SUSTAINABLE FISHERIES MANAGEMENT PROJECT (SFMP)

Continuous Technology Development on Low PAH Stove Ahotor Oven

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Cover photo: Practical training of stove builders on low PAH stove in Tema harbor (Credit: SNV)

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ACRONYMS

BaP	*Benzo(a)pyrene*
CCM	Centre for Coastal Management
CEWEFIA	Central and Western Region Fishmongers Improvement Association
CHF	Cooperative Housing Foundation
CRC	Coastal Resource Center
CSIR	Council of Scientific and Industrial Research
CSLP	Coastal Sustainable Landscape Project
DAA	Development Action Association
DAASGIFT	Daasgift Quality Foundation
DFAS	Department of Fisheries and Aquatic Science
DMFS	Department of Marine Fisheries Sciences
DQF	Daasgift Quality Foundation
EU	European Union
FAO	Food and Agricultural Organization of the United Nations
FRI	Food Research Institute
FtF	Feed the Future
GIFA	Ghana Inshore Fishermen's Association
GIS	Geographic Information System
GNCFC	Ghana National Canoe Fishermen’s Council
HM	Hen Mpoano
ICFG	Integrated Coastal and Fisheries Governance
MESTI	Ministry of Environment Science and Technology
MOFAD	Ministry of Fisheries and Aquaculture Development
NDPC	National Development Planning Commission
NGOs	Non-Governmental Organizations
PAH	Polycyclic Aromatic Hydrocarbons
SFMP	Sustainable Fisheries Management Project
SMEs	Small and Medium Enterprises
SNV	Netherlands Development Organization
SSG	SSG Advisors
STWG	Scientific and Technical Working Group
UCC	University of Cape Coast
URI	University of Rhode Island
USAID	United States Agency for International Development
WARFP	West Africa Regional Fisheries Development Program

TABLE OF CONTENTS

CONTENTS

LIST OF FIGURES

LIST OF TABLE

1.0 BACKGROUND

The Sustainable Fisheries Management Project (SFMP) being funded by USAID seeks to rebuild marine fisheries stocks and catches through the adoption of responsible fishing practices. The project contributes to the Government of Ghana's fisheries development objectives and USAID's Feed the Future Initiative. The Coastal Resource Center (CRC) of the University of Rhode Islands (URI) is the main implementer, working with international and local partners, including SNV Netherlands Development Organization.

The Sustainable Fisheries Management Project is implementing a number of interventions along the coast to contribute to its bigger goal. The Fishing Community Livelihood Development Value Chain and Post-harvest Improvement Program is one of the interventions that seeks to improve upon post-harvest activities in fisheries sector by promoting the production of quality and safe smoked fish for the Ghanaian market.

The most popular fish smoking technique in Ghana, the Chorkor stove has some limitations that deserve greater attention in order to significantly improve small-scale fishers' livelihoods and respond effectively to product safety challenges – especially linked to controlling contamination by polycyclic aromatic hydrocarbons (PAHs), which is a public health hazard. PAHs are carcinogenic, fat soluble, nonvolatile and extremely persistent, and develop especially during the incomplete combustion of organic materials. Globally, PAH levels in food are monitored by regulatory agencies with a combination of four compounds (PAH4) being of specific interest: benz[a]anthracene, chrysene, benzo[b]fluorantene and benzo[a]pyrene. Under EU food standards, the level of PAH4 in smoked food products should not exceed 12 µg/kg and for benzo[a]pyrene (BaP) 2 µ/kg.

Although the high PAH levels found in Ghanaian smoked fish present a potential danger to the health of the population, the definitive effect at the macro level is not yet established. In addition, the traditional smoking process, comprising preservation, flavoring and coloring - is expected to continue as these constitute an important part of what the consumer values in the product. Hence the focus should be on developing and deploying new types of low-PAH fish smoking stoves that are energy-efficient, low cost and made with local materials.

Subsequently, a series of stove models were developed and tested for PAH levels. One key element of this process was the development of the downdraft technology – a fired-brick combustion chamber that allows for the use of a small but efficient fire, the combustion gases from which are then pre-mixed with a larger flow of clean air, to give a faster flowing but cooler gas stream at an optimal temperature of ~120°C (250°F). This is then used to smoke/dry the fish in conditions that prevent the formation of high PAH levels. However, the downdraft design is very cumbersome and complicated to construct. Also, although it is easy to operate, using it could be quite frustrating due to high temperature gradient in the smoking chamber which disallows uniform smoking in the combustion chamber, causing only the fish at the upper part of the chamber (top 4 trays) to receive enough heat for smoking whereas fish at the lower part of the chamber will not smoke at all. The only way to get the fish at the lower part of the chamber to cook is by moving it upwards.

To address this challenge, the Ahotor oven was developed as a retrofit of the Chorkor stove to reduce PAH levels in smoked fish and smoke exposure to stove users as well as resolve the lack of uniformity in smoking observed with the downdraft designs. The Ahotor oven comprises of a combustion chamber fitted centrally to a Chorkor – like an outer shell, with fish processing trays above as in a normal operation. It can be either a retrofit or a new-build, with the latter made from sandcrete blocks and cement, in single or multiple unit models. Above the combustion chamber, a prefabricated fat collecting tray is fitted that allows the hot gases to flow up through to the fish while preventing any fat etc. from dropping down into the fire. The Ahotor technology is simple, easy to build, functional and user friendly.

During the second half of 2016, the Ahotor technology was piloted in the coastal regions of Ghana for end-users experience and feedback. Between 16th and 20th January, 2017, a beneficiary satisfaction survey was conducted to gather feedback from stove users on performance, user friendliness, energy savings etc. These findings together with existing information on energy and PAH assessment were analyzed for review. A technical review committee evaluated the end-user feedback and proposed improvements to the Ahotor technology.

This report thus documents the procedures and results of the continuous technology development work.

1.1 Objectives

The objectives of this assignment were to;

- Review beneficiary satisfaction report and propose improvement options.
- Review the stove designs for improvements
- Improve the Ahotor technology to reduce PAH levels and fuelwood consumption.
- Conduct tests to verify and confirm improvements and PAH results on the technologies.
- Promote the improved stoves to beneficiaries

2.0 AHOTOR OVEN PERFORMANCE EVALUATION & USER FEEDBACK

A comprehensive stove performance assessment and beneficiary satisfaction survey was carried out on the Ahotor oven. The main objective of this exercise was to receive inputs from end-users for stove performance improvement. Thirty (30) fish processors having both Ahotor and Chorkor oven were interviewed across eight communities; Elmina, Apam, Winneba, Mumford, Moree in the Central Region, Anlo Beach, Takoradi and Sekondi in the Western Region.

Using questionnaires, the various components of the ovens and its functions were investigated in relation to user experience and satisfaction. Also, user comparative assessment of the Ahotor oven to the Chorkor stove in terms of cooking time, fuelwood consumption, flexibility among other indicators were investigated.

Findings

Respondents provided comments on the stove's performance relative to two indicators, namely; **GOOD ENOUGH and NEEDS IMPROVEMENT**. Whereas GOOD ENOUGH means the current levels are acceptable and should be maintained if not improved, NEEDS IMPROVEMENT required technical review of the technology to enhance or improve the current performance.

Good Enough

The plate 1 below outlines performance factors respondents consider to be good enough and should be maintained.

Plate 1

Positive feedbacks

- ✓ It saves fuel – respondents said they use about two thirds of what they use for Chorkor
- ✓ Smoke emission is drastically low
- ✓ The smoked fish has a more attractive and healthy appearance, unlike the highly smoky appearance of fish processed with the Chorkor stove
- ✓ Operators experience less problems with eye irritations, making the stove very user friendly
- ✓ Less burns and accidents are experience because the walls of the stove do not heat up intensely. Respondents are protected from excessive heat as the combustion chamber conserves and shields the heat
- ✓ The fish has a more delightful taste
- ✓ Products from Ahotor oven has a higher market value
- ✓ Less heat is emitted to the immediate environment
- ✓ When stove is pre heated, it cooks faster
- ✓ It dries the fish better than the Chorkor

Needs Improvement

The second indicator captured end-user feedback regarding issues that required technology improvements. With their rich experience from the use of the Chorkor oven, all factors that is below the performance of the Chorkor oven is considered sub-standard. End-users made further recommendations and improvement suggestions for consideration in order to increase the user acceptability and adoption. Plate2 below outlines the factors that requires technology improvements.

Plate 2

Corrective feedbacks

- ✓ The Ahotor takes longer time to smoke fish than the Chorkor
- ✓ The Ahotor has low capacity (volume) as compared to the Chorkor stove.
- ✓ There is an uneven heat distribution resulting in uneven fish smoking. The fish in the middle part of the oven does not receive enough heat for cooking in time.
- ✓ The stove needs to be pre-heated in order for fish to smoke in time
- ✓ Additional effort is required to keep the fat-collector clean.
- ✓ Where the fat collector is not cleaned before being used again, it produces smoke.
- ✓ The fat-collector has sharp edges and can cut during cleaning.

Improvement Suggestions

- One heat injection hole should be created at the center of the fat-collector to enable enough heat uptake.
- The hood should be secured against rodents and other pests.
- The firewood entrance is too small and should be opened up a bit.
- The height of the base of the Ahotor oven is quite higher than Chorkor; it should be reduced

2.2 FIRST TECHNOLOGY REVIEW MEETING

Following the Ahotor oven performance evaluation & end-user feedback, a technology review meeting that assembled key post-harvest stakeholders and stove experts in Ghana was held to review the outcome of the beneficiary satisfaction survey and to generate ideas for the redesigning of the downdraft technology and to address the shortcomings of the Ahotor technology. Feedback from end-users together with testing information on energy assessment, PAH analysis as well as inputs from stove companies was discussed to clearly define the way forward. The review and brainstorming meeting was organized in January 2017 with a total participation of 25 people, 16 males and 9 females across a range of stakeholders; FRI-CSIR, GSA, IIR-CSIR, SFMP partners, End-users, Gratis, FC, and Stove builders.

Figure 1: Participants of the first technology review meeting

Participants were grouped according to common expertise to device redesigning solutions to addressing the above concerns. Table 1 outlines the prevailing problems and the proposed solutions to be considered.

Table 1: Problems identified with Ahotor oven and proposed solutions

Problem	Improvement Required	Proposed Solution
Uneven heat distribution in smoking chamber	Fat-collector needs to be improved as it doubles as the heat redistributor	• The diameters of the cones /openings should be reduced to increase the number of the mushroom (cones) from eight to nine or more • Stoking of fuelwood into the chamber properly at maximum 2/3 of the dimension of the chamber

		• End user should adhere to the limit of number of trays. Thus ten (10) trays maximum to an oven (20 to double unit) • Recommended material for fat-collector construction should be stainless steel. Galvanized sheet is used because it is affordable and accessible • There should be a standby or back-up fat collector to reduce the hustle of frequent cleaning and washing • Artisans should adhere to the dimensions of the fat collector base (where the fat collector sits) • The thickness of the fat collector should be 1.5mm • The sharp edges of fat collector should be smoothened
Energy Efficiency	Combustion system requires improvement	• Always consider the direction of the wind before construction. The back of the oven should face the direction of wind to allow oxygen through the primary air inlet. • The bigger the primary air inlet, the more the oxygen for efficient combustion. This reduces smoke and smoking time. • The grate should be used always for efficient combustion. • Preheat the stove before smoking to reduce smoking time • The hood must be fitted with an end cup after work to avoid contaminations • Split fuelwood must be used for firing • Very dried fuelwood must be used • Do not use rubber, used tyres, waste or diesel oil as fuel for smoking or for firing • Do not allow burning wood to quench before introducing new one. Consistent refueling eliminates smoke.
Low levels of Acceptance, Adoption and Use	• Improve End User Satisfaction. • Enhance stove Dissemination	• Healthy fish market should be developed to encourage the adoption of the technology • The price of the oven should be reduced further to a level that can be accommodated by operational costs • Wire mesh preference for end-user should be considered before smoking. • Delayed in cooking time • Extra effort is required for fat-collector cleaning. • We must use the mass media also for Ahotor stove promotion in addition to other awareness campaigns and sensitization

Reduce Stove Cost to Increase Adoption	Identify alternative materials	• Use of clay bricks instead of fired bricks (this can be done on site) • The base should be made of clay. This will reduce stove lifespan. • To train locals to build the stoves • Target groups should retrofit their existing stoves instead of building new ones

Subsequently, sub-committees were formed from the technical group to design and come up with technical details and specifics for addressing the issues raised above. An implementation guide was developed, assigning each sub-committee a task and time frame to submit results. The output from each committee would be verified, tried and tested, and further shared with the entire technical team for review. Table 2 presents the implementation guide developed for the sub-committees.

Table 2: Implementation guide developed for the sub-committee

Item	Issue	Activity	Coordinator	Deliverable	Deadline
1	Uneven heat distribution during fish smoking.	▪ Redesign of fat collector to enable evenly distribution of heat ▪ Simulation of fat collector ▪ Building of samples ▪ Testing of samples	*Lead*: Lawrence & Turkson *Support*: Erasmus, Gabriel, Kwarteng, Commeh	Evenly heat distribution Fat collector	March 03, 2017
2	Rodents accessing smoked fish	Designing End Cup for hood	*Lead:* Morrison & Philip Gameli	Improved hood	Feb 10, 2017
3	Improving Energy Efficiency & PAH levels	Reviewing Combustion System & Heat Injection	*Lead*: Dr. Laryea, Ishmael, *Support:* Commeh, Lawrence, Morrison, Nketia, Kwarteng	▪ Improved combustion system ▪ Built prototypes	Feb 10, 2017
6	Reducing cost of Ahotor Oven	Identify cost-effective alternative materials to reduce cost of installation	*Lead:* Philip *Support:* Ekem, Erasmus, Turkson	▪ List of materials ▪ Built Prototypes	March 15, 2017

Item	Issue	Activity	Coordinator	Deliverable	Deadline
7	PAH & Energy Efficient levels of improvements made	Conduct PAH and Energy Efficiency Assessment test	*Lead:* Dr. Paul, Dr. Laryea, Ismael, Samuel Kwarteng, Dr Atikpo	▪ Testing protocol ▪ Testing report	April 20, 2017

To begin with the continuous technology improvement works, sub-technical committee meetings were held to review and finalized the proposed changes to the technologies. The meetings held on April 11, 2017 in Accra brought out various recommendations to enhance the stoves' performance. The following technical recommendations were made with more specific details;

Recommendations from the technical team

- The draft system; the opening of the primary air in-let should be increased and the secondary in-let decreased. This will increase air in-flow which will in turn increase combustion and eventually decrease the smoking time of fish.
- The hood should be conical i.e. it should have a broad base and a conical top.
- The mushroom heads on the fat collector should be modified. The mushroom heads could be double-headed, 10 cm high or slanted as shown in the figure below (so that the time-height distribution of heat will be the same).
- The mushroom heads could be slanted (so that the time-height distribution of heat will be the same).
- Ideally, no mushroom head should be located directly on top of the combustor to enable even heat distribution.
- The fat collector should be made of stainless steel or other material to prevent rusting.
- Partitions should be introduced into the down draft system.
- Holes should be created around the bottom of the smoking chamber.
- Using the biogas system as a reference, the design can be done in a cylindrical form rather than square shape.

Recommendations by Christa Roth – an international stove expert

As part of Ahotor stove's continuous improvement initiative, an international stove expert – Christa Roth was consulted to review the Ahotor and the downdraft designs and make recommendations for improvement and completion. The following are her overall recommendations, punctuated with basic technological development principles;

- ➢ Keep it simple

- A stove is the combination of two functional units that need to be perfectly tuned together: heat generator and heat transfer unit. Understand the optimisation factors for each and apply the principal design features to each unit separately first then bring them together for fine-tuning of draft etc.
- Form follows function. Understand what the functions are then design the shape of the application.
- Differentiate between must-haves and nice-to-haves, between essential parts that influence performance and others that are cosmetic where appearance matters.
- Evolution instead of revolution: Base a design on what people know. If possible don't design something that requires a complete or severe behaviour change.
- It is easier to adapt technology to people than the other way around.
- Not everything that is technically doable is economically feasible, convenient and easy to use or build.
- Don't sell what you can build, but build what you can sell (quote Carlo Figa Talamanca)
- Use existing construction materials and try to avoid specialised inputs. They create a bottleneck in the supply chain and are the enemy of scaling up efforts.
- Work with existing materials and apply your engineering skills to overcome constraints around them. The art is to make it simpler but functional, not more complicated.
- Think about the entire marketing and value chain from raw materials to the finalised product and the user training. Each and every step in that chain needs to be equally strong or the chain will break at the weakest link.
- Reduce consumable parts in number and size (e.g. smaller grate) to enhance the overall useful lifespan of the stove at lower costs.
- Reduce metal wherever you can and use brick along the flow path of the hot flue gases.
- Soot never lies. Follow the soot-path and learn how to interpret the writing on the wall and analyse what it tells you.

The consultant provided further details comprising learnings and recommendations on relevant aspects of the technology, which are explained as follows;

On the Ahotor Design,

The learnings from the Ahotor design and recommendations are captured in Table 3 below:

Table 3: Learning on fish-smoking and stove design by Christa Roth

Learning	Recommendations/Conclusion for stove design
There are two phases, curing/cooking by heat, the smoking for flavour.	Separate the two phases, but not in a separate place (like in the FAO-design) but in a sequence by adding wet fuel onto the fire once the fish has reached the final curing stage (like the RAKU ceramics).
PAH are higher if temperature is higher. Optimal temperatures for fish curing are between 80 – 100°C.	Create the highest temperatures possible in the combustion chamber to achieve complete combustion, but then dilute the flue gases with (preheated) ambient air to get to the desired temperature.
A big source of PAH is the grease falling into the fire, so a grease collector is essential to reduce PAH. The metal pan with the mushroom caps looks great but it warps when it is hit by hot flue gases.	Currently the metal pan functions as heat distributing rebounding plate which is directly hit from below by the vertically flowing flue gases exiting the fire chamber with force. It will warp less if the temperature of the flue gas will be lower and the dispersing of the flue gas / heat distribution is done before the stream hits the horizontal metal.

On the Downdraft Design

The ‘down-draft’ with the high chimney does not function well (complicated, expensive, uneven heat transfer), nor does the model with the stepped spiral inside, where also heat is very unevenly distributed.

This downdraft design should be discontinued, with efforts channelled towards work on the Ahotor oven which may require only some tweaking.

On Chimney

Chimneys are potential fire and accident hazard especially in areas where ‘preventive maintenance’ is lacking. A chimney that is not maintained by being regularly swept is a fire hazard. Moreover, sweeping a chimney is a potential source of accidents.

Additionally a chimney always draws heat away. The flue gases go where they find an outlet, so the more flue gas flow in an area, the hotter it gets because, as the hot gases pass they give off heat. That accounts for a high heat in the direct/shortest flow path between the fire chamber and the chimney, while the rest stays cold.

Hence, to even out heat distribution, the flow path of the flue gases needs to be interrupted and the gas/heat directed the gas / heat via a designated outlet.

Heat-generator / combustion chamber

In the new design with a better grid covered with a wire-mesh, the combustion is pretty well optimised. There are no coals left, only ash with non-calorific value. So all the fuel has been utilised for combustion.

The idea of the specialised round bricks to enhance better combustion and avoid cold corners in the fire chamber is in principle good, but in practicality not feasible. We tried a stove model in Malawi and it phased itself out because of the supply chain challenges. I would not try this again.

What might be something to try out is to make the combustion chamber narrower e.g. 15x15 cm. This can work with firewood, but it might not work if coconut shells/husk are used as fuel. Something to be tried.

Heat-transfer unit

Where there is a major problem still to solve is the heat transfer unit as the distribution of heat is uneven and the temperatures above the fire chamber are too high. The fish at the peripheral areas of the trays get overcooked with high PAH levels, while in the centre are not getting hot enough.

Up to now this has been tried by blocking the flow-path with a metal rebounding plate, which was not very successful as the metal always warps when heated from one side. There are special techniques that can limit the warping e.g. used in the space heating stoves in Europe with expansion slots fixed with alternating bars welded at the back to stabilise the plate.

Metal is expensive and corrodes quickly especially close to the seaside with the salt. So the best is to reduce metal components and have anything in the direct flow-path of the hot flue gases out of locally available ceramics and not out of metal.

My suggestion there is to 'cap' the fire chamber on top to interrupt the upward flow of the flue gas and force it sideways. The available brick with the 3 round holes are ideal for that if they are put on edge like displayed in the photo. Then covered with a layer of bricks on edge maybe with some small gaps in between to form long and narrow slots for some flue gases to go up vertically if the area above does not get hot enough.

 **Figure 2: Four bricks on the edge of the combustion chamber to improve heat distribution**	 **Figure 3: Four bricks sealing off the opening of the combustion chamber to improve heat distribution**
4 bricks on edge around the fire chamber to force the flue gas to go sideways through the holes and gaps between bricks	Covered by 4 more bricks on edge with small slots to let some heat pass if needed

This layout should allow easy iterations of gap sizes to find out where the sweet spot is between flow restriction, pressure and heat distribution.

In general the surface area of the outlets should be more or less equal with the square area of the combustion chamber. In general the dimension of the 'pure dogma of rocket stoves' is that the square area of the flow path of the flue gases should be kept constant to avoid restriction, but it can become narrower as the gases cool off and shrink in volume. E.g. in the institutional stove we worked with a vertical gap of 70% around the cooking pot as major heat transfer takes place on the bottom of the pot and the gases cool down from 800°C to less than 150.

The other measurement is on the rocket stove elbows that the total height is 2.5 times the diameter of the firebox. So if we would go on a 15 cm diameter, this would be 38 cm height, so that the final course of the 'cap' can be at the same height of the current top of the fire chamber. Even if the fire chamber remains at 18 cm diameter, the total height of the combustion chamber can be lower as the fire will be more contained and kept hot with more complete combustion expected to happen inside the capped fire chamber. Care has to be taken not to restrict the flow too much and create backlashes of fire out the front of the wood inlet.

We also discussed that the inlet of the 'dilution air' to cool down the hot flue gas should be different. If the cold air comes in at the top of the combustion zone it can disrupt the combustion process by cooling and create more emissions. I suggested to close that inlet at the top and create two inlets in the front bottom of the stove, on either side of the firewood entrance. Like this ambient air has to pass the outside of the fire chamber and can pick up heat from there, recycling it into the system. The slightly preheated air will coming up vertically will then meet the horizontally directed and dispersed flue gases, that have been forced through small gaps and holes, enhancing the turbulence and remaining combustion. If there is still combustible gas, there is then a better chance that it might continue combusting when the now dispersed gases mix with the preheated air as if it were to meet colder air directly. To be found out.

Grease collector

The mushroom-cap is a good solution if the grease collector has to double the function as rebounding plate. The high heat exposure will lead to more corrosion and a reduced lifespan. In future with the flame-distributor on top of the fire chamber it is hoped that the grease collector can be redesigned to function just as the collector. This could be also in the form of v-shaped strips of tin or more robust angle irons arranged in two layers: the top layer with the ridge pointing upwards and the bottom the other way round, with the open end on top and offset to receive the grease.

Chimney cap on top of the trays

After returning to the office I discussed with Benedicta one of the earlier designs with no combustion chamber and a chimney behind the stove: So if the heat should go into the fish, then the chimney should be on top of the fish stack, like I have seen now in the 'hoods' with a chimney cap that are put on top of the stack of trays. This looks like a very good improvement.

3.0 IMPLEMENTATION OF PROPOSED CHANGES

Out of the larger technical group, a working team was constituted to implement the recommendations and changes from both the local technical team and international consultant. The composition of the working team cut across metal fabricators, stove builders, researchers, project partners and end-users for effectiveness and inclusiveness.

3.1 Fat-Collector

In the attempt to solve the uneven heat redistribution in the smoking chamber, the design of the fat-collector was made to distribute evenly in the smoking chamber. To achieve this objective, series of designs were fabricated with varying dimensions and holes (See Figures 4 to 8).

Figure 5: Fat collector with double mushroom head

Figure 4: Fat collector with mushroom head at an angle of 45 degrees

Figure 6: Fat collector with 9 mushroom heads

Figure 7: Fat collector with 8 holes and 6cm hole in the center

The main challenge of these designs was getting enough heat at the center of the oven. Inefficient heat at the center contributed to delay in cooking time. Figure 8 shows some of the different fat-collector designs fabricated in the course of the research. In figure 5, the mushroom-like cover plate on the fat-collector holes were slanted at an angle of 45^o. The intention was to ensure heat redirection to enhance evenly heat distribution. This principle did not work because, the fish at the front roll received more heat than necessary whereas fish at back roll was getting limited heat. To solve this problem, the trays needs to be constantly turned around to prevent burning at one side, adding up more task to processors.

Maintaining the dimension of the combustion chamber, the different fat-collector models were varied and tested for heat distribution efficiency. It was observed that, the fat collector with 8 holes (19cm x 19cm diameter each) and a center hole of 6cm diameter had an averagely evenly heat distribution and faster cooking time. To ascertain this fact, the test was repeated 5 times. After the repetitive tests, it was concluded that the fat collector with 8 holes and a 6cm diameter hole in its center had the optimum evenly heat distribution and faster cooking time.

3.2 Combustion Chamber

Figure 8: Combustion chamber of the Ahotor oven

Modifications were made to the combustion chamber to address feedbacks on prolonged smoking time and limited heat for bigger capacities at a go. The proposal from the technical team was to make the column narrower and circular. However, molding a circular column, was very difficult to achieve as it will increase the cost and time for construction. The inside dimension of combustion column was reduced from $17cm^2$ to $15cm^2$ to make it narrower using the same materials for construction. With this new dimension of the combustion column, the height of the stove could be reduced by 10cm which partly addresses the concerns raised on the stove height being high. Effecting this change to the combustion system resulted in an improved heat ejection velocity up to the tenth tray. It also significantly improved the cooking time with the Ahotor oven.

4.0 PAH RESULTS OBTAINED

Prior to the technology improvement work on the Ahotor oven, the technology had achieved 6 µg/kg and 53 µg/kg for BaP and sum of PAH4 respectively, considerably lower than the Chorkor. In addition, the stove was 32% more fuel efficient and produced less harmful smoke than the Chorkor according to an energy assessment report by Institute of Industrial Research – CSIR.

4.1 Without Ash

Effecting the various improvement options to the technology, the stove was tested for PAH levels. The results indicated a significant improvement in the PAH levels. The table below provides the test results for BaP and PAH.

Table 4: PAH test results

Test	BaP	PAH 4
1	1.28	47.21
2	0.61	29.45
Average	**0.95**	**38.33**

4.2 With ash as fat absorber

Further technology improvement ideas suggested the introduction of ash as an absorbent in the smoking chamber to mob out the drippings from the fish during the smoking process. The ashes would be spread on the drip-collector to cover the entire tray to ensure drippings do not have direct contact with drip collector. This is because, usually when the drip/fat collector gets heated especially in a case where the surface is rough or rusted, the liquid is unable to flow out properly and therefore ends up burning and emitting smoke. This subjects the fish to the same toxic smoke as if there was no fat collector. The ash therefore is to soak up or absorb the liquids and prevent it from burning. This intervention significantly reduces the PAH levels in smoked fish and also makes cleaning of fat collector easier. Depending on the depth of ash used in every smoking session, the levels of PAH could be reduced beyond the detectable limits. Table 5 below shows the preliminary test results from 3 different fish smoking samples analyzed in the presence of ash. A more comprehensive study shall be designed and carried out to ascertain facts on ash depth in correlation with PAH levels vis a vis fish preference.

Table 5: PAH test results with ash as fat absorber

Test	BaP	PAH 4
1	0.22	18.15
2	0.50	12.80
3	1.07	1.83
Average	**0.60**	**10.93**

4.3 With ash as fat absorber and coconut husk to improve fish colour

Introducing ash in the smoking process further reduces the smoke levels, making the fish look pale instead of the original golden brown colour which is most preferred by consumers. To address this concern without compromising fish safety, after smoking with ash and fish is almost ready, less lignin smoking materials like sugar cane husk or coconut shells are used to generate some level of smoke to achieve the kind of color preferred. This process was also tested to check the PAH levels.

Table 6: PAH test result with ash as fat absorber and coconut husk for smoke

Test	BaP	PAH 4
1	0.64	25.90
2	2.02	41.54
Average	**1.33**	**33.72**

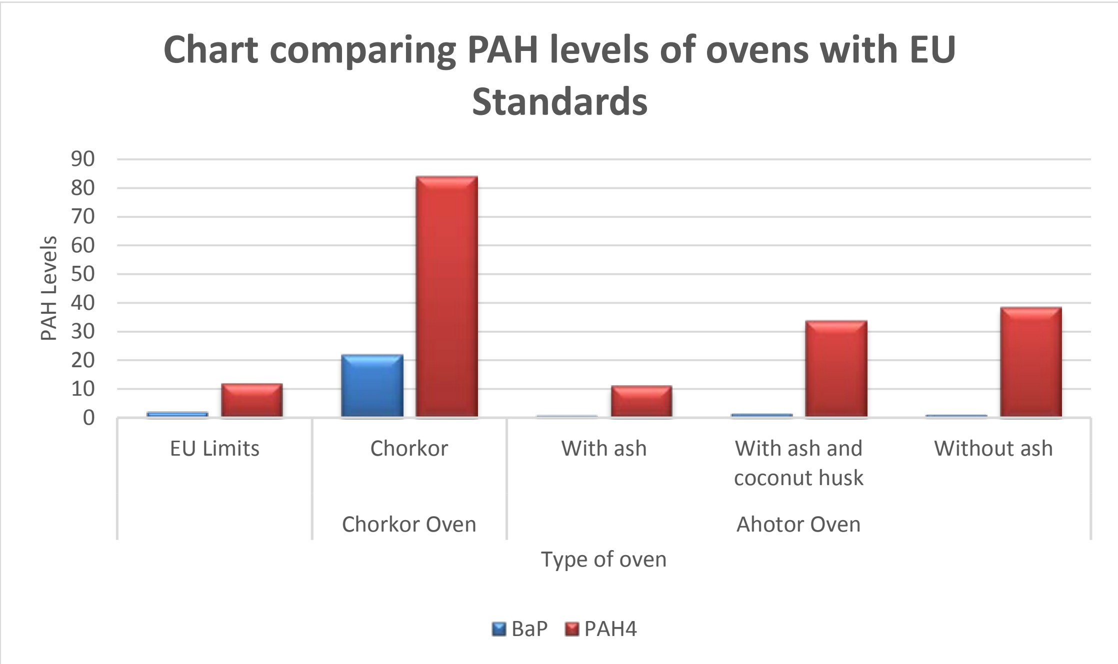

Figure 9: PAH results of Ahotor oven against Chorkor and the EU standards

5.0 FINAL COMMITTEE REVIEW MEETING TO EVALUATE IMPROVEMENT RESULTS

The committee discussed the progress of work made on the Ahotor oven to date. There was a discussion on the various stages of changes that the oven had undergone.

On the combustion chamber, the chamber has been reduced from 17cm x 17cm to 15cm x 15cm to enhance the heat ejection in the oven. The reduction in the combustion chamber resulted in a well circulated heat as well as a better heat ejection, with heat reaching the tenth tray.

Figure 10: Showing committee members the various types of fat collectors designed for the test

The various modifications that the fat-collector had undergone were also discussed during the workshop. The various changes in the fat-collector had significant effect on the evenness or otherwise of the cooking of the fish. It was realized that the fat-collector with the optimum performance in terms of all fish being cooked evenly was the fat-collector with a 60mm hole in the center.

The discussion showed that ashes could also be put on the fat-collector to absorb the fat, blood and water that drips from the fish during smoking. Since the ash prevents the fluid from coming into contact with the hot surface of the fat-collector and evaporating, it reduces the level of smoke produced. Reducing the level of smoke produced in turn reduces the PAH of the fish smoked in that manner. PAH results from such method provided lower levels of PAH as shown in the PAH results in Figure 9 above in this report.

In reducing the amount of smoke produced during smoking, it was suggested that the committee designs another Ahotor stove with a motor to separate the smoke from the fish, for research purposes.

5.1 Downdraft design

There was a discussion as to whether there is the need to continue with the downdraft design or to discontinue it. The committee agreed to discontinue the technology due to associated complications and its inability to function after series of readjustments and reviews. The committee also referred to recommendations from Christa as valid for withdrawing investment into the technology.

5.2 Refresher Training for Stove Companies

The technical committee meeting was followed with a refresher training to update the stove building companies on the technical changes effected to the Ahotor technology.

The stove building companies were trained on the technical changes and its impact on health safety. To be sure they understand and can construct to the new standards, they were grouped into teams of four to construct samples. In addition to the technical training was the training on financing scheme for acquiring the oven.

Figure 11: Participants of the technical training constructing samples of the Ahotor oven to the new specifications

Participants were invited to share the field experience and suggestions for improving the stove promotion program. Some of the challenges outlined included inaccessibility and unaffordability of building materials in some communities making cost of materials very expensive. Reviewing of stove price was deemed necessary as there were complains of increment in material cost.

5.3 Review of Stove Cost

Per the request of the construction companies, there was a review of the cost of constructing the stove. At the end of the discussions, the cost of constructing the stove base (without trays) of a double unit of the Ahotor stove went from GHS 1,610.00 to GHS 2,670.20, indicating GHS 1,060.02 (65.84%) increase in price.

Table 7: Reviewed price for constructing the base of the Ahotor oven

Stove Type	Chamber Type	Materials	Quantity	Unit Price (GhȻ)	Amount (GhȻ)
Just RETROFIT		Bricks	210	1.8	378
		Clay & sand			100
		Cement	3 bag	35	70
Bricks & Blocks 1 unit	**Brick Work**	Labour	2 people for 2 days	60	260
		Iron rod (quarter)	1	6	6
Bricks & Blocks 2 units		Cement block	70	3	210
		Transport			150
Bricks only 1 unit	Fat Collector		2	400	800
	Combustion grate		2	40	80
	Subtotal				**2,054**
Bricks only 2 units					**30% profit margin**
			2,054 X 1.30		**2,670.20**

6.0 CONCLUSION

The results of the recent trials indicate massive improvements in terms of PAH levels, offering the Ahotor stove as a safer fish smoking product. This implies that, if all fish processors switch to the Ahotor oven, more healthy fish would be sold in the Ghanaian market.

Technical issues like uneven distribution of heat and inability to cook about ten trays, as raised by the fish processors, have been improved tremendously. Inputs from end users contributes significantly to improvement success of the Ahotor oven.

However, the cost of constructing the Ahotor oven has gone up by about 65.84%. This might be a great deterrence to most of the fish processors because they see the technology to be quite expensive especially where the alternative, the Chorkor oven is quite cheaper.

RECOMMENDATIONS

On the basis of findings from the trails carried on to improve the Ahotor oven the following recommendations are offered:

- A comprehensive study should be carried out on the Ahotor oven in an internationally accredited lab to confirm the PAH results.

- Energy efficiency improvements assessment should be carried out on the Ahotor oven to verify fuelwood savings, cooking time, specific fuelwood consumption, rate of smoke exposure etc.

7.0 APPENDIX

PAH Testing Methodology

Determination of PAHs levels in fish samples

Polyaromatic Hydrocarbon Analysis in Fish by GC/MS

Reagents and Chemicals

All reagents and solvents are HPLC or Ultra-pure grade. Acetonitrile and other reagents were obtained from VWR International (West Chester, PA, USA). The 18-component PAH standard used was obtained from Dr. Ehrenstorfer GmbH, Germany.

Solution and Standards

The PAH stock standard solution (10 µg/ml of 18 polyaromatic hydrocarbons) was diluted in acetonitrile to produce a spiking solution of 1ppm (µg/ml). The spiking solution was used to prepare the 6 points multi-level calibration curve containing concentrations of 5, 10, 20, 50, 100 and 200 ppb.

Sample Preparation

Before analysis, the bones and heads of the fish samples are removed. The samples are then comminuted thoroughly to achieve sample homogeneity, ready for extraction or can be kept in freezer at ≥ -20oC.

Extraction and Purification

The extraction used the QuEChERS method followed by dSPE clean-up technique. Weigh 3g sample (± 0.05g) in 50 ml centrifuge tube.

NB: Quality control (QC) samples are spiked with an appropriate amount of PAH spiking solution to yield QC sample with concentrations of 50 and 100 ng/ml (ppb).

Add 12 ml of de-ionized water (DI) and 15 ml of acetonitrile, then macerate the sample for 1min using Ultra-Turrax homogenizer. Add the QuEChERS extraction salt containing 6g MgSO4 and 1.5g NaCl to the centrifuge tube. Shake the capped tubes vigorously for 1 min on Vortex Mixer possibly at 1500 rpm. Centrifuge at 4000 rpm for 5 min.

Then transfer 6 ml of the acetonitrile (ACN) layer to dSPE clean-up agents consisting of 300 mg PSA, 300 mg C18 and 900 mg MgSO4 in 15ml centrifuge tube.

Vortex 1 min and then centrifuge at 4000 rpm for 5 min. Transfer 4 ml of the upper ACN layer to pear-shaped flask and then concentrate to dryness using rotary evaporator.

Re-dissolve the dry extract in 1 ml ethyl acetate, and then transfer quantitatively into 2 ml autosampler vials, ready for GC/MS quantitation.

PAH conditions were as follows:

- Injector temperature: 280 ^{0}C, splitless mode
- Injection volume: 2 µl
- Column type: HP-5ms (30 m x 0.25 mm x 0.25 µm)
- Column flow – 1.25 ml/min
- Ion source – EI mode
- Source temperature: 300 ^{0}C
- MSD transfer line: 325 ^{0}C
- Column conditions
- 70 ^{0}C (hold, 2 mins) to 150 ^{0}C (at 25 ^{0}C/min) to 200 C (at 3 ^{0}C/min) to 280 ^{0}C (hold, 12.133 mins)
- Solvent delay: 4 mins.
- Total Time: 44 mins.

PAH test results with ash as the absorbent

Ash was spread on the fat collector to absorb the drippings (fats, blood, water etc.) from the fish. As the fat-collector heats up, there is the tendency of burning some of the deposit of fats and blood which will intend increases the smoke and subsequently increases the PAH.

PAH Test results with Ash as fat absorber and coconut husk for smoke generation

The test was conducted the same way as the above. However, coconut husk smoke was introduced to at the final stage to give the fish the appealing colour customers require.

PAH test results without ash as fat absorber

Smoking was carried out with all the components of the oven in place without any ash or coconut husk.