drying is too fast or high temperatures are used earlier on, the leaf will be killed off too soon leading the green color remaining and a subsequent decrease in value of the tobacco crop on the market. A typical graph for the tobacco curing schedule is shown in Figure 5.

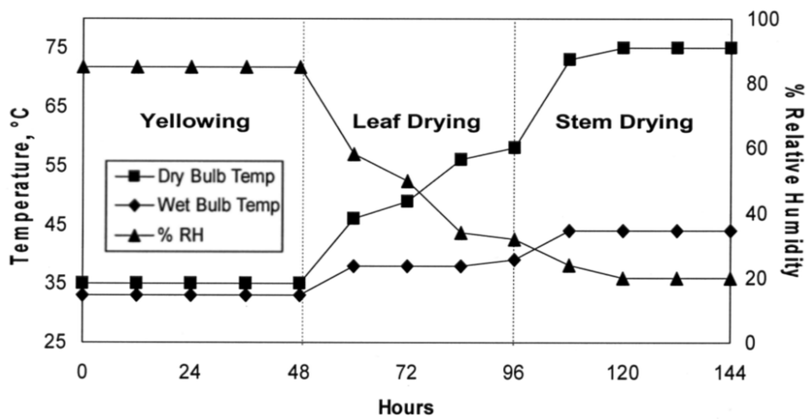

Figure 5 Typical curing schedule for flue curing tobacco(Deangelis, 2007)

Color has a very significant influence on flue-cured market value. A uniform yellow color assures the buyer that curing was done in the correct way and therefore acts as a sign of quality. However, the tobacco chemical quality is not necessarily dependant on the leaf color as various leaf compounds contribute more to the final smoke quality than the color itself.

3.2.1 Bulk tobacco barn

The operating principals for barns are reviewed and checked on if they can be retrofitted to use biogas. Bulk barns can be fabricated in one location and then assembled in another location, to make sure that the barn is made to certain standards and specifications. Bulk barns can be fired using a variety of fuels including coal, diesel, natural gas and LPG, the only difference would be on the type of burner used to provide heat. The two types of bulk barns are updraft and downdraft barns. The direction of airflow is determined by a fan that is placed strategically in the direction of heat flow from the furnace or burner. Hot air is forced up and as it comes in contact with tobacco being cured, it loses heat and becomes denser, and as more hot air is forced into the barn the colder air leaves the barn at the exhaust at the bottom, see Figure 6. The right side shows the pictorial views of a bulk barn when curing tobacco.

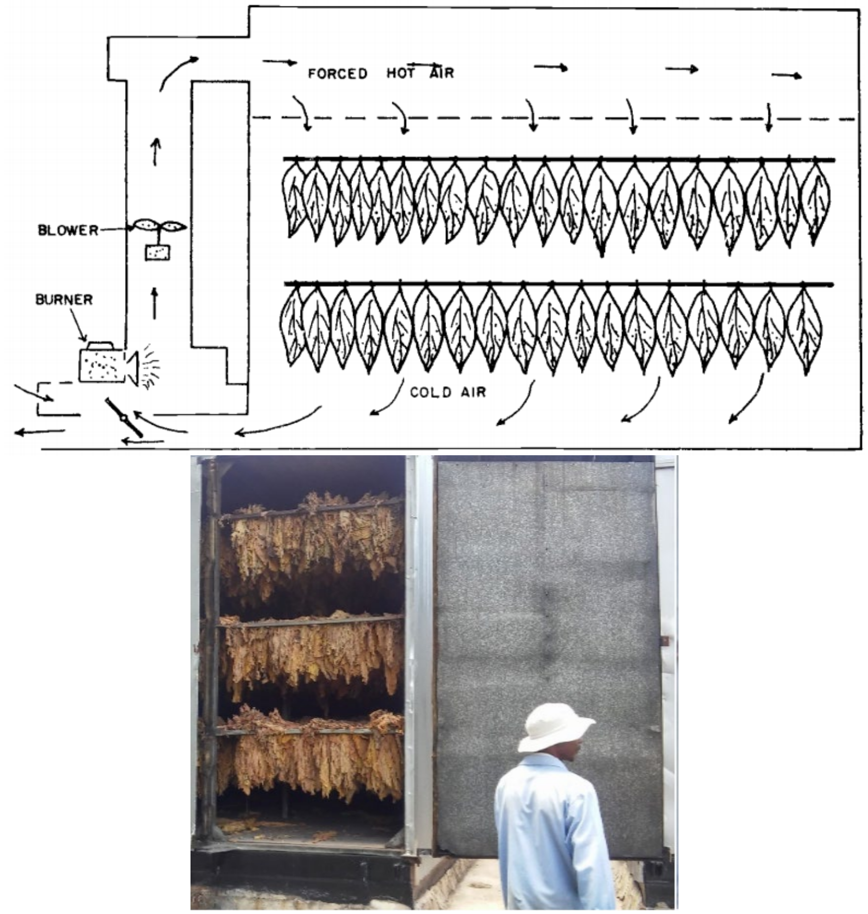

Figure 6 Downdraft bulk tobacco barn

Conventional updraft and downdraft barns utilize natural air ventilation to transfer heat from flue pipes to the tobacco leaves via convection in Figure 6. As the air is heated up by the flues it becomes less dense hence it is forced to rise though the tobacco. While the air rises it also loses the heat it would have gained and begins to move towards the heat source to be reheated. The bottom vents allow new air to enter the barn and top vents are for exhaust.

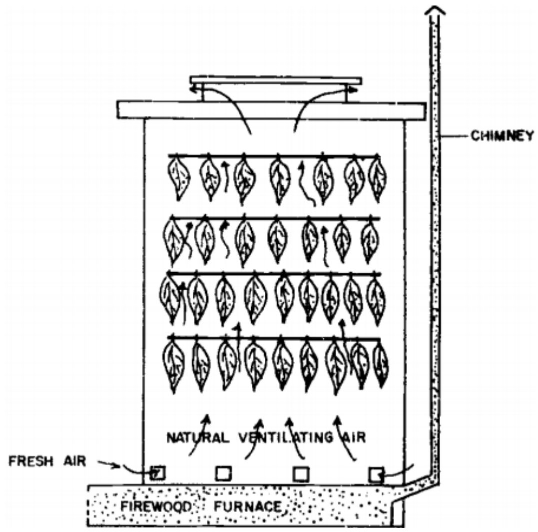

Figure 7 Conventional updraft barn utilizing natural ventilation to flue cure tobacco

Unlike its updraft counterpart, in order to reduce heat losses the ceiling of a conventional downdraft barn is insulated and allows no air to escape. Warm air is moved about in the barn by the use of a fan and a portion of the air is exhausted at the same time an equal amount of fresh air is drawn in. The drawn in and recycled air are reheated by the furnace which is usually coal fired and re-circulated with the help of the fan.

3.3 Biogas tobacco curing

The underlying principle of using biogas for tobacco curing comes from the fact that biogas can be used in place of liquefied petroleum gas (LPG) for different applications(Karlsson *et al.*, 2014). In order to make tobacco curing using biogas, possible limitations of biogas as compared to other fuels have to be addressed.As biogas is corrosive, it needs special burners that are corrosion resistant and as well as allowing for premixing before use.. For tobacco curing, the premixed burner type works very well with biogas as it offers a stable noiseless flame with uniform burning intensity (Harris, 2008). The size of orifice at the flame end of the burner depends on the pressure and velocity of the biogas. A premixed type burner is shown in Figure 8 below

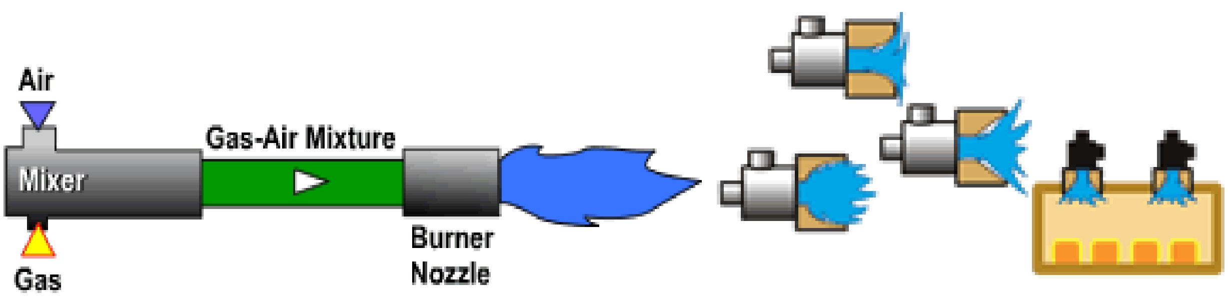

Figure 8 Premixed biogas burner sectioned schematic and require high heat flame

An effective premixed burner to effectively cure tobacco, it should produce a flat fireball and cone-shaped flames for high heat release in confined spaces such as the tobacco ban space. This biogas burner is made of stainless steel to as it is not affected by the corrosive nature of biogas impurities and it allows proper mixing of biogas with air. This type of burner removes the need to further purify biogas before burning it, making it ideal in cases where additional costs are not wanted. The main outputs of biogas tobacco curing are biogas and bio-slurry from the digester.

4.Methodology

The feasibility of curing tobacco using biogas was carried out using various research methods, collecting relevant qualitative and quantitative data. A feasibility study is the determination whether a proposed project is technically possible, and if it can be carried out within estimated costs (Rauhala, 2013). This definition holds especially from an engineering perspective where new technology has to be vetted as to its practicality before being implemented. Feasibility studies are very effective in predicting likelihood of success for any project, weighing the risk against the benefit of the project. A survey based approach was conducted with questionnaires and site visit interviews. Followed by technical evaluation, optimization and design of the biogas/tobacco connection, as well as drawing bill of quantities and costing to draw cost/benefit analysis in conjunction with the Zimbabwe Tobacco Research Board (TRB). For optimizing the system, the researchers modeled the chosen digester and tobacco barn using software such as AutoCAD and SolidWorks.

5.Findings

Firewood was the most common fuel for curing tobacco because it was cheap however it is a limited resource therefore there was need for alternatives. 80.1% of farmers who responded to the questionnaire use firewood only, the rest use a combination of both firewood and coal.The researchers targeted farmers in group settings such as training workshops at the Tobacco Research Board (TRB) or at the tobacco sales floor.

The correlation between amount of biogas resources available to a farmer such as livestock and the amount of tobacco produced is just about non-existent. From the collected data, average main resources per house hold are 8 cattle, 7 goats, 39 birds and 10 people. Others had outliers from the chosen population like ducks, pigs and rabbits.Farmers were also quick to point out that their tobacco yield can vary each season so there is need to account for this when sizing the digester. The average tobacco produced for the sample surveyed was 2.8 tonnes, which is the acceptable yield per hectare for a good farmer, as small scale farmer yield would range between 1.2 to 2.5 tons per hectare (Mutenga, 2014). Considering that the national average yield of tobacco is around 2000kg per hectare ((TIMB), 2016) and using simple proportion we get a curing capacity of 1.4 hectares for 2800kg, this is the tobacco that has to be cured in order to safely ascertain feasibility of the project.

6.Detailed design development

6.1 Tobacco curing barn

The chosen barn was the downdraft bulk barn which could efficiently cure 2.8 tonsor 1.4 hectares of tobacco (average from the research sample population of farmers). The typical bulk barn can cure$\pm$2 ha $\pm$1ha as stated in literature making it ideal for the capacity needed for this case. The main concept behind curing using biogas lies on its ability to be used on almost all applications that can use natural gas and LPG. The working principle of the bulk barn can work efficiently using a gas burner.The bulk barn is modular in nature thus if need arises it can be moved with relative ease, this opens up possibilities such as minimizing transportation costs between the barn and the biogas digester, this also means the system can be implemented where there are already existing biogas digesters with relative ease.

6.2 Biogas burner

In biogas tobacco curing a premix burner is preferred as it allows for better burning efficiency for high gas volume applications. Below is a labeled schematic for a premix gas burner

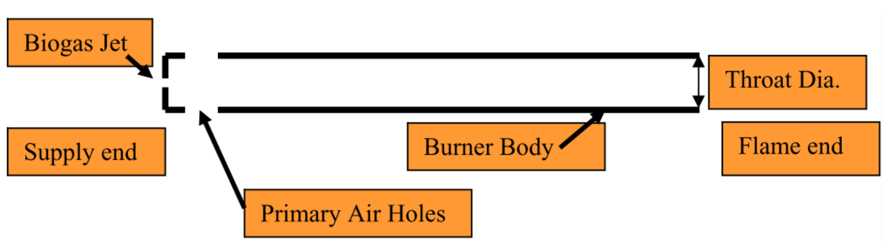

Figure 10. Premix gas burner

Biogas burners tend to have larger gas inlet and bigger throat diameter as there is need for more gas for biogas to perform as well as other gases.

Energy requirements
Maximum energy demand occurs at the final stage (stem drying), hence the design for the burner focused on that stage for the maximum design parameters (see Figure 5).Following the dry bulb temperature profile in Figure 5 the steepest section is found at the beginning of stem drying with temperature change from 55-74ºC thus a difference of 19ºC. Time taken for this change is 12hours as the graph has been divided in 12 hour sections to simplify the stages and temperature changes. Considering the tobacco curing barn as a room with dimensions 8m x 4m x 3m the energy required to raise the temperature by 19º C can be calculated.

Burner area is usually 10% bigger than the body making it 44mm diameter for the throat and primary air holes. Therefore, taking a diameter of 44mm we can decide how to distribute the area covered by the burner. The burner area can be utilised to bring about different flame configurations from a single large hole or distributed smaller ones thus for this case we need a flame that is distributed and uniform in a confined space to give the desired temperatures in the barn.Using tables we get a burner with 20 x 10mm diameter holes to cover the 1520mm^2 area covered by the burner. Thus **20 holes with a diameter of 10mm** are needed for the burner.

The researchers were able to model the proposed design for the tobacco bulk barn retrofitted with a biogas burner and heat exchanger in Figure 11.To understand how the barn works the side view has been labeled and the airflow illustrated

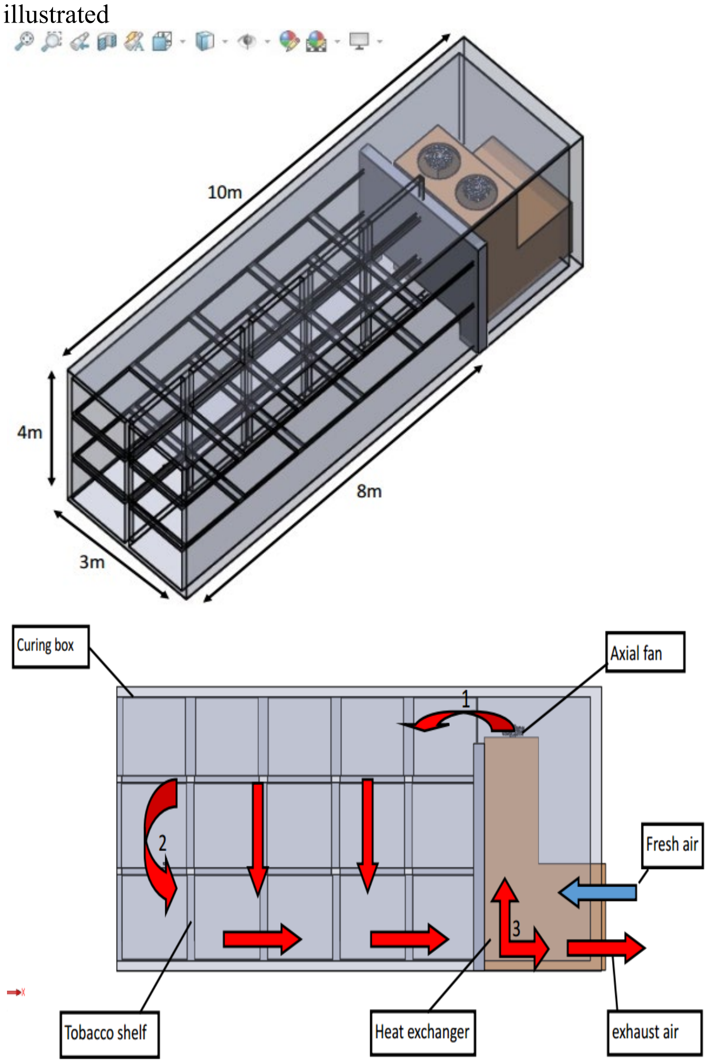

Figure 11 Model biogas fired barn during operation (with air flows)

The cycle starts as heated air is forced into the barn by the axial fans labeled on the diagram, the arrow labeled 1 represents the direction of flow of the heat as it enters the tobacco compartment of the barn. As the air circulates it is

naturally directed to bottom of the barn as it loses heat energy to the tobacco and becomes denser, it is also pushed by air coming from the heat exchanger. Arrow 2 on Figure 11 represents path of the cooler air as it moves to the exhaust of the system and is replaced by warmer air. At arrow 3 some of the air from the barn is recycled and is reheated while the remainder leaves the barn as exhaust air.This heat circulation cycle is repeated constantly during the curing process.
The tobacco section of the barn was modeled with tobacco leaves represented as semi-porous rectangular slabs uniformly packed within the barn. In this simulation heated air enters the compartment from the top left corner at the top of the cube and moves as explained from above, then it exits at the bottom left. The temperature profile at each of the three main stages, yellowing, leaf drying and stem drying can be seen In Figure 12 , the left shows the temperature distribution at the middle of the barn and to the right the temperature distribution at the edges.

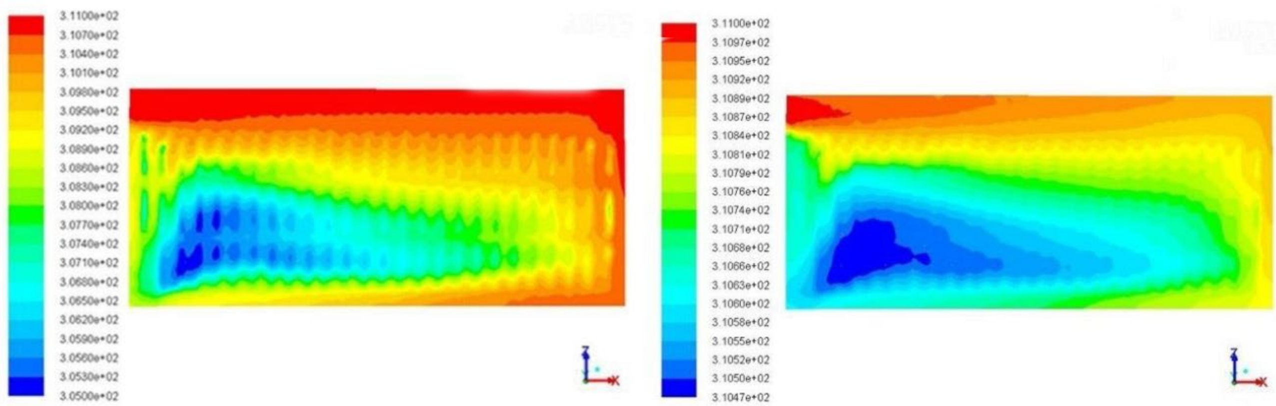

Figure 12(a) Yellowing

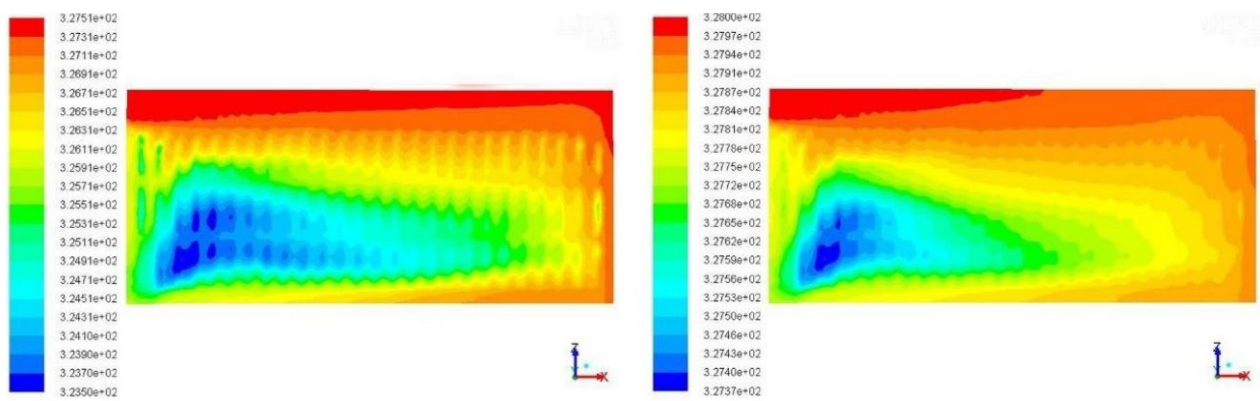

Figure 12(b) Leaf drying

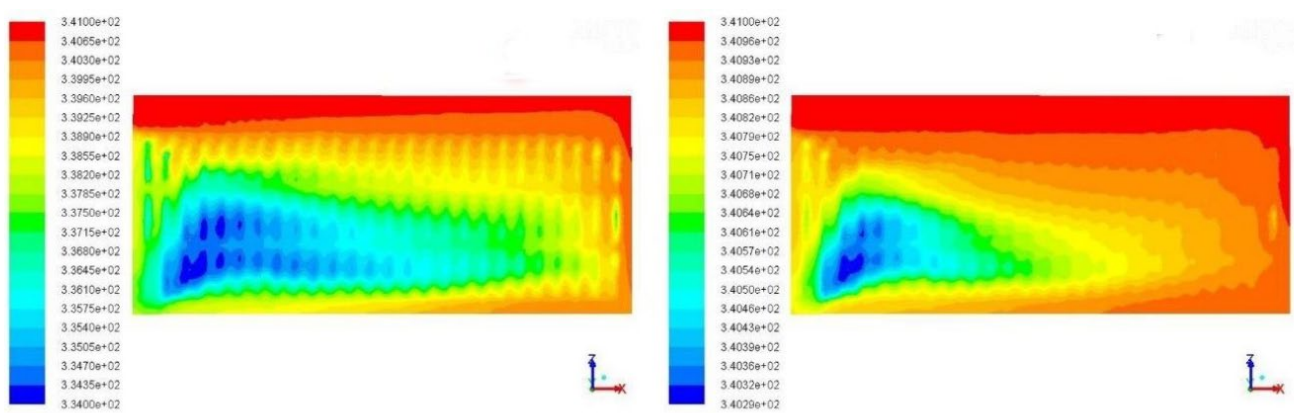

Figure 12(c) Stem drying

A very clear observation is a cold spot at the bottom of the barn during all curing stages - this is due to the contact of water vapor from the leaves with cooler air at the exhaust. For a perfectly cured batch of tobacco there may need to be some rotation of the tobacco or place the more ripe tobacco in the lower shelves as it takes less energy to cure. This profile is basically the same for all downdraft bulk barns and the effect on cured tobacco quality has never been raised meaning the effect is minimal to the end results of curing.

6.4 Design summary

Biogas digester size=12m^3
Biogas digester type=fixed dome
Gas produced per day=2.6m^3
Total biogas per year=948.9 m^3
Biogas required to produce 2.8 tons cured tobacco =1475.8m^3
Barn type=Bulk barn
Barn dimensions=3m x 4m x 8m
Biogas burner type= premix (stainless steel)
Burner flow rate of gas = 18.1 liters per minute at energy demand
Burner dimensions: Gas jet diameter= 5mm
Throat and primary air intake diameter=44mm
Area distribution = 20x10mm diameter holes

Biogas can be used to cure tobacco as it can definitely reach desired temperatures. The burner has been designed and it can be retrofit in an existing bulk barn as other bulk barns already use gas burners for curing tobacco curing. The biggest challenge to technical feasibility is that the amount of biogas required for this energy intensive process for the average farmer is much more than one can produce on a average farm area.

7.Recommendations

The need for renewable energy sources in the tobacco industry cannot be overemphasized, the industry is vital to the nation of Zimbabwe however it may be doing more harm than good in the long run. Beside biogas there are other energy options that can be used for curing tobacco in a sustainable manner and these include using solar energy and also firewood from sustainable sources. There have already been studies on the use of solar and efficient curing systems such as the rocket barn show the potential for a sustainable tobacco curing future. Combining either of these sustainable solutions will result in increased reliability of tobacco barns that use the technology for instance combining biogas and solar allows curing to occur even when there is no sun to supply solar energy as the biogas system can act as a backup. Such a system allows for minimal amounts biogas to be used thus ensuring that the supply will be able adequate in the case of the average tobacco farmer as defined by project research.

In order to generate enough gas, the most ideal solution would to be to have a biogas digester that can generate enough gas continuously such that curing requirements are met without much need for gas storage but such a digester would be uneconomical to build at best not to mention the biomass required to feed the digester would be too much for a single farmer. Thus, the researchers suggest having a combination of biogas digesters in a community connected to a single gas storage point which will be connected to the retrofitted tobacco curing barn. The system can be made active as the curing season approaches with farmers connected to this "grid" curing their tobacco for free and also getting revenue from other farmers who would use this eco-friendly barn. In order to make biogas tobacco curing a reality the researchers suggest a model in which the farmer can use half of the produced biogas per day at most. What this ensures is that the farmer also benefits from the installation of the biogas digester on a daily basis rather than collecting biogas all year for the curing season. This model however brings in possibilities such as using biogas to complete part of the process rather than complete the whole process. The remainder of curing can be achieved by using a hybrid system with other renewable forms of fuel such as biomass briquettes.

8.Conclusion

The survey study concluded the average tobacco produced by the sample of farmers to be 2.8 tons on a farm of 10 people with 8 cattle, 7 goats and 39 chickens.The recommended digester size for the average farmer was

12m^{3}producing 2.6m^3 of biogas per day. Suggested biogas storage option was having two 500m3 plastic bladder type storage units for the 949m^3 of gas produced per year.The amount of gas required to cure 2.8 tonnes was calculated to be 1475.8m^3 thus the deficit can be clearly seen therefore for the average farmer the gas produced was less than the gas required for curing the tobacco.The most important biomass resource was cattle as they were responsible for most of the gas produced per household.Cost of implementing a biogas tobacco curing system on an existing tobacco barn was calculated as \$144.54 /m^{3}of biogas digester designed. From the financial analysis all tests performed had positive results in terms of feasibility and profitability of the project.Financial benefits of curing tobacco using biogas included lessening the cost of buying coal and firewood for curing. It should be noted that the most important benefit of curing tobacco with biogas which is to save the environment does not have much direct financial benefit that could be calculated using the capital budgeting techniques applied in the financial analysis.

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Biography

Ignatio Madanhire graduated with a PhD in Engineering Management at the University of Johannesburg, South Africa, he is also a Senior Research Associate. He is also a Senior Lecturer with the Department of Mechanical Engineering at the University of Zimbabwe. He has research interests in engineering management and has published works on cleaner production in renowned journals.

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