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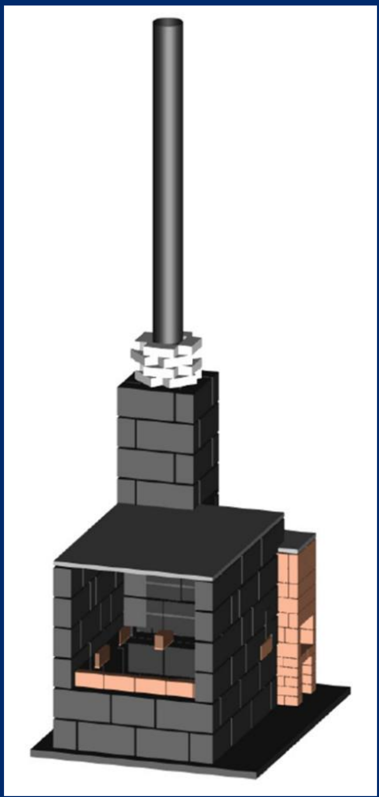
Low PAH Improved Fish Smoking Stove Design Development Report



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For more information on the Ghana Sustainable Fisheries Management Project, contact:

USAID/Ghana Sustainable Fisheries Management Project
Coastal Resources Center
Graduate School of Oceanography
University of Rhode Island
220 South Ferry Rd.
Narragansett, RI 02882 USA
Tel: 401-874-6224 Fax: 401-874-6920 Email: info@crc.uri.edu

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Detailed Partner Contact Information:

USAID/Ghana Sustainable Fisheries Management Project (SFMP)
10 Obodai St., Mempeasem, East Legon, Accra, Ghana

Telephone: +233 0302 542497 Fax: +233 0302 542498

Maurice Knight	Chief of Party	maurice@crc.uri.edu
Kofi Agbogah	Senior Fisheries Advisor	kagbogah@henmpoano.org
Nii Odenkey Abbey	Communications Officer	nii.sfmp@crcuri.org
Bakari Nyari	Monitoring and Evaluation Specialist	hardinyari.sfmp@crcuri.org
Brian Crawford	Project Manager, CRC	brian@crc.uri.edu
Justice Odoi	USAID Administrative Officer Representative	Jodoi@usaid.gov

Kofi.Agbogah
kagbogah@henmpoano.org
Stephen Kankam
skankam@henmpoano.org
Hen Mpoano
38 J. Cross Cole St. Windy Ridge
Takoradi, Ghana
233 312 020 701

Andre de Jager
adejager@snvworld.org
SNV Netherlands Development Organisation
#161, 10 Maseru Road,
E. Legon, Accra, Ghana
233 30 701 2440

Donkris Mevuta
Kyei Yamoah
info@fonghana.org
Friends of the Nation
Parks and Gardens
Adiembra-Sekondi, Ghana
233 312 046 180

Peter Owusu Donkor
Spatial Solutions
powusu-donkor@spatialdimension.net
#3 Third Nautical Close,
Nungua, Accra, Ghana
233 020 463 4488

Thomas Buck
tom@ssg-advisors.com
SSG Advisors
182 Main Street
Burlington, VT 05401
(802) 735-1162

Victoria C. Koomson
cewefia@gmail.com
CEWEFIA
B342 Bronyibima Estate
Elmina, Ghana
233 024 427 8377

Lydia Sasu
daawomen@daawomen.org
DAA
Darkuman Junction, Kaneshie Odokor Highway
Accra, Ghana
233 302 315894

Gifty Asmah
giftyasmah@Daasgift.org
Daasgift Quality Foundation
Headmaster residence, Sekondi College
Sekondi, Western Region, Ghana
233 243 326 178

For additional information on partner activities:

CRC/URI:	http://www.crc.uri.edu
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ACRONYMS

BaP	Benzo(a)pyrene
CoP	Chief of Party
CR	Central Region
CSIR	Council of Scientific and Industrial Research
EU	European Union
FAO	Food and Agricultural Organization of the United Nations
FRI	Food Research Institute
FTT	FAO Thiaroye Technology
GHs	Ghanaian Cedi
PAH	Polycyclic Aromatic Hydrocarbon
SFMP	Sustainable Fisheries Management Project
SNV	Netherlands Development Organization
USAID	United States Agency for International Development

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INTRODUCTION

Context

Across Africa various traditional methods are employed to process, preserve and store fish. These include smoking, drying, salting, frying and fermenting and various combinations of these treatments. The advantages of smoking fish are manifold: it prolongs shelf life, enhances flavor, reduces waste in times of bumper catches and permits storage for the lean season. It increases protein availability to people throughout the year and makes fish easier to pack, transport and market. It is a major source of income for coastal-dwelling communities and traders. In Ghana, smoking is the most widely-used method for preserving fish and is the most common activity for women in fishing communities. Practically all fish species available in the country can be smoked. It has been estimated that between 70 and 80 percent of the domestic marine and freshwater fish catch is consumed in smoked form.

SNV (Netherlands Development Organisation) Ghana is committed to combating deforestation, to increasing the profitability of agro-processing businesses in Ghana and to improve the working environment for women entrepreneurs. Through the introduction of energy efficient and clean cooking technologies, all these targets can be addressed. Improved cooking stoves and dryers/smokers can significantly reduce fuelwood consumption and reduce human exposure to heat and smoke. The Sustainable Fisheries Management Project (SFMP) is a 5-year intervention aimed at introducing improved food processing and other renewable energy technologies to agro-processing communities.

Recent studies by SNV have shown that improved fish smokers produce products with levels of Polycyclic Aromatic Hydrocarbons (PAH) that are well above current recommended levels for human health. Because there are different sets of PAH monitored for food quality regulation, we note here for clarity that the EU uses PAH(4) and PAH(8). This means, depending on the variable, they regulate the levels of either 4 or 8 of the most harmful compounds in the PAH family. All are considered carcinogenic. Other jurisdictions use, or track, PAH(7) and PAH(16).

Objectives

This study seeks to assess improved fish drying technologies and provide design guidance for the development of an adequately efficient fuel device that produces dried fish with low PAH levels. This report presents an overview of the fish smoking process and a review of five smoking stoves tested by SNV: three existing low-cost stove designs (Chorkor, Morrison and Open Source), plus the two higher-cost stove designs (FAO Thiaroye Technology (FTT) and Divine), with respect to performance, construction, costs, capacity, user-friendliness and PAH levels in fish. Based on this analysis, the optimal conditions for this process are recommended and a design process is outlined that resulted in two new prototype fish smoking stoves– a new build downdraft stove and a combustor to retrofit to existing stove types.

OVERVIEW OF FISH SMOKING

Smoking is a traditional processing technique used to preserve fish. It also gives color and a range of tastes appreciated by consumers. It consists of exposing fish to the effects of heat and smoke, both produced by the combustion of biomass (wood, sawdust, coconut husks, etc).

Smoking process

There are two types of smoking: hot smoking and cold smoking, characterized by the processing temperature and the temperature reached at the centre of the fish flesh.

- Cold Smoking: It is practiced primarily in the North. The smoke temperature is maintained between 20°C and 25°C and should never exceed 28°C as the fish should neither cook nor be too dry. The length of treatment varies from a few hours to several days, depending on the type of installation and the desired product. Cold smoking requires strict hygienic conditions and quality control as the final product has high water content. Its shelf life is limited and it is usually vacuum-packed and stored cold or frozen.
- Hot smoking: In this case, the fish is cooked while giving it a smoky flavor. This is the most common practice in developing countries because it gives a relatively stable product. The fish is usually salted and dried before smoking. The smoking temperature varies between 60°C and 120°C. The water content of the finished product is quite variable because it depends on the desired product and the fish species used.

Depending on the type of fish being smoked and the product presentation (species, thickness, and way of cutting it), its ultimate use and the length of time it has to be stored. The hot smoking process can take from 1 hour to 2 days. It is done at temperatures above 80°C which is high enough to cook the fish:

- "Soft smoking", which usually takes about 1-2 hours, yields a moist, versatile product with about 40-55 percent moisture content and a shortened shelf life of 1-3 days which limits its market distribution radius.
- "Hard smoking", which is usually preceded by soft smoking, takes about 10-18 hours depending on the weather, yielding fish with 10-15 percent moisture content. It is even possible to bring it below 10 percent. Fish smoked by this process have a shelf life of 6-9 months when stored properly. As a result it can be traded over a large geographic area.

Actions of smoke

During the smoking process, smoke has different actions on the fish:

- Organoleptic action: the color of smoked fish is mainly due to the Maillard reaction (hot smoking). The longer the smoking process, the more the color of the fish will be transformed, but it can also vary with the species of wood used. Phenols are primarily responsible for the aroma.
- Chemical Action: smoked fish using traditional techniques may undergo slight denaturing of some proteins. The important chemical action is the effect of phenols on fish lipids: they inhibit the propagation of auto-oxidation.
- Bacteriological action: in hot smoking, it is the heat that destroys microorganisms. Smoke may have an antiseptic role through the phenolic fraction but this action is low.
- Toxic Action: the preservative functions, flavoring and coloring of the smoking process are well correlated with the smoke intake but it is also known that the smoke carries polycyclic aromatic hydrocarbons (PAHs), known for decades as carcinogenic in humans. Today, smoking processes are under surveillance of the authorities as the European Union (EU) applies a new health standard to smoked products. Per EU standard, level of PAH(4) in smoked fish products should be $\leq$ 12 mg/kg and that of Benzo(a)pyrene (CR) should be $\leq$ 2 mg/kg.

FISH SMOKING STOVES

The five fish smoking stoves tested by SNV in Ghana are described below based on data provided by SNV and from the literature.

Chorkor

Named after a small fishing hamlet on the outskirts of Accra, the Chorkor stove was developed and introduced in 1969 by the UN Food and Agriculture Organization (FAO) and the Food Research Institute (FRI) of the Council of Scientific and Industrial Research (CSIR) in Ghana. See Figure 1.

Figure 1 Chorkor stove

The Chorkor is composed of a square combustion chamber with one hole in front. It can be constructed in single or double units. Wooden trays (~8 per unit but can be more in peak season) are loaded on top of the combustion chamber. Heat and smoke generated in the combustion chamber rise through the wooden trays, drying and smoking the load of fish in a single stage process. Compared with traditional smoking stoves, the main improvements of the Chorkor stove include a greater heat retention in the structure, a larger smoking capacity and in consequence, reduced fuel consumption and a shorter smoking time.

Constructed with locally available materials: clay and clay bricks, plastered clay bricks (fired or not), the cost of construction is low, around 400-800 GHs depending on labour, numbe of trays etc.

Since its introduction, the Chorkor stove became popular in Ghana and in most western, central and eastern African countries for the following reasons:

- Low construction costs and long life (4 to 8 years depending on construction materials)
- Large capacity (up to 18 Kg of fish per tray, with 16 trays per double unit)
- High quality and uniformity of product, reduced smoking time
- Ease of operation: less time and effort required
- Lower fuel consumption than traditional processes

The advantages of the Chorkor should however be considered as relative to previous, inefficient smoking technologies. Indeed, fuel consumption of the Chorkor is still high. In addition, the stacking order of the trays has to be changed during the process. This is laborious as all trays have to be removed. Also, the working environment is smoky as there are gaps between trays and there is no chimney to carry the smoke away. Last and certainly not least, levels of PAH in the end product are higher than the traditional method and according to SNV tests, well above EU regulation limits: 11 times BaP limit and 7 times PAH(4) limit.

The increase in PAH levels can be explained by the greater confinement of the smoke witinh the Chorkor, the increased concentrations of pollutants from the smoke and the higher processing temperatures.

Morrison

The Morrison stove is a product of Morrison Energy Limited, a private Ghanaian enterprise that aims at improving the fish smoking industry with new processing technologies that are more energy efficient and more user friendly. In 2009, Morrison Energy Limited proposed some improvements to address the high fuel consumption and various smoking problems associated with the Chorkor stove. See Figure 2.

Figure 2 Morrison stove with two work stations

The design of the Morrison stove is very similar to the Chorkor stove detailed above. With a simple combustion chamber having the same characteristics, albeit with additives to the clay mix to improve thermal performance, the main differences are the interlocking tray frame and the addition of short a chimney on top. The interlocking frames carrying the fish are designed such that they overlap preventing the loss of heat and smoke, a noticeable problem with the Chorkor stove. Lastly, the Morrison stove is built with a 24cm high chimney cover attached. This device prevents the heat and smoke from spreading into the room, enhancing the drying and smoking function.

The Morrison stove can be built using similar materials as the Chorkor stove: clay mud, clay-mud blocks sun-dried or baked with clay-mud mortar, wood planks, and or softwood. However, due to additional work on tray construction, new material for the chimney as well as a margin for Morrison Energy Limited, its price is 1200 - 2000 GHs, depending on the materials used.

According to preliminary energy assessments conducted by SNV Ghana, the Morrison stove is 38% more fuel efficient than the Chorkor stove, using 0.38 kg fuel wood per kg smoked fish, while the Chorkor stove uses 0.62 kg fuel wood per kg smoked fish.

The Morrison stove therefore reduces fuel consumption and smoke emitted around the stove during the smoking process which were the main objectives of its development. However, some constraints remain such as the difficulty of arranging the positions of trays during the process, made even more difficult by the top chimney. The confinement of heat and smoke does reducing fuel consumption but the combustion itself was not improved. In addition, levels of PAH in the end product are higher, 15 times BaP limit and 9 times PAH(4) limit based on SNV tests. The earlier assumption that the higher levels of PAH between the Chorkor and the barrel are due to the greater smoke confinement seems to be confirmed as levels of PAH with the Morrison are higher than with the Chorkor and the main difference between the two is the greater smoke confinement.

Open Source

After supporting various private stove building entrepreneurs in technology development, SNV Ghana adopted a different approach to reach a larger impact: an open source model. A workshop was organized by SNV in May 2015 to introduce the open source stove technology. See Figure 3.

Figure 3 Open source

From the outside, the Open Source stove is similar to the Chorkor and Morrison stoves. The main difference is the design of its combustion chamber, based on the up-draft principle. The stove is also insulated with a mixture of clay, wood ash and sawdust between the combustion chamber and the stove body brick walls. A metal sheet with perforated holes is fixed on the top of the combustion chamber as a buffer to avoid direct flame to the fish. Above the perforated metal sheet, the combustion chamber is widening in a conical shape to the size of the fish smoking tray. The trays are stacked one on top of another and at the top a hood and short chimney are isntalled.

According to preliminary energy assessments conducted by SNV Ghana, the burnt brick Open Source stove shows about 26% fuel saving over the Morrison stove. This improvement is mainly due to the design of the combustion chamber, with is smaller and insulated.

No data on levels of PAH in the end product from the Open Source stove are available yet but it is likely that levels in the end products will be higher than EU regulation limits due to the similarity in design to the Morrison and Chorkor stoves.

Divine

The stove was developed in 2004 by Benvic Food Processing and Training Company due to the rising cost of fuel for smoking and the not-user-friendly nature of the existing stove (excessive smoke and heat generated during smoking). See Figure 4.

Figure 4 Divine stove

The Divine stove consists of two main components, the smoking chamber and the burner. It is a metallic stove made of aluminum and stainless steel. The smoking chamber is a squareshaped metal box and consists of two sections, one for drying and one for smoking. The inside of the smoking chamber is partitioned into six parts; the bottom three partitions are mainly used for drying (cooking) while the remaining top three partitions are used for smoking.

The burner consists of a steel cylinder. It is filled with sawdust or rice husk by the help of a PVC pipe that fits in a 5cm hole at the bottom and between three-legged stands at the top. Once the fuel is compressed, the PVC pipe is removed creating an internal combustion chamber. Approximately 5kg of saw dust are needed to fill one cylinder which will burn 5 hours.

The Divine stove is mainly built with stainless steel and aluminum, relatively expensive materials. The current price of constructing one Divine stove is around 3800 GHs.

Comparing the energy consumption of the Divine stove with that of the Chorkor, the efficiency improvement of the Divine stove is about 32%.

In terms of PAH levels, the Divine stove is significantly better than the Chorkor and the Morrison stoves. Tests were performed on 3 different kind of fish (sardinella, barracuda and tuna) and levels of PAH were below EU regulation limits for tuna only, which is not oily compared to the 2 other species. The Divine stove has therefore some potential but still requires further technical improvements to meet the EU set standards for all smoked products.

FTT

The FAO Thiaroye Technology (FTT) is a technique drawn from the collaborative efforts between the FAO and the CNFTPA training institute in Senegal. It was recently introduced to Ghana by the FAO and SNV IFS project. (See Figure 5)

Figure 5 FAO Thiaroye Technology (FTT)

The stove uses a two chamber process with drying conducted on one side fired by charcoal and smoking on the other side utilizing a separate fuel source for smoke generation. Because the first chamber charcoal uses a low PAH emitting fuel the result is good. Between the chamber and the furnace, a metal tray prevents fish oils from falling on to the charcoal fire, which again reduces the generation of PAH. The chamber has a hot air distributor composed of two metal boxes. This system improves the vertical distribution of hot air in the tray and reduces the frequency of interchanging the trays. Once the process is complete, racks loaded with cooked fish are transferred from the cooking compartment to the smoking one. The second compartment of the kiln is used for the indirect smoking. It is connected to a smoke generator with a smoke filter in between. A sponge of plant origins (loofah), moistened with water is used to purify and cool down smoke from the smoke generator. The fuel of the smoke generator, coconut fibre, is also humidified at 16-20% to avoid flames from forming. Smoking is performed during an hour at a temperature between 30 and 34 °C.

Because of the different metallic parts made of galvanized steel, required for this stove, its construction cost is quite high, around 5600 GHs.

The main advantage of this technology is the very low levels of PAH contamination that are below the EU export limit. This is achieved by the use of two different chambers for cooking and smoking, the prevention of oils dripping on the fuel during cooking and the use of a low PAH emitting fuel, charcoal, for the cooking phase.

This stove also presents opportunities for additional revenue for fish operators, with the possibility to process by-products. Fat gathered through the fat collection tray allows, for example, the manufacturing of soap or can be used as cooking or frying oil.

Stove technology analysis

Based on the data provided by SNV and data available from the literature, the following chart presents a summary of the stoves' specifics[1][2].

Table 1 Stove technology analysis

Stove	Performance	Construction materials	Cost (GHs)	Capacity (fresh fish)	User-friendliness	PAH levels in fish
Chorkor	- Baseline stove - High fuel consumption - 0.62 kg fuel wood per kg smoked fish (soft smoking) - 25.43 MJ/kg smoked fish (soft smoking)	Clay mud, wood	400-800	300 kg	- Easy to use - Smoky and hot working environment - Tray arrangement difficult	High 11 times EU BaP limit 7 times EU PAH4 limit
Morrison	- Improved mainly due to greater smoke confinement - 33% more efficient than the Chorkor stove (soft smoking) - 0.38 kg fuel wood per kg smoked fish (soft smoking) - 1.41 fuel wood per kg smoked fish (hard smoking)	Clay mud, wood, metal	1200	300 kg	- Less smoke - Tray arrangement more difficult due to the top chimney	High 15 times EU BaP limit 9 times EU PAH4 limit

[1] No information was available on smoked fish quality: Chorkor, Morrison and Open Source stoves are more likely to produce quite dark smoked fish due to the use of wood first and the simultaneous conduction of the cooking and smoking phases.

[2] Performance data are to be used with precaution: results were obtained from different tests, done with different fish species and not following the same cooking process (soft vs. hard smoking). Tests were also not conducted at full capacity, more likely leading to higher specific fuel consumptions.

Stove	Performance	Construction materials	Cost (GHs)	Capacity (fresh fish)	User-friendliness	PAH levels in fish
Open Source	- Combustion efficiency improved - 25.5% more efficient than the Morrison (soft smoking) - 1.05 fuel wood per kg smoked fish (hard smoking)	Bricks, metal, wood		300 kg	- Less smoke - Tray arrangement more difficult due to the top chimney	N/A (likely similar to Chorkor and Morrison stoves)
Divine	- Use sawdust as fuel - 32% more efficient than the Chorkor stove (hard smoking) - 17.34 MJ/kg smoked fish (soft smoking)	Aluminum and stainless steel	3800	N/A	- Smoke-free working environment - Tray arrangement difficult due to heat - More care and maintenance needed	Below EU limits for some fish such as tuna, above for other oily fish species
FTT	- Improved process with separate cooking and smoking phases - 33% more efficient than the Chorkor stove (hard smoking)	Bricks, galvanized steel, wood	5600	200 kg	- Smoke-free working environment - More care and maintenance needed	Below EU limits

OPTIMAL PHYSICAL CONDITIONS IN VIEW OF REDUCING PAH IN THE FISH SMOKING PROCESS

Source of PAH in the fish smoking process

The amount of PAHs formed during the processing of fish depends mostly on the conditions of smoking. In traditional smoking, smoke is generated at the bottom of an oven and the fish is placed directly over the smoking wood. In these conditions, PAHs are mainly produced by the following:

- incomplete combustion of wood: generation of wood smoke during curing is a typical example of incomplete combustion, and above 400°C PAHs are generated and released into the various smoked products
- oil pyrolysis: the formation of PAHs is known to occur through pyrolysis of oil at temperatures above 200°C and it is highly stimulated at temperatures over 700°C. When the fish is placed over the wood, oil drops in direct contact with the flame, generating PAHs that become deposited back on the fish

In some case, PAHs can already be present in fresh fish due to natural (forest fires) and human activities (anthropogenic sources) around the water. PAHs are lipophilic in nature and usually accumulate in the fatty tissues of organisms. These levels might not be detected in the fresh fish due to low concentrations but during the drying process heat will burn down the fat deposits causing some of the PAHs to escape and to be deposited on the fish.

Situation in Ghana

In Ghana, the smoking of fish using traditional kilns is generally carried out with wood at temperatures of 300°C to 700°C. With basic combustion technologies and incomplete combustion due to the need to produce smoke, significant amounts of PAHs are produced. In most cases cooking and smoking phases are performed in the same chamber at the same time, therefore exposing the fish to PAHs over a long time, especially for the hot smoking process. There are examples of operators drying with a clean(er) fire then smoking afterwards with, for example, coconut husks which produce copious amounts of smoke. Critically, since little to nothing is done to prevent oil from dropping directly in the fire or immediately next to it, additional amounts of PAHs are generated by the fire and these pass into the gas stream.

For all the above reasons, levels of PAHs in smoked fish produced by the Chorkor, the Morrison and more likely the Open Source stoves are high and well above the regulated EU limits. Efficiency improvements such as a greater smoke confinement can even increase levels of PAHs in the end product. The main issues with the barrel, the Chorkor and the Morrison stoves are:

- poor control of the fire power resulting in high temperatures well above optimum
- in many cases cooking and smoking phases are concurrent
- in those models, nothing preventing oil from dropping on the fire
- the deflector plate in the Open Source model is intended to distribute the hot gases more evenly across the tray area. This has the effect of collecting the falling oil drops and providing a roasting surface heated by the fire and the PAH rises into the fish above.

The Divine stove has some potential in producing smoked fish with PAHs levels below EU regulation limits. However, more research should be conducted as tests show that this was only achieved with one fish species, the barracuda – a low fat fish. As oil cannot drop in to the fire, it may be that the detectable PAH was formed within the fish by the high processing temperature rather than deposited from the smoke. If correct, this would explain why higher fat fish species yield higher PAHs levels.

At present, only the FTT stove produces smoked fish with levels of PAHs below EU regulation limits. This is achieved in part by using separate cooking and smoking phases, the elimination of oil dropping on fire and the use of a low PAHs emitting fuel during the cooking phase followed by a low temperature smoke generator in the smoking phase.

Design Recommendations

In order to reduce PAHs levels in smoked fish to a level nearer to EU standard No 835/2011, the following recommendations are made:

- Cooking and smoking phases should be done separately: the separation of the two phases presents the advantage of cooking first without or with very low levels of PAHs, then smoking during a reduced duration.
- Where this is not practical or affordable the drying should be done with a clean burning fuel+combustor combination, followed by smoking using either a second fire chamber or in a manner which offers effective control over the combustion conditions.
- Indirect cooking or direct cooking with low PAHs concentration: If the drying and smoking phases are separated, no smoke is applied during the drying phase. Ideally, drying should be done indirectly, with fish placed in a chamber heated from the outside. This presents the advantage of not requiring a very clean combustion because there is no contact between smoke and fish. It is however, more expensive to implement and is likely to affect the taste. Direct cooking can be done but with heat from a clean combustion or, as temperature should not be too high, with any smoke diluted with clean air.
- Moderate cooking temperature: a temperature of 80°C is enough to cook the fish. Ideally, it should not be over 85°C in order to mitigate against high temperature fat-burning and the direct formation of PAHs in the fish. Depending on the fish species and

the quality of the end-product sought (‘soft’ or ‘hard’ smoked), the drying time can be adjusted but do not raise the drying temperature.

- Completely avoid dropping fish oil onto the fire: In order to prevent oil pyrolysis and the generation of PAHs, a mechanism should be created either to collect the oil and remove it without being heated, or the heat should be generated on the side and not directly below the dripping fish.
- Low gas temperature for the smoking phase: Separating the drying and smoking phases will reduce PAH formation and deposition as the smoking duration will be shortened. Having limited the formation of PAH inside the flesh during the drying phase, the deposition of PAH on the surface automatically limits the level inside. The EU tests the level in the whole flesh, not only the surface. It is possible to reduce the PAH formatting within the flesh even further by cooling the smoke to a temperature of about 30°C, by using a water bath for example.
- Taste: It is not known how much of the taste is provided by the drying temperature, the ‘cooking’ of the fish and or the deposition of the smoke, and even the level of deposition. In some regions of Africa the fish is expected to have a slightly crispy exterior produced during a brief ‘roasting’ in the dryer. Until the factors affecting taste can be clearly defined, the system should be as controllable and as flexible as possible within budget limitations.

By implementing these recommendations, it is possible to produce smoked fish with very low levels of PAHs, much lower than are presently being detected and even lower than the current EU requirements. The FTT stove is a good example. Other research and development can be referenced:

- Collaboration between CIRAD in France and LFCIA in Senegal: through the implementation of a step of dehydration/curing without smoke followed by a smoking phase, the level of Benzo(a)pyrène in the smoked fish was below 1 ppb and total HAPs were below 5 ppb.
- IRT in Gabon: development of a smoking stove with separated cooking and smoking phases, indirect cooking and direct smoking with cooled smoke.

STOVE DESIGN REVIEW

The ancient practise of fish smoking has received attention from numerous development initiatives seeking to improve the capacity, working conditions, quality and fuel efficiency of this widespread industry. Smoked fish, either soft-smoked or hard-smoked, is a part of a traditional diet. The processing allows for fish, which otherwise have a very short shelf life at room temperature, to be sold over a much larger area beyond the coastal region. The practical marketing radius is about 200 km from the point of origin.

It is well known that smoking foods introduces smoke particles in two forms: solid particles that are essentially uncombusted carbon, and condensed or gaseous volatiles containing a myriad of chemical components including polycyclic aromatic hydrocarbons (PAH). There are several ‘sets’ of PAH’s that are monitored in the food supply, varying from one jurisdiction to another. In the EU, the set monitored are known as PAH(4).

Testing during the contract period provided some interesting guidance on the origin of the following:

- Pyrene
- Benzo(a)anthracene
- Chrysene

- Benzo(a)pyrene

Benzo(a)pyrene (BaP), is so important a toxin that it is separately tracked and its maximum separately regulated. It seems to be largely created by heating the oil of the fish, not from the smoke. To limit the level, the fish surface should not be heated above 100˚C or preferably, not more than 90˚C. When the maximum air/gas temperature was kept below 105˚C, the BaP level was extremely low (under 1 part per billion – ppb).

It appears that the other three PAHs - Pyrene, Benzo(a)anthracene and Chrysene - are largely influenced by the content of smoke. When the fire is smoky, the levels rise, but if it is still relatively cool, the BaP does not. Limiting the levels of all 4 requires addressing two separate issues:

- Temperature of the processing air (which includes the emissions from the fire and the air mixed with it) has to be limited to a temperature of <105˚C. In order to do this, it is important that there be a heat production zone, an air entry and mixing zone to cool the gases and dry the air, and a chimney provided with sufficient heat so as to pull the air through the trays of fish.
- Limiting the generation of smoke to a low level requires that the fire be built in a chamber which, through its inherent design features, provides a high combustion efficiency and a temperature high enough to combust the smoke. While this may at first seem contradictory – limiting the smoke production in a fish smoker – it is essential that the smoke level be low throughout the drying process. Smoke can easily be added at any stage of production, and preferably at the end so it has little opportunity to penetrate the flesh of the fish. The construction of a low-smoke wood fire burning damp fuelwood gathered near the sea, is not particularly challenging. It is done by using a low level grate to elevate the charcoal produced by the fire and by combusting the smoke and CO in a vertical brick-lined chimney. Further, the excess air level in the fire should be low so as to prevent premature cooling of the gases (before they finish burning to completion). This type of construction was tested and found to be highly effective at creating a clean hot exhaust gas that was suitable for mixing into a supply of clean ambient air.

Analysis of Existing Designs

There are two popular designs of smokers. They are functionally the same and have the following features:

- The bottom consists of a low wall with a combustion zone in which fuel is burned.
- Trays of fish are loaded and set upon the wall, as many as a dozen of them.
- The air which dries the fish is supplied through the fireplace. The devices differ in the details of the fireplace, but the function is the same – a fire burning in an enclosed space with all the air necessary for drying the product passing through the same space. This has the effect of chilling the fire, increasing the smokiness and raising the carbon monoxide level (CO). Higher CO means less efficient combustion.
- The bottom tray is nearest to the fire and hot air, so it dries first. In order to process a number of trays at once, it is necessary to remove the bottom tray before the others, or else the fish starts to cook. This is inconvenient and unnecessary work. A great deal of the time is spent when trays are being removed and re-arranged so as to get an even processing of fish.
- The trays are not very effective at keeping cool ambient air from leaking through the gaps between trays. This leakage reduces the temperature of the processing air, and reduces the draft pulling on the fire. This hot air draft is what moves the air through the

fire and then to the trays. The Morrison stove includes a cover that guides the gases into a chimney. The chimney serves as a waste pipe and to add draft on the whole system. To the extent it is effective, it also cools the fire creating poorer combustion conditions because the air has to pass through the combustion zone.

- There is no ‘combustor’ other than a hole in which the fuel burns on the ground. The floor chills the fire, creating copious amounts of charcoal which cannot burn properly during the main burn. Later, the accumulated charcoal burns out, but this energy for the most part is not usefully applied.
- In all cases, the construction of the structure of the stoves and the trays are completely localised requiring little expertise. None of the dimensions are critical and the function is largely unaffected by, for example, a change in height or the materials selected. More expensive stoves are more durable because they are made using better quality materials.
- The release of oils and moisture from the fish, towards the bottom of the chamber that is often quasi-conical in shape and having a hot suface, results in the evaporation of the liquids at high temperature, the creation of PAH chemicals and their deposition on to the fish.

Impacts of Existing Designs

The main factors of interest in existing designs are that the smokiness of the gas stream is not well controlled, or controllable, and that the temperatures of the gases reaching the product are easily high enough to create unacceptable BaP levels. See Figure 6. Thus there is little possibility of controlling the PAH(4) except by operating them with a very small fire and taking many hours to complete the drying process. This is impractical.

Of lesser importance is the distribution of heat across the area of the tray. Poorly distributed heat (see Figures 7 and 8) causes some fish to be cooked or even burned.

This is a resolvable problem as was demonstrated during the first field visit to a producer. By using a baffle plate (see figure 8), or a series of baffles, the hot gases can be reasonably well distributed across the tray area but this does not address the greater issues affecting product quality and performance.

Placing a perforated plate over the fire chamber exit, with care to block the front edge, the heat can be spread over the fish product resulting in two benefits: even drying and less ‘cooking’ of overheated areas .

While an attractive and inexpensive implementation, the result of food testing for PAH is not encouraging. The PAH levels remain high because in order to complete the drying in a reasonable time, the fire and the air/gas temperature is simply too hot under normal operating conditions.

Figure 6 Smoking fish

Figure 7 Distribution of heat across the area of the tray

Figure 8 Baffle plate

DESIGNING A LOW PAH IMPROVED FISH SMOKING STOVE

Initial Design Approach

Following the PAH report by Pemberton-Pigott and Beritault (presented here in sections 1-5), it was concluded that a completely new approach to drying fish was required that would simultaneously address the following issues:

- Overheating of the product
- Evaporation of drippings causing severe contamination
- Lack of meaningful control over the level of smoke applied, especially during drying
- Inconvenience and drudgery swapping trays in the stack
- Uneven product quality caused by uneven heating of the tray.

Separate the fire from the air supply, mix after combustion

In order to address all of these simultaneously it was decided to separate the fire and its exhaust gases from the general air supply to the drying operation. The fire would be created to the side of an air chamber, and air entering through a separate entrance would be mixed with the gases prior to being applied to the product.

See Figure 9: The combustion zone (1) is beneath the brick flame tunnel rising from the right hand end. The hot exhaust gases are then mixed with air in a mixing chamber (3).

Figure 9 The combustion zone (1) is beneath the brick flame tunnel rising from the right hand end. The hot exhaust gases are then mixed with air in a mixing chamber (3).

Control

The use of a chimney is not new, but the provision of heat directly from the fire into the chimney to maintain a minimum level of draft is novel. There is an operable vent that bleeds hot gases into the chimney directly from the top of the flame tunnel. In this implementation, a stainless steel plate slides in a frame to open a vent into the chimney. The hot gases entering the lower part of the chimney create draft in the whole system. Even if the system is cold, by heating the air in the chimney it can be made to draw air through the air path (i.e. inlet, combustion zone, fish smoking chamber, chimney) as the hot air will rise and cause the whole system to flow. It is akin to having an exhaust fan, but this one is powered by heat from the fire. By setting the opening, the level of heating and thus the chimney draft can be regulated. (Figures 10 and 11)

Figure 10 Stainless steel plate slides in a frame to open a vent into the chimney

Figure 11 By setting the opening, the level of heating and thus the chimney draft can be regulated

Self regulating

The upper limit on the temperature of the mixture of exhaust gases and air can be regulated by design, that is, the device can be made reasonably fail-safe. The draft from the chimney is dependent on the buoyancy of the air in the chimney. By creating an appropriately sized air entrance and sufficient mixing chamber volume, the operator of the fire finds it impossible to over-heat the air. Even the largest fire – limited by the height and cross-section of the vertical flame channel – cannot create a temperature above a given level because as the fire increases in power, the amount of air drawn by the chimney also increases. Thus balancing the fire chamber design and the air channels, the drying air can be limited in temperature. This is a significant improvement over the traditional devices which are dependent on operator skill, experience and guesswork about the temperature applied.

The initial design was inadequate in respect of size of the air entrance. It had to be enlarged in subsequent models until an optimum was found. The upper limit seems to be about 120°C and the relative humidity is about 3%; an extremely low moisture level. This provides excellent conditions for drying.

Figure 12 Air entrance

Combustion quality

Already referenced in the description above, the reduction in smoke from the fire is a key part of gaining control over the product quality. The approach used is to confine the fire and smoke within an appropriately sized tunnel or chamber that is placed vertically above the ‘far end’ of the fireplace. In Figure 13, the ‘far end’ is on the right. The tunnel through which the flames rise is tall enough so that the flame is ‘finished’ by the time the gases emerge into the air mixing chamber above. Figure 14 shows the top of the flame tunnel, the vent into the chimney at the back, and the mixing chamber. Light can be seen shining in through the cold air entrance at the bottom. The two stacked bricks provide a baffle to force the gases to mix with air in the chamber and not proceed directly into the drying chamber to the left.

The vent control is shown in position ‘2’ in Figure 14. It was determined during tests that the typical position would be ‘4’. This setting provides enough heat to operate the airflow mechanism and provide optimal drying.

Figure 13 Top of the flame tunnel and drying chamber

Figure 14 Top of the flame tunnel

Pre-cast cement cap on the air mixing chamber

The top of the fire chamber, which is also the top of the air mixing chamber, is capped with a heat-resistant cover in the form of a pre-cast cement slab. (Figure 15) This material is sufficient to deal with the temperatures experienced at the top of the chamber. The mortar used for building with bricks is a high temperature mortar made from a mix of clay and wood ash, and is traditionally used for high temperature stoves. It dries rapidly, has adequate strength and is inexpensive.

Figure 15 Heat resistance cover at the top of the fire chamber

Downdraft drying chamber

The biggest change to the traditional approach is to flow the hot gas-air vertically down through the trays rather than upwards. There are four major benefits for doing this:

- Even drying: The temperature is nearly homogeneous across the whole tray because ‘hot air rises’ and if any area is slightly warmer than the rest, it rises, spreads and equilibrates.
- Much less work: The top tray gets processed first, with the result that it can be removed when fully processed without having to disturb any of the other trays. This reduces the physical work needed to a fraction of what is required with current models.
- PAH reduction: The drippings from the fish, fall to the bottom of the chamber where it is now the coldest, instead of the hottest. This completely removed, as far as we can tell, any evaporation and deposition of PAH materials.
- Recirculation: The hot air entering on one side (on the right as seen in the photos) can be used to drive a circulation pattern limiting the difference in temperature between the top and bottom trays. This homogenisation of temperature reduces the difference in processing time between the upper and lower trays.

The term ‘downdraft’ means that the hottest air is at the top and the coolest at the bottom, and the hot air is pulled down through the trays towards the floor by the suction of the chimney. This cool exhaust air, laden with moisture, is conducted to the bottom of the chamber where the updraft of the chimney removes it to atmosphere, to be continually replaced by hot dry air within the chamber. The height of the chimney must be adequate to accomplish this, and the heat vented directly from the fire provides the energy necessary.

The downdrafting flow is the result of the updraft in the chimney being sufficient to overcome the natural tendency of the hot air in the drying chamber to rise, as well as having additional updraft necessary to drive the flow at an adequate rate. In other words it is not enough to have just a little more updraft, it must be able to flow the hot air through the fish trays at a rate that accomplishes complete processing within an acceptable time, which we were informed is 90 minutes under ideal conditions, for soft smoking.

Gas Exit Tunnel

The cooled and humid air that reaches the bottom of the chamber is conducted to the chimney through a tunnel of brick. This must be large enough in cross-section not to be a restriction on the flow. The entrance of the tunnel is approximately in the centre of the floor space of the drying chamber.

Chimney

The cross-sectional area of the chimney (Figure 16) has to be adequate to conduct the gas volume coming from the chamber and the vented gases entering directly from the fire. The total height is important, however there is a practical aspect that must be considered. The processing workshop will in most cases have a roof over it and the chimney has to pass through this roof. Given the climate, the needed working space and the building materials available, the chimney height will be at least 3.5 to 4 metres high. To clear the roof and not have back-drafting as a result of the relationship between the roof and the top of the chimney it is recommended that the total height be 4.2-4.5 metres from floor to the exit. The area of the chimney is 700 cm^2 in the brick and block section at the bottom where the coolest air enters, and 350 cm^2 in the upper section where it moves through one or more metal tubes. The total draft produced is applied to the fire, via the air mixing chamber, and the air intake in a ratio of approximately 1:6. The experiments we conducted indicate that the upper limit of the air temperature was about 120°C at full flow, and that the vent from the fire to the chimney was 50% open during this operation.

Figure 16 Chimney

Maximum temperature available in the drying chamber

Although it is reported above that the temperature of the heated air maximises at about 120°C, it is possible to use a combination of controls and timing to raise the chamber temperature higher. Once the drying chamber is heated and the exit temperature reaches 60-80˚ it is possible to raise the temperature by closing the vent from the fire into the chimney and driving all the hot gases into the drying chamber air supply. This reduces the draft in the chimney and slows the entry of fresh air into the mixing chamber. The slowing of the gas flow reduces the dilution of the hot gases with cool air. Experiments showed a terminal temperature of about 180˚C can be achieved in this manner. There are cases when the skin of the fish should have a 'toasted' appearance. This requirement can be accommodated if this combination of conditions can be achieved.

Materials used in construction

Every attempt was made to create a dryer that could be constructed from materials available in most Ghanaian fishing communities. The result was the use of bricks, hollow cement blocks, ash-clay mortar, sand-cement mortar, wood, wire mesh, nails, blockboard or cast sand-cement slabs, steel bars and hinges. The only specialised component required is the sheet metal vent controller that was fabricated from locally available materials.

Preliminary Construction

The first unit was constructed with advice coming from the local consultants via online discussions, drawings and emails. The initial tests showed that the downdraft configuration was effective and easily managed but tended to over-heat the fish. Several iterations were tried with ever-larger air supplies until version 0.3 was showing greater promise.

V0.2 is a half-sized unit able to accommodate five trays on shelves. This was an idea arising from the local consultants and it was evaluated as a way to eliminate having to remove stacked trays from a pile in order to remove the bottom one. The problems with it are two-fold: the cost is high; the stacking of trays. Figure 17 shows that more trays can fit into the available space and when using the downdraft air flow, the top one is finished first so there is not need to remove the lower ones.

Cost and convenience considered, there is no need to build a steel frame with tray holders. With particular reference to the PAH(4) levels, every advantage is gained by avoiding an updraft configuration. The steel shelves were primarily designed to avoid a problem created by having the hot gases rise from below. Reversing the direction of flow negates the need.

Figure 17 Preliminary Construction

Second design phase

Following the rather lengthy process of getting test results from the food quality laboratory, we had enough data to conclude that the origin of the PAH contaminants was indeed split between overheating the fish and the deposition of smoke. The major shortfall of the preliminary design was that the fire had to be kept relatively small in order to limit the processing temperature. The problem with increasing the fire power was that it did not increase the air flow sufficiently so as to keep the chamber temperature under 120°C.

In version 0.3, the steel shelves were retained because they were already in the chamber. The air entrance was increased twice in cross-sectional area and volume, providing enough data to make a prediction as to what the 'ultimate design' would be like. The chimney height was increased and the size of the combustion chamber reduced in an effort to limit the excess air level in the flame tunnel. All of these modifications achieved the desired results.

Final optimisation of the design

Dubbed version 0.4 this unit was constructed anew and did not make use of any of the original construction. It was built in the centre of the building to provide room for a much taller chimney. The draft necessary to draw in the air through the system when the fish is cold (or frozen in several cases) is much easier to generate by simply using a taller chimney.The drying chamber was constructed from less cement blocks, as was the lower portion of the chimney. The fire chamber and the air mixing chamber were made from bricks as before, because of the strength and fire resistance needed. The fire is built upon a grate that sits on the flat floor (Figure 18), with an air supply drafted through the side wall at the 'far end'. This air supply burns the charcoal created by burning wood in a confined space. The vertical flame tunnel (Figure 19) was increased in area to 12.5 x 12.5 cm. As a result the fire has a horizontal fuel combustion zone followed by a vertical gas combustion zone (within the flame tunnel).

Figure 18 The fire is built upon a grate that sits on the flat floor

Figure 19 Increased vertical flame tunnel

TRAINING OF TRAINERS

This was accomplished simultaneously during the design and construction of versions 0.3 and 0.4. Instead of directing the construction of v.0.3, a loose stacked 3D model was loosely assembled (see Figure 20). The trainers were tasked to build a copy of it using bricks and mortar and to test it by drying a load of fish. (Figure 21) The team successfully replicated the model using the materials available and conducted a drying test.

Figure 20 Loose stacked 3D model of v 0.3 was loosely assembled

This was followed by team discussions on the way forward: Why was the result so good? Which result was best? What were the conditions that produced the lowest PAH(4) contamination? How can the tray size be increased? What are the popular tray sizes in various regions? Was it worth changing the size to accommodate the dryer, or was it better to adapt the dryer to the existing stock of trays?

After agreeing on a way forward, version 0.4 was designed and was constructed by the artisans using their existing skillsets.(See Figure 22) This involved wood working (trays, doors and covers), working with cement blocks (lower sections and low temperature portions) and brickwork. By this time they were familiar with the fire chamber construction which was by far the most difficult part of the construction. It is assumed that during replication in fishing communities, the all-brick fire chamber and air mixing chamber will be constructed first by a specialist and the larger portion built by an artisan of lesser skill. The fire and air mixing sections are working very well and can be applied to any drying task where a large supply of hot dry air is needed. Examples of this are fruit and vegetable drying, wood treatment, crop processing and processing of high protein foods.

The artisans demonstrated a good understanding of how the system works, and suggested improvements to it. One valuable suggestion is that the air entrance on the right side of the chamber should be placed about half way up the wall so as to drive a flow of air up the right side, across the top, down on the left and under the bottom tray to return to the air entrance.

This can be accommodated within the design, but not within the same space. It is this idea which holds promise to reduce the temperature differential between the top and bottom trays. It should be implemented as a version 0.5.

Figure 21 Laying fish on trays

Figure 22 Construction of version 0.4

LAB TEST RESULTS

While many tests of drying at different temperatures and under different conditions were conducted, the number of test results received was quite limited. It is not clear why this is so. The lab has limited capacity and the turn-around time was quite lengthy. For this reason, design decisions had to be made based on best guesses confirmed by what test information was available. We leaned heavily on the PAH report prepared before the work started which provided general guidance.

Test Results

As can be seen in the chart below, there is a general lowering of PAH(4) levels as development progressed, with latter v0.3 and v0.4 tests showing much promise. Final performance and PAH test results will be presented in an additional report.

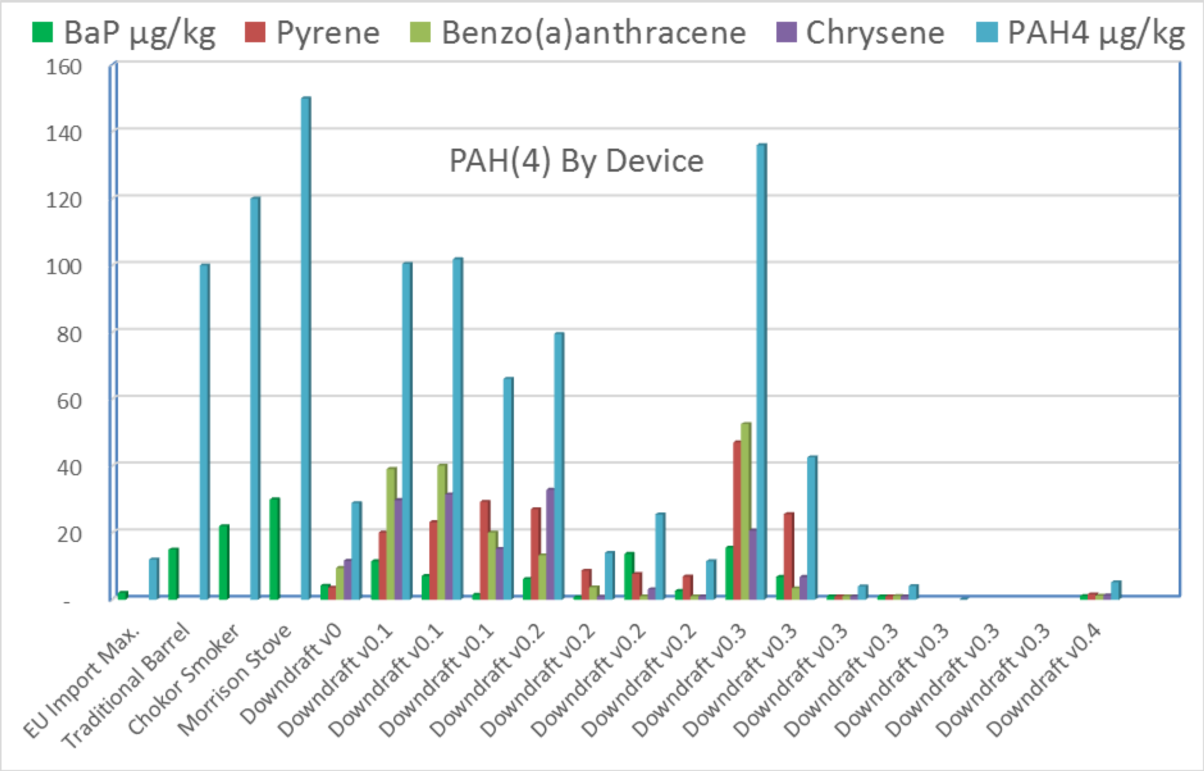

Figure 23 PAH(4) By Device

Way forward

A complete design for v0.5 has been provided in ANNEX 1 with brick by brick instructions for the construction of a dryer with circulation driven by the hot air entering on one side behind a false wall that provides a space for the buoyancy to exert pressure on the upper portion of the chamber. This will drive the circulation within the chamber

A design for a retrofit combustor was provided in ANNEX 2, aimed at being an initial design of a low-cost combstor that can be fitted to existing Morisson and Chorkor stoves.

CONCLUSION

The smoking of fish with traditional stoves leads to high PAH levels in the end-product, well above EU regulation limits. Most of the improved fish smoking stoves developed in the past 45 years have been designed to reduce fuel consumption and to ease operating process by reducing smoke and heat released in to the working environment. Recent studies by SNV have shown that some of these energy efficiency improvements produce fish with even higher levels of PAHs, most likely due to the higher processing temperature. A newly developed fish dryer, the FTT, produces smoked fish with very low levels of PAHs but is however costly, thus limiting its large scale dissemination.

This report presents a review of fish smoking technologies available in Ghana and draws recommendations on the optimal physical conditions in view of reducing PAH formation during the fish smoking process. It is based on the guidance provided by these recommendations that a low PAH, low cost and energy efficient fish smoking stove was designed and constructed, which delivered promising results at the prototype stage.

As a next stage, it is recommended that limited field trials are conducted in order to gather user-feedback and real world performance results, to then be incorporated into a second phase of development. While the work outlined in this report has achevied some significant results, this was conducted on a limited budget and so additional funds should be sought and partnerships developed in order to more fully develop this promising technology.

In addition, a low-cost combustor was also designed to offer a semi-improved performance that could be retrofitted to existing stove models. However, further development work is needed as initial results were mixed.

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Documents provided by SNV Ghana:

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- Final Fish Smoking Energy Audit October 6 2013
- 20150805 SFMP Stove Session Final
- An Assessment of the Efficiency and PAH of Divine Stove Draft
- SFMP Post Harvest Extension Strategy
- ENERGY AUDITS
- Factsheet PAH
- FINAL COMPOSITE REPORT - SNV IFS STOVES JULY 2015
- Final Presentation on PAH
- Fish Smoking Stoves Available Locally and Internationally
- Guide for developing and using the FAO
- OPEN SOURCE FISH SMOKING STOVE AUDIT REPORT
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- PAH ABU ABDALLAH
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- PAH Comparative Analysis Report FINAL
- PAHs Factsheet 2015 FINAL
- Robinson 20150806 SNV Overview SFMP Yr 2 planning workshop

ANNEX 1: DOWNDRAFT STOVE V0.5

Fish Smoker Version 0.5

Crispin Pemberton-Pigott

International Technical Consultant to SNV Ghana

Version 0.5 was developed from v0.4 which had been constructed and tested in Accra, June 2016.

Here (Figure 24) is v.0.4 which has a heat generating section on the bottom right, a drying chamber on the bottom left and a chimney that extracts air from the drying chamber. There is a vent allowing fire heat to be led directly into the chimney in order to make it function even if the change outlet gases are cool. The total height is 4.6 metres. The double 140mm diameter chimney was installed because we did not have at hand a large enough metal chimney (204mm).

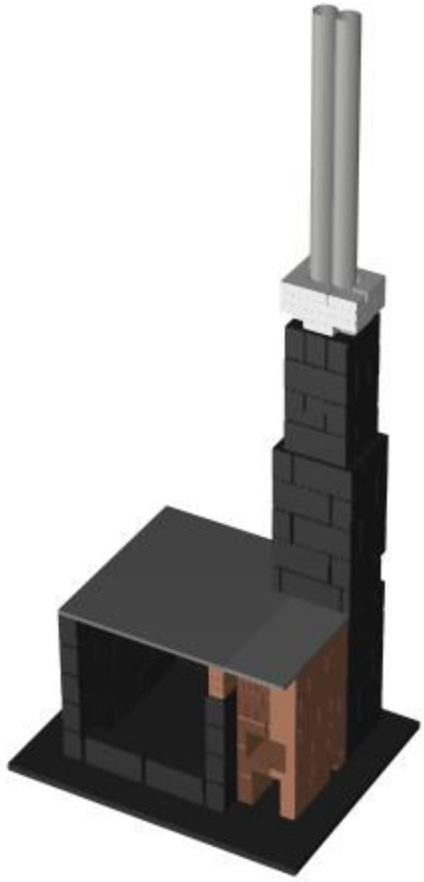


Figure 24 Stove Version 0.4

The performance was very good in the narrow sense that the PAH(4) levels in the fish for all trays were well within the EU limits. The combustor is very effective, producing a very low smoke exhaust. The clean air entry is large enough to hold 10 trays. It has no metal shelves.

The major concern is that the top tray is subjected to a higher temperature (110°C) than the lowest one (55°C) resulting in the rapid drying of the top load while those below were progressively slower.

Advantage 1 of this result is that the top tray dries first and can be removed easily without having to touch the others. The heat that was being dissipated into the fish products on the top tray moves to complete the drying of the second tray. This ‘top tray off’ sequence reduces greatly the work involved in managing the trays. At present the top tray in v0.4 is finished in about 90 minutes, and the bottom tray takes twice as long. Tests indicate that the PAH formation in fish on the top tray is slightly higher than the bottom tray, which we interpret as the result of the lower processing temperature.

Advantage 2 of this version is that the temperature of drying is low enough not to stick the fish to the supporting wires, and seems so far to have eliminated the need to invert the load to get even drying throughout the vertical height of the fish. This save is very convenient for the operator.

Advantage 3 is that the downdraft air flow causes the heat to spread out very evenly with only a small difference in temperature across each tray. This is much better than the bottom-up approach taken historically. The concentration of heat near the centre of the older technologies is a very big problem causing the fish with the most heat to cook and the edge fish to remain raw or barely untouched by the heat.

Advantage 4 is that smoke production in the new combustor is so low as to leave the fish dried, virtually 'unsmoked'. This means the amount of smoke, and the type of smoke desired, can be added afterwards in a separate operation. This two-stage processing is capable of delivering EU-compliant food products.

New developments

The high processing temperature and spatially inhomogeneous heating and drying are the major challenges encountered with the older technologies. Downdraft air flow seems to resolve this so well, it should be shared as the only approach worth considering when equipment cost is an over-riding factor. The approach to the distribution of heat (self-levelling in a descending air column) is automatic and inexpensive. The bottom-up method requires air dispersion plates and baffles. Further, even when correct, they only operate really well at one firepower level and air flow rate.

Version 0.5 is proposed to add a circulation component to the airflow without disrupting the spatial distribution achieved with the downdraft flow. The proposal is to provide an uplift on one side of the chamber driven by the fire and inducted behind a false back wall. The introduction of the gas flow in this manner will create an overturning circulation at a much higher rate than the air extraction rate into the chimney. As a result the air will flow vertically downwards, then recirculate up again, pushed by the incoming hot air. The overall effect will be to reduce the vertical temperature inhomogeneity between trays. The expected result is that the top and bottom trays will dry in more or less the same amount of time, certainly reducing the current difference. It will permit the fire to be operated at a higher power without increasing the processing temperature of the top tray.

The delivered benefits should be: reduced fuel consumption, faster processing of the whole load and less attention required by the operator.

Version 0.5

Materials are:

- standard local bricks,
- 125mm cement blocks
- 160mm cement blocks
- cast concrete top
- 204mm metal chimney
- ash-clay mortar for firebox

See the complete set of PDF files for construction information (63 files).

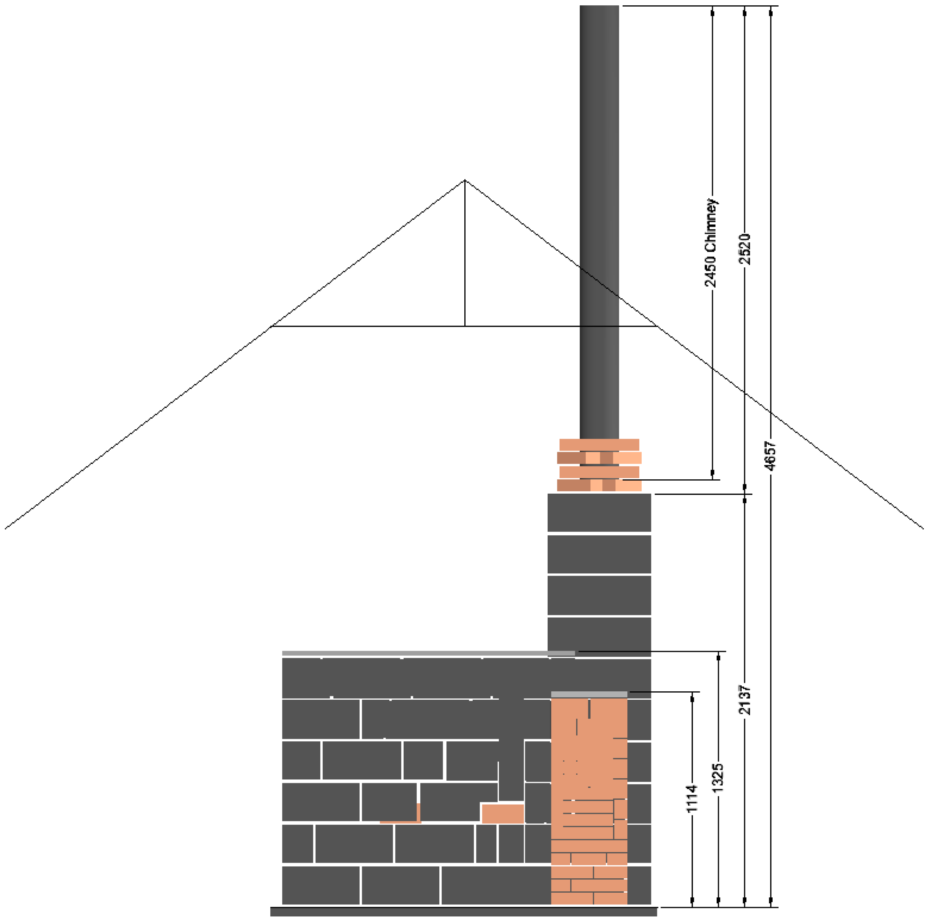


Figure 25 Version 0.5 of stove

Size

The drying chamber is centred approximately on the combustor and chimney. It doesn't have to be exact. The width of the chamber can be varied by moving the walls apart or closer to suite various sizes of tray. If the trays are much larger and the load heavier, it will be desirable to increase the firepower. This means substituting the combustor with another one. This can be done independently of the chamber. More firepower means a wider wood chamber and a 'flame tube' with a larger cross sectional area. The grate will be correspondingly wider and the combustor does not have to be taller.

Combustor

The fire chamber drawings can be created separately from the drying chamber, and can perhaps be constructed by someone more skilled than the drying chamber. As the power increases, the air passage under the side wall will be widened. Contractors should probably have a fire chamber specialist construct that first, perhaps with the chimney up to waist height and the bleeder installed - that is where most of the skill is needed.

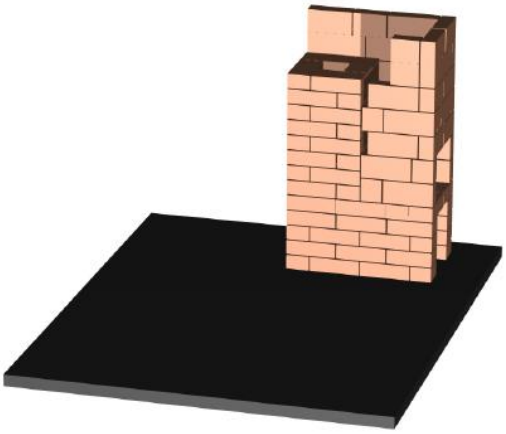
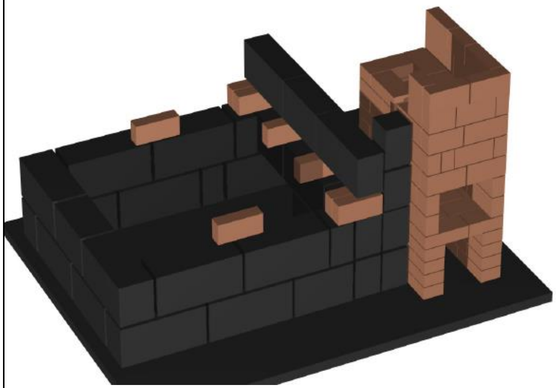
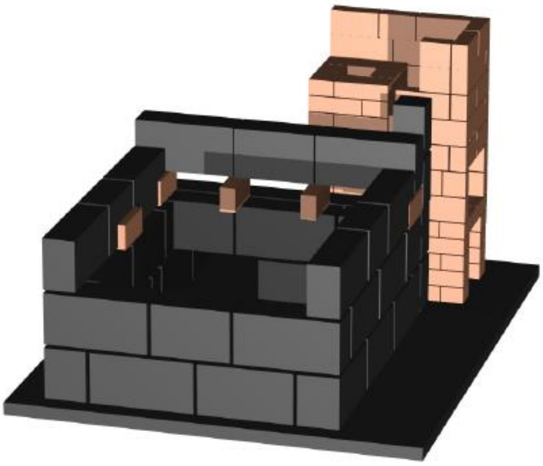
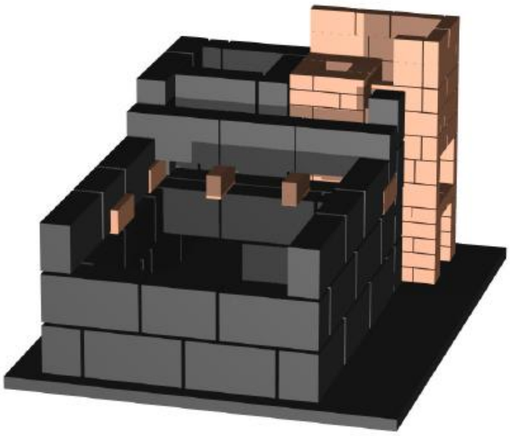
Wooden frame under the trays

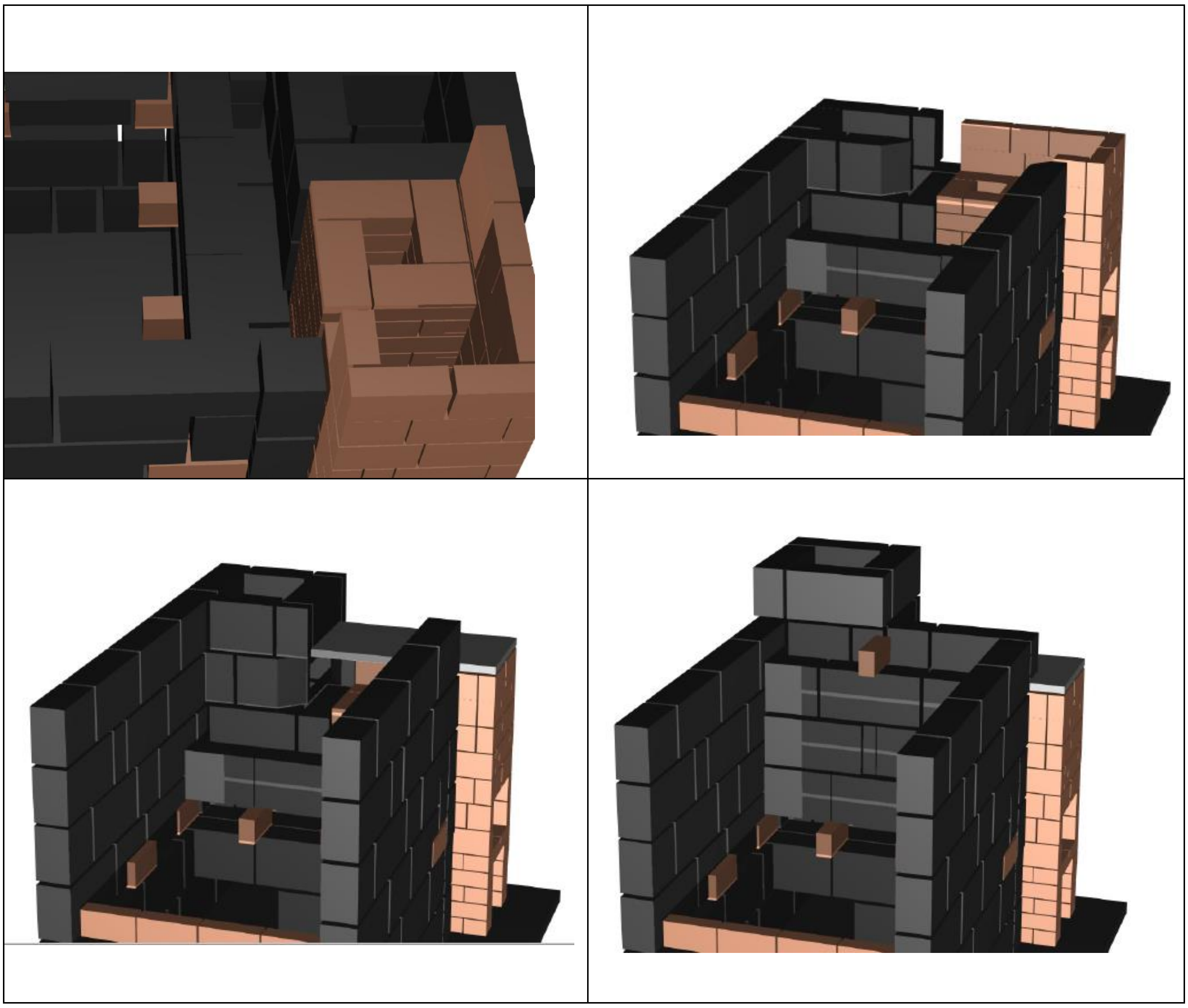
Not shown is the wood frame that should underlie the trays. It will make life easier when sliding in longer trays.

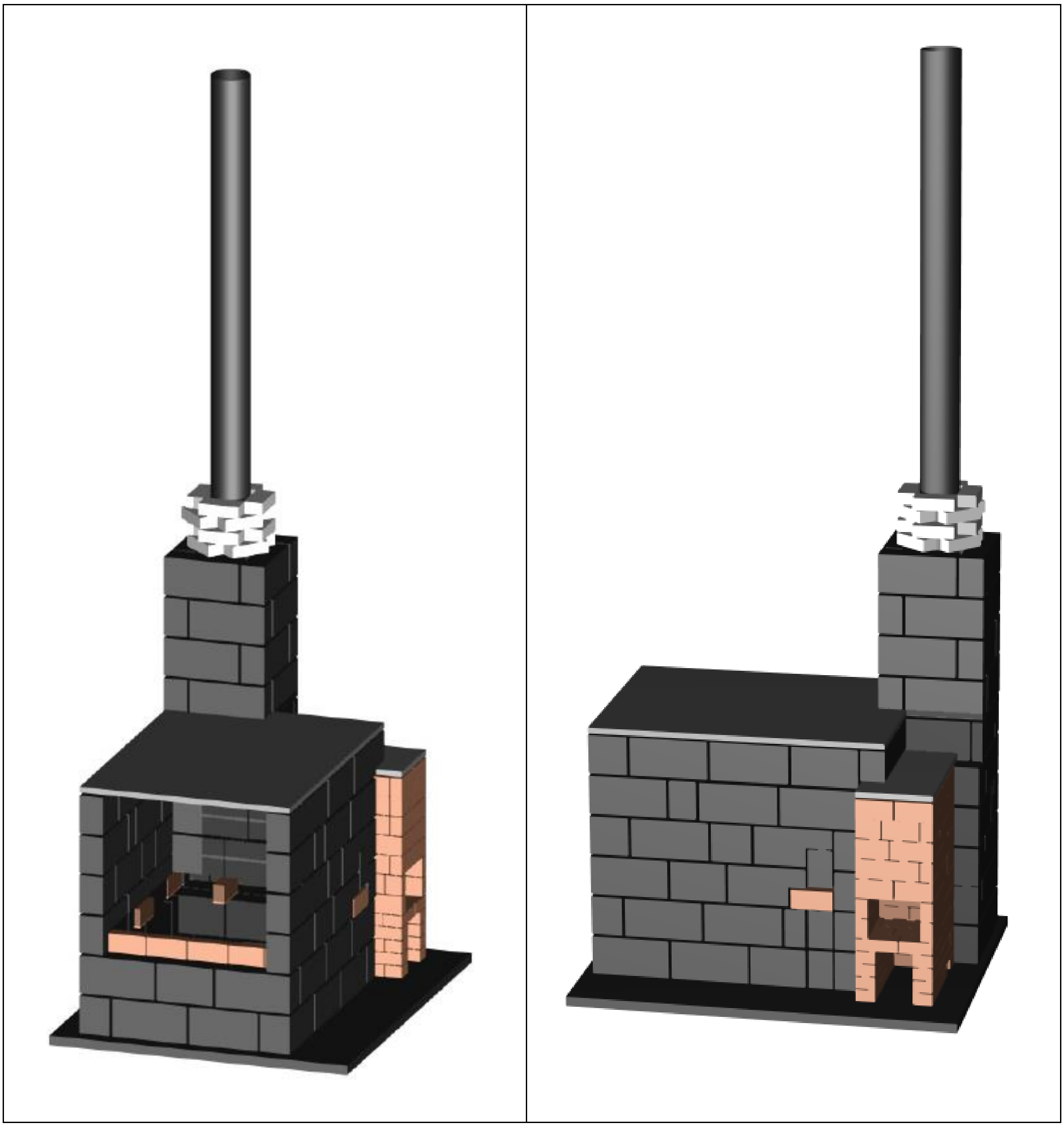
False wall at the back keyed into the side walls:

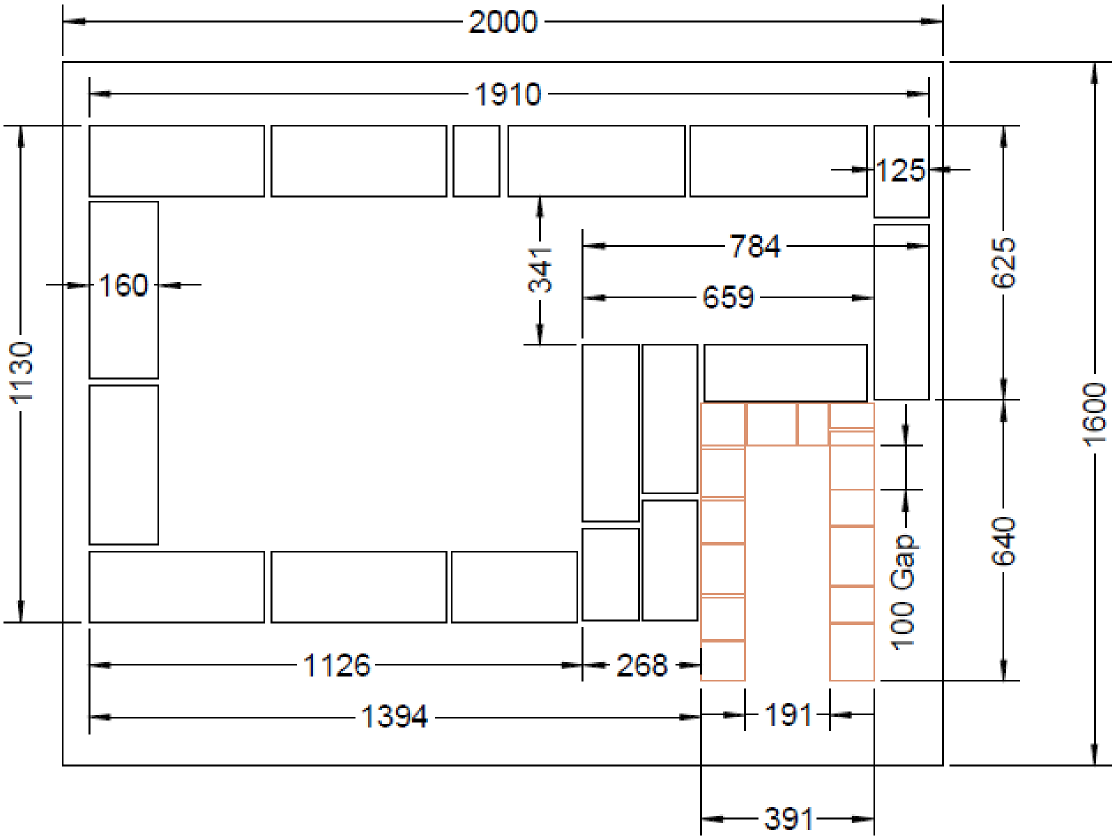
The bottom course passes into the side walls. The middle one doesn't. The top one can, and should, because people will slam the full trays back into the chamber, hitting the back wall. When the heat and cooling fractures the mortar joints, the top course being keyed into the side walls will keep it working for years.

Table 2 Construction sequence for 0.5 version of stove

Construction sequence	
	
	







SNV Fish Dryer
v0.5
24 July 2016
C Pemberton-Pigott

Figure 26 Construction plan for 0.5 version of stove.

ANNEX 2: MORRISON/CHORKOR RETROFIT DESIGN

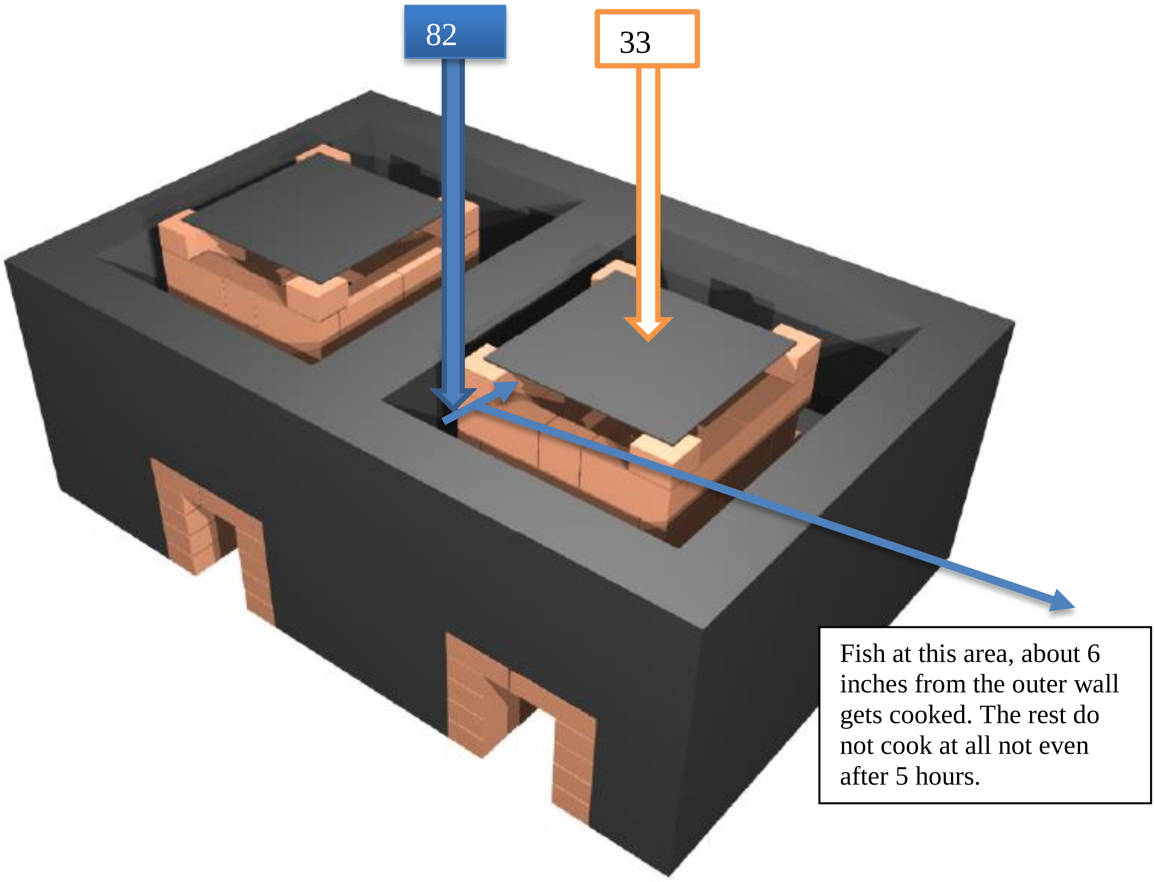


Figure 27 Retrofit of Morrison/ Chorkor stoves

The stove was constructed to the exact dimensions as in the documents submitted by the international consultant.

Observations

- There is an incomplete combustion of wood resulting in high production of charcoal
- Introducing a cover at some point raised the temperature at the center from 33°C to 50°C.
- The stove could not cook fish after 5 hrs.
- There were oil drops on the metal plate, as well as in the gap between the wall of the combustion chamber and the outer wall. We anticipate continual deposit of oil and blood at the place may cause some health issues.

Figure 28 SNV Fish Smoker – Morrison Stove Retrofit View 1

Figure 29 SNV Fish Smoker – Morrison Stove Retrofit View 2

General approach

This retrofit involves opening a new hole in the front and patching the existing fire hole. It requires a new hold made through the back wall to admit air and to help clean out the ash that falls through the grate.

The combustor is basically the same as the Version 0.4 and 0.5 (the DownDraft models). The upper portion of it is shorter and diverts the fire to the left as it enters the air mixing chamber.

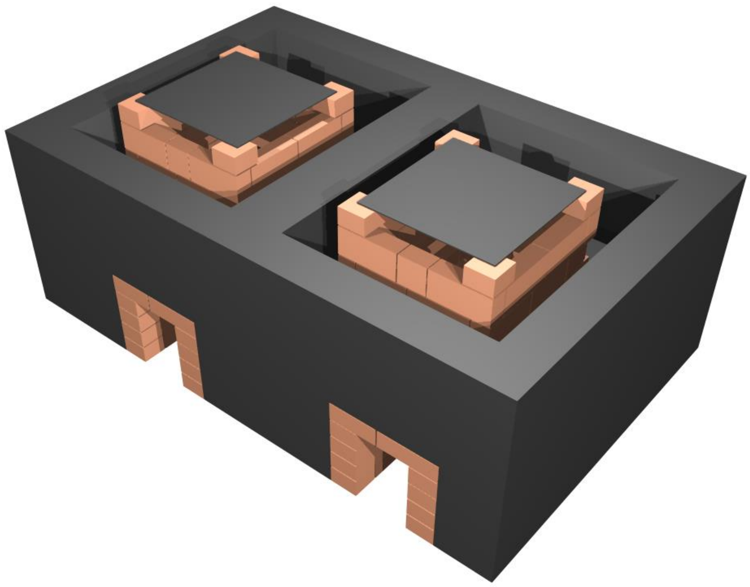


Figure 30 Retrofit view of Morrison Stove

View 1

The walls shown are the standard height of 771mm. On top of the combustor sits a metal plate 475 x 475mm with a thickness of 2mm or more. It may require holes in it to provide some heat to the centre of the plate, however this must only comprise a small percentage of the total air flow.

The plate rests loose on the four supports. It might be changed to a larger dimension such as 475 x 625 to push the hot gases towards the ends of the chamber.

The top course of 4 bricks are 100mm square and serve to create an exhaust path for the hot air. The height of the supports should be 50mm or more. A brick is suitable (63mm) but the extra 13mm of height is not required.

The next course is **optional** and it is not known at this time if it is required. It is preferred to build the unit as shown and test it. This will require raising the entire working deck enough to lift the bottom tray above the metal plate, preferable by 75mm or so. If the system works well (with the addition of holes in the plate as needed) then the second course of bricks can be removed to see if it still works. The volume contained in the second-from-top course of bricks on their side provides a mixing space for air and hot gases.

The back section is for air entry only, and has a cap of 30mm thick cast concrete, measuring 520 x 360mm. This cap does not get very hot.

Wooden frame

The latest Morrison Stove includes a built-in wooden frame. This is not shown on the drawing and should be fitted as necessary and appropriate.

Fish oil dripping

It is well known that the roasting of the fish oil dripping from the product onto the hot parts of the stove creates PAH. The operating temperature of the lower chamber is significantly reduced by this design, save the metal plate which may or may not be cooled sufficiently in the air mixing chamber. It is expected that with the greatly reduced operating temperature, the formation of PAH from dripping oil may be significantly reduced. It should be tested to see if this is the case. A drip tray is to be avoided if this change removes most of the PAH problem.

If a drip tray has to be installed, the gap between the plate and the product (lowest tray) must be increased to enable all hot air to get under the lowest tray, remembering that without perforations, the centre will be difficult to heat evenly.

Metal plate

The plate is shown without any perforations because they may not be necessary, and if they are, it will have to be determined by experiment, where to put them and how big they should be. At this time I am inclined to recommend that the holes be made with a cutting disk (angle grinder) which would make them 3mm wide and about 150mm long. The number and position is to be determined by examining the dried product.

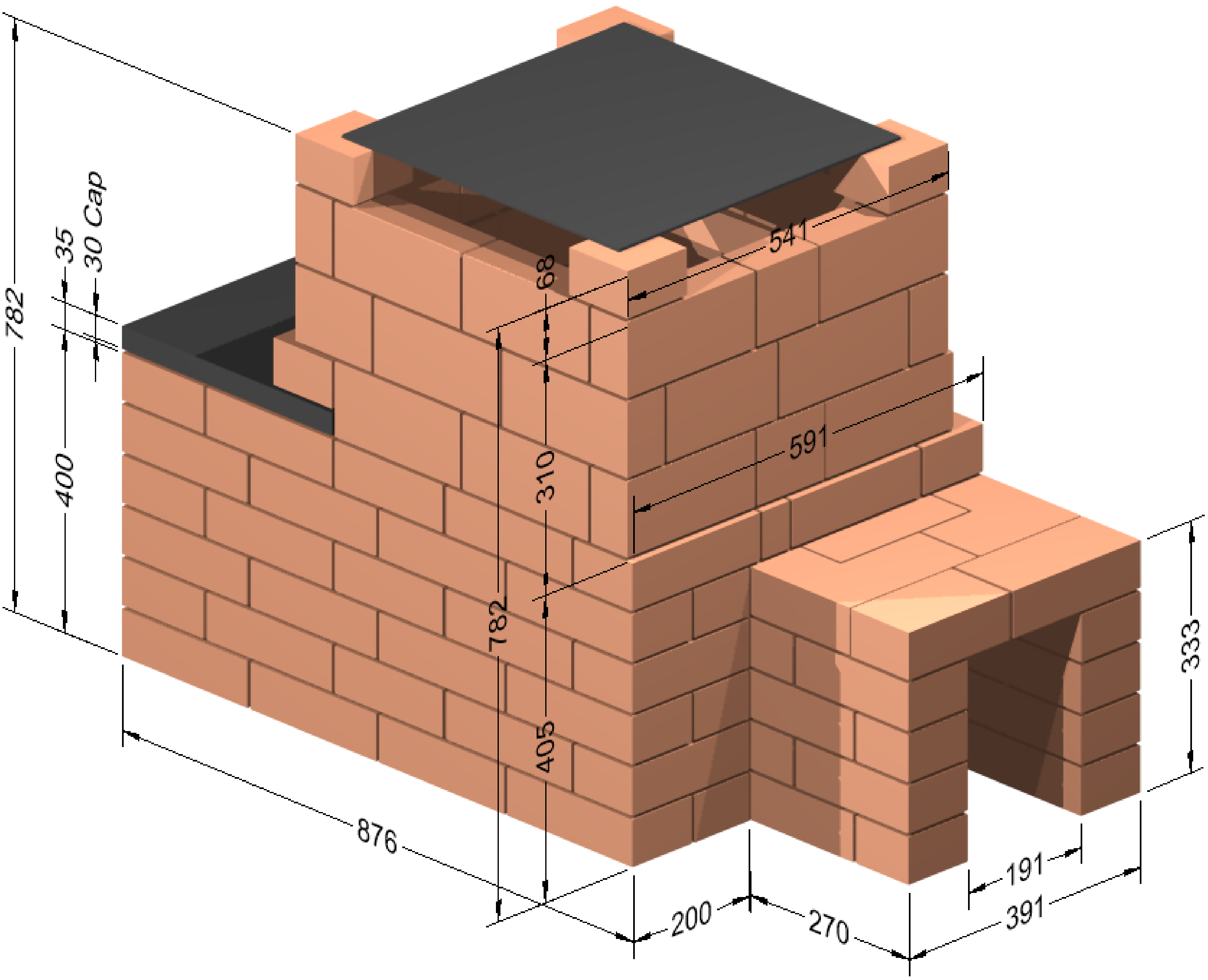


Figure 31 Drawing Retrofit Combustor