Design of Thick Porridge Mixing Agitator for Commercial Kitchens

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Abstract
The research study looked at coming up with a cheaper design of a mealie-meal thick porridge agitator cooking process which could be used in commercial kitchens. The design was generated to handle the effective stirring as the porridge becomes thicker and becomes increasingly difficult to stir around. Agitator design concepts were generated and evaluated for suitability and robustness. A detailed design was undertaken to come up with a 200 litre capacity thick porridge agitator, which can reduce cooking time to 45 minutes after the boiling of the water. It has also to be fabricated and installed at a cost of less than USD5000.

1. Introduction
In today's modern kitchen different equipment has been designed with the aim to improve the process of cooking food (Taylay&Fransials,2004). In the region the preparation of thick mealie meal porridge has remained the same over the ages. The popular meal is mostly prepared manually though out a number of countries in Southern Africa. This has been observed to be a challenge when it comes to preparing the meal for a large numbers of people. At universities, hotels, boarding schools and hospitals in Zimbabwe, large volumes of thick porridge are consumed per day since it is the staple food. Regardless of the large consumption, the process is still done manually, and kitchen staff use long flat wooden poles to mix when preparing the thickened porridge. This type of work is usually done by men rather than women because a lot of upper body strength and stamina is required. As such cooks often take turns or use two poles to speed up the process of preparing the porridge. The conventional way of preparing thick porridge was found to be long, tedious and laborious and inadequately hygienic. Hence there is need to improve the quality and process of preparing thick porridge in an enclosed environment to minimise external contaminating factors for bulk food preparation. The design of a mechanical agitator would go a long way in assisting with the mixing and as it would reduce human effort required when preparing thick porridge particularly in a commercial set up environment.

2. Justification
The agitator would continuously mix the mealie meal throughout the whole cooking process to achieve improved heat transfer and reduce inconsistency of the thick porridge within the container. Other than ensuring uniform consistency throughout the large pot, the agitator would create the required convenience in reducing meal preparation time for other pressing activities. This would be enabled by improved the heat transfer throughout the material contains as heat is evenly distributed from the top to the bottom of the pot. The entire process of preparing of thick porridge is done under a closed pot to avoid any contamination while cooking. A number of countries in the Southern Africa Development Community (SADC) region may be interested in using this agitator cooker design if it to be commercially available.

3. Thick porridge preparation review

3.1 Preparation process

The crucial process when preparing thick porridge entails first simmering of thin, final thickening and final simmering. The first simmering is the most critical stage to preparing thick porridge. Thick porridge is a bad conductor of heat. So heat is transferred into the cooking mixture mainly through convection currents (Jeane & Ashkenazi, 2011). Convection currents are only possible when the mixture is still runny, most of the cooking happens at this stage for better taste and smell. The stirrer must insure that the mealie meal does not sit at the bottom of the pot. This happens when the fluid is not yet homogenous, (Berg, 2007)and the solid particles are heavier and tend to fall to the bottom of the pot. The porridge should maintain a uniform consistency to insure even cooking and heat transfer by conversion. If this stage is compromised in any way, the result is ungelatinized or uncooked thick porridge. Also when the porridge is not properly cooked it will not thicken properly and will form lumps and will not hold together as a homogenous fluid. If proper stirring and cooking is done the final stage of thickening is easy maize meal added in the final thickening stage gives the porridge its body. The thickening process is challenging because large amounts of toque are require to mix and stir the fluid around. This is where more energy is required used because the fluid is elastic and sticky strong forces oppose every motion round the pot.

There are two main methods used to prepare thick porridge which are the manual and the automated methods. The manual method is the most common one in family set ups and in boarding schools, while the automated method is mostly used in commercial kitchen for large number of people. The preparation of thick porridge is still done manually at most institutions regardless of the number of people to be served.

3.2 Manual method

The major components of available cooking equipment are an oil jacketed kettle and a stirrer. The 200 litre kettle is made of two pots one mounted inside the other with an oil layer lying between the two pots. Heating element raises the temperature of the oil as it circulates between the two pots. By conduction oil simultaneously heats the inner pot, and as the temperature of oil increases so does the inner pot surface. The stirrer is incorporated to mix boiling water as well as breaking the lumps which are formed when mealie meal is added to boiling water. It also ensures that mealie meal paste does not settle at the bottom of the pot but remains in suspension. So the stirrer is used to insure uniform consistency throughout the pot. The process of making thick porridge using this equipment entails boiling 200 litres of water in an oil jacketed kettle, only then can 20 litres of cold water mixed with 20kg of mealie meal to form a paste is added to the boiling water in the kettle. The solution is stirred continuously using the stirrer for 10 minutes until no lumps or agglomerates are present in the pot. Now the porridge is left to simmer for 30 minutes. Another 20kilograms of mealie meal is added in small parts over a period of 20 minutes, while mixing the mealie meal into the porridge until it reaches the required thickness. The thick porridge is further left to simmer for at least 5 minutes before being served. Thus the whole process including necessary preparations takes over 2hours to make thick porridge manually. Although less electricity power is used, there is room for improvement in terms of time taken and possible convenience to users.

3.3Automated method

The only known such machine to automatically cook thick porridge without human assistance was developed by William Gwata. In subsequent years a smaller version was developed with a smaller capacity (Gondo 2015).The equipment entails maize meal dispenser, pot, agitator and electronic control unit. The mechanism has a screw conveyer at the bottom of the holding container, which pushes the mealie meal from the dispenser to the pot depending on the stage in the cooking cycle (Gondo, 2012). The pots use steam heating system where hot steam passes between the mounted two pots of the kettle. The steam takes only eight minute to bring 500 litres of water to boil. The pot comes fitted with a steam boiler unit. The steam on contact with the inner metal surface of the pot condenses, thereby having latent heat transferred from the steam to the inner pot bring the inside water or porridge to boil quickly. The agitator is directly above the pot and used to mix the water and the porridge until it is uniform and homogenous. A motor driven impeller is used to mix in the thick porridge in the closed pot. The impeller is connected to the shaft through a couple which can easily be removed for easy cleaning.

The control unit is used to initiate the cooking process and monitor all the stages of the cooking cycle from start to finish. An administration screen allows the operator to see the process as they occur as they are displayed (Gondo, 2015). Once the parameters are set the cooking process can begin and they cannot be changed mid-way through the

cycle. Different sensors in the pot allow the controller to motor the cooking process. These include temperature sensor, a viscometer and timer this all come together to ensure a good product. It controls the motor of the screw conveyer to get the right amount of mealie meal into the pot at the right cooking stage. A timer is used to set the time for the first and second simmering and also the length of every cooking stage. It also controls the speed of the agitator

The process for making thick porridge using this equipment entails pouring mealie meal into the dispenser and three ¾ of required water into the pot before any cooking is done. The machine is started and it takes 10minutes to bring the water to a boil using steam jacketed pots. When water reaches 80^{o}C, the screw conveyer feeds the maize meal directly
into the pot while it is closed. After enough mealie meal is added the screw conveyer is stopped by the controller. The porridge is mixed continuously by the impeller as it simmers. After 30 minutes the control system starts the screw feeder again to add more mealie meal while the impeller mixes the porridge. The speed of the impeller is automatically controlled depending on the thickness of the porridge. Once the required thickness is reached the screw conveyer is stopped, and the thick porridge is left to simmer for 10 minutes.

While this equipment is an efficient and fast method of preparing thick porridge, it is also easy to use and only takes 45 minutes, which is very convenient; the piece of equipment cost about USD40 000 plus additional cost for steam unit. It requires a lot of high grade electricity and the machine is sophisticated hence it has been used in very industrial area where there is 3 phase(Gondo2012).

3.4 Challenges in preparing thick porridge

The main challenge in the development of a thick porridge cooker is the properties of mealie meal which is used to prepare it. Dry maize is not wettable that means it does not easily mix with water. Vigorous mixing is required for the meal to mix well. Hot water seals and stabilizes the lumps causing agglomerates to form making them difficult to disperse, break or mix (Owens, 1969). But, lumps in cold water are less stable and easy to disperse. That is why cold water is used to make a paste first before adding the solution to hot water in the manual method of preparing thick porridge. However in the automated method this is not necessary as the agitator is powerful enough to disperse and break any lumps that form (Gondo, 2012). Cooking thick porridge require a lot of mixing and stirring because the mealie meal as said does not easily mix with water. High toque mixing is also required to in the final mixing stage of the cooking process hence high power is needed to successfully mix the porridge. Precise designing of the impeller, motor size, and speed regulator has to be done to ensure that the mixer will successfully mix the porridge and will not get over powered or fail to break the agglomerates and the lumps. All this has led to the preparation of thick porridge remain relatively manual in most parts of the country. Therefore there is need to develop a cooker that is cheaper to maintain and repair at a very low cost.

4. Materials and methodology

Three possible solutions were generated and, a binary dominance matrix analysis was conducted to select the solution which closely met the agitator requirements. During the analysis these attributes were used to establish price, ease of manufacture, stability, ease of operation, ease to repair, functionality and applicability. Stress analysis is done on the machine and von Mises analysis was done to prove that the machine would work also using Solid works 2016. Finally by use calculation of ANSYS would analyze the fluid dynamics throughout the mixing process. This software was also used to do vibration analysis of the machine. Experiments were done to determine the density of thick porridge (between 150 and 160 Pa).

5. Detailed design

The cooker design comprises of a portable cooker (Figure 1), with top which allows the agitator into the kettle. Also the agitator pot has opening in which mealie meal can be added without opening the pot. The agitator is mounted to a frame which is on wheels. The agitator can be raised or lowered by a power screw into the pot. During operation the agitator is placed into the water, lid closed. Water is then heated to appropriate temperature. The agitator is started and mealie meal is added manually through the other opening. When enough mealie meal is added the opening is closed and the agitator is left to mix the mealie meal through the water for 30 minutes. Then the opening is closed and the more mealie meal is added to the pot through the opening and then closed. The agitator is left to thicken the porridge to for 10 minutes.

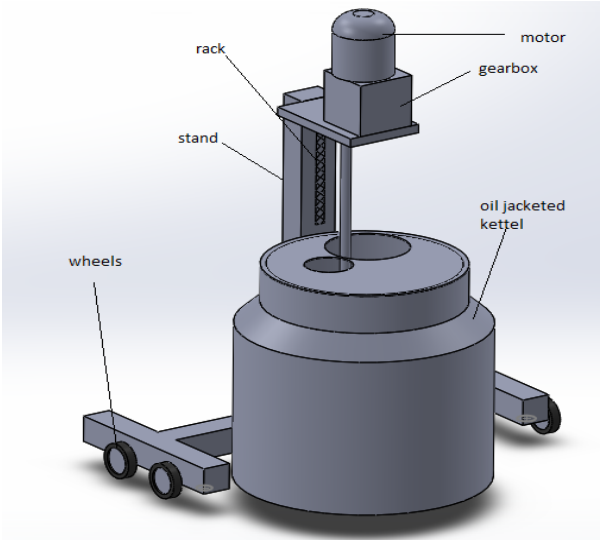


Figure 1.Portable cooker design

The major components of this design entail a power screw to move agitator up and down, helical impeller, gear box and mobile stand. The design is cheaper, and it requires less manual work from the operator, it saves time and can be adapted for use in multiple pots. Although not manual it is not fully automated and requires use electricity.

5.1 Impeller

The agitator has to stir dry mealie meal into the hot water and to thicken the porridge, as well as to improve the heat transfer in the cooking kettle so as to reduce the cooking time. With the viscosity of thick porridge ranging from 25Pa up to 200Pa, the impeller has to mix through the whole fluid. It must provide high axial force to prevent the mealie meal particle from settling at the bottom of the pot. Helical ribbon impeller is the selected impeller (Figure 2)..

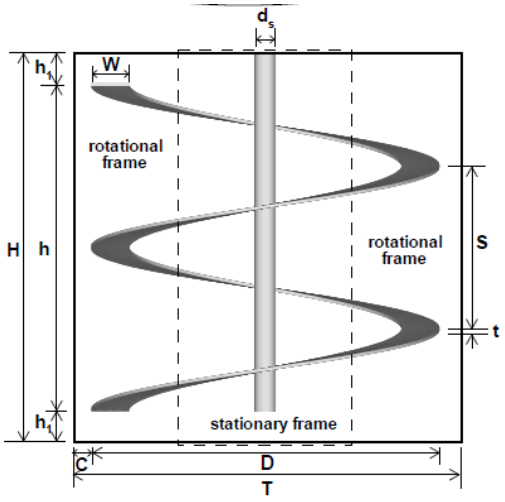


Figure 2. Helical ribbon impeller

For a standard commercial 200 liter jacketed kettle, using tables of diameter, 0.85m and height, 0.8m; the helical impeller diameter was established to be (D_i) = 0.8m. And clearance (C) = 0.85-0.8=0.05m; with width of impeller (w) = 80mm. Pitch of the impeller (p) = 0.8m, with height of the impeller H = 0.72m. Finally the blade thickness (t) = 5mm.

Since the impeller is to be used in a food industry where contamination is of concern the impeller blades and shaft are to be made of Stainless Steel 304.

5.2 Power required

The impeller power required by the impeller is supplied by the motor. The motor power supply to the agitator must be able to mix mealie meal in hot water first and then thicken the resulting porridge to required thickness. To properly mix the mealie meal the impeller must rotate with enough speed to prevent the particle to settle at the bottom of the pot. To do this Zwittering equation can be used. This gives the minimum stirring speed at which no mealie meal particle will remain stationary on the kettle base for more than 2 seconds. For the agitator to reduce the cooking time the mealie meal should be mixed throughout the whole fluid under a 5 minutes to improve from cooking manually which take more than 10minutes. Grenville equation is used to find the speed of the impeller in order to achieve this mixing time.A 3 horse power motor is required to successfully mix 200 liter of thick porridge. The motor provides more than 2kW and, it has to be light weight and uses single phase power. The selected motor specifications are:

Power	: 3Hp
Voltage	: 240V
Size	: 40Kg
Poles	: 4
Frequency	: 50Hz
Phase	: Single

5.3 Agitator shaft

The shaft is made of Stainless Steel 304 and diameter of the shaft should be 52mm. The muff couple is used to join the impeller to the drive shaft. Then the suitable key is also design.

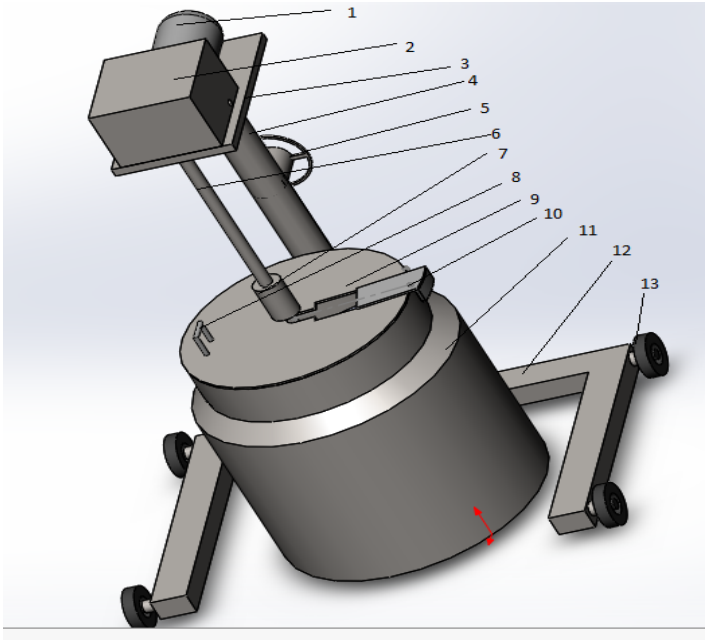
5.4 Gear box

The system needs a reduction system to reduce the speed from 1500rpm to 20rpm. This should be done on a very limited space. VR of the gear box is to be 60. Design of the first reduction step is a worm to gear configuration reduction .The parameter speed of worm 1500 from the motor, and required reduction ratio is 20:1. Power supplied is 2200W

5.5 Power screw

The design has to lift a lift 3hp motor of approximately 30kg and gear box also about 30kg .
Stand approx. 20

The final configuration of the detailed drawing is given by Figure 3 below, with all the parts shown.



1-3hp motor; 2-gear box unit; 3-top stand; 4-holding stand; 5-lifting wheel; 6-connecting shaft;
7-muff coupling ; 8-handle; 9-lid; 10-slider ; 11-jacketed pot ; 12-bottom stand; 13- wheels

Figure 3.Detailed drawing solid works

The cost of making the portable thick porridge cooker is USD1940.

6. Recommendations

The slider is used to allow for required mealie meal to be poured into the pot , as it is used as the closing and opening mechanism. Once the thick porridge is ready the lid is opened and the impeller is lifted from the kettle using a stirring wheel connected to the power screw. The impeller is separated from the muff coupling and is washed immediately. The stand which carries the agitator can be pushed to a secure corner or another kettle for cooking another pot. Although this design is keen to improve the preparation of thick porridge using a simplified cooker which is not necessarily automated, there is room for further development. This can be done on the stability of the stand when cooking, this can be done by installing belts which runs from the back of the stand to the front of the kettle .This will ensure that the vibrations are reduced due to damping and also the unit is solid and stable.

7. Conclusion

The design study was based on the fluid mechanics theory, design principles to available agitators and cooking methods already being used in the commercial kitchens. It also took a look at the agitator components, mechanism and power sources in the design process. The use of the thick porridge agitator concept can be a valuable design and will go a long in savings on labour required and time taken in the preparation of the meal for public entities. Limited research has been conducted in improving the method of preparing thick porridge however with the help of this design there is hope that other designers can take up this challenge and manufacture a more efficient and cost effective thick porridge cooker.

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Biography

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

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