Designing an Activated Carbon Adsorption Column to Mitigate Mercury Pollution from Artisanal Small-Scale Mining in Ghana

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March 2, 2020

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A Major Qualifying Project
Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
In partial fulfillment of the requirements
For the degree of Bachelor of Science
Sponsoring Agency: Okyeman Environment Foundation

Report submitted to:
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Date: March 2020

Abstract

This paper discusses the design of an activated carbon filter made in Kyebi, Ghana to remove mercury pollution caused by small-scale gold mining. The paper elaborates on the health and safety information regarding exposure to mercury while discussing the collaboration effort with the government and miners of the region. We studied alternative approaches to artisanal mining and interviewed miners to identify the health risks of the process. In collaboration with Kyebi Senior High Technical School, we created a prototype of the filter with a three layer design: bleach activated carbon heated with an LPG oven, a clay-sawdust filter made with a 1:1 ration of clay and sawdust and a locally sourced woven cloth. The paper concludes with recommendations to expand the water filter project.

Acknowledgments

Our team would like to thank the following individuals, organizations, and institutions for their help with our project.

- **Our collaborators at Kyebi Senior Secondary Technical High School, Emmanuel and David, and the students from the sculpture and chemistry class** for giving us the materials, lab space and extra hand throughout the creation of our filter.

- **Our project advisors, Professor Robert Krueger and Professor Pratap Rao**, for their guidance and advice throughout the duration of our project.

- **Our Sponsor, Kofi Gyimah Amoako-Gyimah, The Executive Okeyman Environment Foundation Development Coordinator,** for sponsoring our project and for coordinating connections with the local miners.

- **Worcester Polytechnic Institute** for giving us this amazing opportunity to study abroad

Last, but not least, we would like to thank **our families and friends** for their never-ending love, care, and support without which this project and experience would not have been possible.

Authorship

This list states the primary authors of each section though many sections were edited by all three authors. Any photo without credit was created by the authors of this report.

Jessica Antoine -wrote the Introduction, Executive Summary, Abstract and Literature Review sections 2.3 Socioeconomic Impact of Gold Mining and 2.6 Summary. In the Methodology, she wrote section 3.2.3 Local High School Engagement. In the Results and Discussions

Ema Mehuljic -wrote Literature Review sections 2.4 The Effect of Mining on Human Health and the Environment and 2.5 Co-design Approach to Reduce Impact of Mercury Pollution In the Methodology, she wrote sections 3.2.2 Using Local Resources. In the Results and Discussions, Ema wrote 4.2.2 Access to People and created Table 2: The Cost of Local Materials for Activated Carbon Filter. Ema wrote the recommendations and conclusion.

Meron Yishaak Tadesse -wrote Literature Review sections 2.1 Global Impact of Artisanal Small Scale Mining and 2.2 Gold Mining Operations in Ghana. In the Methodology, she wrote section 3.1 Production of Activated Carbon. In the Results and Discussions, she wrote 4.2 Tests for Level of Activation.

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List of Acronyms

ASGM: Artisanal small scale gold mining
MQP: Major Qualifying Project
WPI: Worcester Polytechnic Institute
LPG: Liquid Petroleum Gas
US: United States of America
ASM: Artisanal small scale mining
PMMC: Precious Minerals Marketing Company
UC: Unactivated Carbon
B^1BAC: The first batch production of Bunsen-burner Bleach Activated Carbon
B^2BAC: The second batch production of Bunsen-burner Bleach Activated Carbon
B^1LAC: The first batch production of Bunsen-burner Lemon Activated Carbon
B^2LAC: The second batch production of Bunsen-burner Lemon Activated Carbon
LBAC: LPG-stove Bleach Activated Carbon
LLAC: LPG-stove Lemon Activated Carbon

Executive Summary

Artisanal Small-Scale Gold Mining (ASGM) in Ghana has created an environmental and human health crisis due to the use of elemental mercury (Christenson 2019). Ghana's artisanal and small-scale mining (ASM) sector continues to grow in size and significance. Its contribution to wealth creation, employment, and the economy make it one of the nation's most important livelihood activities, directly employing an estimated one million people and supporting approximately 4.5 million more (McQuilken 2016). The majority of miners in Ghana operate informally which has given rise to a to host many environmental problems such as the pollution and destruction of water bodies, degradation of arable farmland, as well as the negative health impacts of working in hazardous conditions (Hilson 2014). The use of mercury to extract gold has placed miners, their families, and the environment at great risk to an endocrine-disrupting chemical that has no viable way to be removed from the human body. The exposure to mercury has increased rapidly as the attractiveness of mercury for gold extraction has been driven by foreign influence and demand.

The Okyeman Environment Foundation is an organization founded by the current Okyenhene (King of Akyem Abuakwa, Isagyefuo Amoatia Ofori Panin) and is devoted to addressing environmental issues in Ghana. The Okyeman Environment Foundation has tasked our team with coming up with a solution to reduce exposure of mercury to miners as well as reducing the environmental impact of mercury use during ASM activities. Along with the help of the local community, we designed an adsorption system that will remove the leftover mercury from mining sites, homes and rivers. The system will provide long-term protection by restoring the environment in and around mine sites. The design includes indigenous species of plants and local carbon sources to help reclaim current damage and mitigate future concerns.

The prototype of our filter included three layers: a woven cloth layer, a clay-sawdust layer, and an activated carbon layer. The cloth layer was used to remove larger particles such as sand and pebbles. The clay-sawdust layer was created to make water potable. Lastly, the activated carbon was meant to adsorb heavy metals, including mercury. A significant part of the time spent on creating the filter was finding the resources to create the various layers. Due to the lack of a kiln, other methods of firing the clay-sawdust filter were experimented; making a pit fire, using a liquid petroleum gas (LPG) fueled oven and using a LPG fuel bunsen burner. We had two methods of activating our charcoal: using a bio activator (lemon juice) and using a chemical activator (bleach). Different methods of cooking the charcoal were also tested. Once the layers were created, they were then tested in the lab space of Kibi Senior High Technical School.

During this time, we were able to engage and teach the students about our project. After building rapport with the students, some students expressed interest in working on the project next year when more students from Worcester Polytechnic Institute (WPI) arrive. Once testing was complete, we were able to either establish sources for material needed to create each layer of the

filter and/or determine the best way of creating that layer. The two months spent in Kyebi, Ghana created connections to the locals that were pivotal in the development of the activated carbon filter.

Based on our overall experience of engaging with the local community to co-design an activated carbon filter, we propose a few recommendations for the continuation of this project: finding different sources of carbon, using activated carbon to trap mercury vapor, mapping mercury sources, and deposits, collaborating with the already established clay-sawdust pot producers in the northern region of Ghana, and establishing infrastructure for the manufacturing of the activated carbon filters. Our project was only the first step to mining, drinking water, and the environment safe for all involved.

1.0 Introduction

Artisanal Small-Scale Mining (ASM) is a sector that includes informal individual miners seeking to supplement their livelihood (Intergovernmental Forum 2019). ASM has experienced explosive growth in recent years as a result of the rising value of mineral prices and the increasing difficulty of earning a living from agriculture and other rural activities (Fritz 2018). ASM is normally low capital intensive and used high labor-intensive technology (Chambers 2019). An estimated 40.5 million people were directly engaged in ASM in 2017(Fritz 2018). ASM is known to play a crucial role in poverty alleviation and rural development, however, the sector is perhaps better known for its high environmental costs and poor health and safety record (Hentschel, 2002). Our study will particularly focus on ASM in Ghana.

Artisanal Small-Scale Gold Mining (ASGM) in Ghana has created an environmental and human health crisis due to the use of elemental mercury. The gold mining sector in Ghana continues to grow and currently employs 1 million people where another 4.5 million people depend on the mining for sustenance (McQuilken 2016). Women make up less than 10% of the legal mining operations but over 50% of the illegal operations which increases the exposure to elemental mercury and leads to increased health risks. Children also work within the illegal sector but are unable to work within the legal sector (Kippenberg 2016). The current framework of laws is only strict rules, penalties, fees to be paid and regulations that are often ignored. Small-scale miners are often displaced due to the higher interest in large operations forcing the ASGM miners further into the mining for mere subsistence. A Draft Mining Policy of 2010 was created to acknowledge the small scale gold mining sector and consider the operations as an equal contributor to the gold production (Esdaile 2018). By acknowledging the effect of small-scale operations, the government understands that the miners and government have a responsibility to reduce the effect together.

The use of mercury to extract gold has been used for many years and is well-established as an effective method for gold extraction. The use of mercury is prevalent due to the cheap cost, accessibility, and efficiency of the chemical. The drastic effects on the people and the environment have taken a great toll on the 5 million women and children that work directly in ASGM operations (Esdaile, 2018). Inorganic mercury is lost to the environment during the ASGM process which contaminates the water. Mercury is an endocrine-disrupting chemical that binds to the central nervous system and causes brain and nerve damage (Hilson 2006). It poses a great risk to fetal development and the potential for mental and physical disabilities. Despite the disastrous effects of mercury, ASGM employs 10-19 million people in over 70 countries (Esdaile 2018). The operations that use mercury operated outside of the legal sphere and the value of gold being so high on the black market are all factors that will most likely ensure the use of mercury for a long time.

The current Okyenhene (King of Akyem Abuakwa, Isagyefuo Amoatia Ofori Panin) has established The Okyeman Environment Foundation. It aims to address the following issues:

1. Promote, cultivate, sponsor, develop, aid and, aid and advance the public interest in and appreciation of environmental and natural resource preservation and protection;
2. Sponsor and assist organizations involved in environmental and natural resource preservation, education and planning;
3. Sponsor and assist individuals in the study of the environment, ecology and the sustainable use of natural resources through scholarship;
4. Sponsor lectures, symposia and workshops and publish/disseminate information about the environment and natural resources;
5. Do other tasks necessary, desirable or useful to accomplish the Foundation's goals on its own or in concert with other organizations and individuals having similar purposes.

The Okyeman Environment Foundation and the Ghanaian Environmental Protection Agency is tasked with simultaneously preventing illegal gold mining operations while remediating the devastating effects of mercury.

Our team has been tasked with designing an adsorption system that will remove the leftover mercury from mining sites, homes and rivers. The system will provide long-term protection by restoring the environment in and around mine sites. The design includes indigenous species of plants and local carbon sources to help reclaim current damage and mitigate future concerns. The project will define one key experimental area to pilot the project that will become the proof of concept. The design will come with a workable plan that can be implemented by the community with multi-year goals. We established a protocol to help enforce the integrity of the test area. We work with a local secondary school, Kibi Technical High School, as well as the local community to acquire resources and build/test the filter.

2.0 Literature Review

2.1 Global Impact of Artisanal Small Scale Mining

ASM can play a crucial role in poverty alleviation and rural development (Hentschel, 2002). Most people involved in ASM are poor and mining provided promising income. Despite this, the sector is also known for its negative environment, health and safety impacts. Many continue to view it as dirty, unprofitable and fundamentally unsustainable. Minerals mined in small-scale and artisanal mines include gold and diamonds, used for jewelry and investment, and tin, tungsten, tantalum, and cobalt consumed in industry, electronics, and batteries that power electric vehicles (Reuters, 2019). ASM is extremely prevalent in three regions: Asia, Latin America, and Africa (Fritz, 2018). Perceptions of ASM vary from country to country.

2.1.1 ASM in Asia and Latin America.

Approximately, 16.3 million people worked in small-scale mining in South Asia and 9.8 million people in East Asia and the Pacific. (Hobson, P., 2019) The largest number of miners in these regions are found in China, Pakistan, and the Philippines. Approximately, 2 million people work in the industry in Latin America and the Caribbean (Hobson, P., 2019). The largest number of ASM operators are found in Brazil and Colombia. ASM in Colombia plays a large part in the nation's total gold production by representing 72 percent. Occasionally, ASM is combined with the agricultural process and the use of hazardous Mercury in the mining can contribute to significant health and environmental issues. For instance, this is observed in a small-scale mining village in Cisitu, Indonesia. Mercury is used to extract gold from ore and contaminates the environment including their fish and rice paddy fields which is their main source of food. Medical examination and reports from this village show severe diseases related to high mercury exposure. This may have been caused by the consumption of mercury-contaminated water and food (Bose-O'Reilly et al., 2016).

ASM policies in Asia can differ drastically within a single country. In the Philippines, for instance, local and regional policies and practices can differ greatly between the 30 provinces where ASM occurs. National legislation regulates ASM but has limited and/or variable impacts on the ground, as there are livelihood alternatives for miners and many regions have their own legislation (O'Faircheallaigh and Corbett, 2016). In Latin America, the policies governing ASM vary from country to country, but also has strict regulations on informal operators and the use of certain substances. However, these policies are not heavily implemented due to limited capacity.

2.1.2 ASM in Africa

ASM plays a significant role in the economies in at least 23 sub-Saharan African countries. The mining sector in Africa is growing rapidly and is the main recipient of foreign direct investment (Chuhan-Pole, 2015). According to reports by Reuters, 9.9 million people worked in ASM in sub-Saharan Africa, with 2 million in the Democratic Republic of Congo and between 1 and 1.5 million each in Sudan, Ghana, and Tanzania (Fritz et al., 2018). The number of people dependent on ASM activity in Africa was found to be between four to 12 times the number of ASM operators and is increasing with time (Fritz et al., 2018). The number of total ASM operators in Africa increased from approximately 2 million to 9.98 million from the period of 1999 to 2014 (Fritz et al., 2018). An increase in the number of involved countries is also observed to increase from 24 countries to 40 countries during the same period of time of 1999 to 2014 (Fritz et al., 2018).

ASM in sub-Saharan Africa is seen as a way to mitigate the problems caused by poverty. (Fritz et al., 2018). It requires intensive labor but provides more job opportunities as compared to large scale mining in Africa (Union, A., 2009). The sector can promote positive impacts such as offering direct and indirect job opportunities and also increase profit generated which increases purchasing power and improves economic activity at the local level (Benkenstein, 2012). This was officially recognized by African Mining Vision 2050 which stated "harnessing the potential of ASM to improve rural livelihoods, to stimulate entrepreneurship in a socially responsible manner, to promote local and integrated national development as well as regional cooperation." Additionally, ASM contributes to foreign exchange earnings and reduces the migration from rural to urban regions. (Union, A., 2009)

Despite the positive impacts, ASM has problems with sustainability. This results from the failure to recognize ASM in local and international development agendas due to the negative perceptions of ASM (Benkenstein, 2012). ASM commonly operates in remote, unregulated and environmentally sensitive areas. Most ASMs also operate with little to no mechanization or equipment, and techniques are rudimentary in nature (Union, A., 2009). In areas where mechanization and equipment exist, they are inefficient and hazardous to the miner and the environment. As a result, production is low and income remains at a subsistence level (Union, A., 2009). Some of the examples of the negative impacts of ASM are child labor and environment pollution (Benkenstein, 2012)

Among the minerals mined by ASM in sub-Saharan Africa are diamond, gold, cobalt, sand, and colored gemstones. The processes of mining available precious minerals vary from country to country in Africa. For example, the main mineral mined by ASMs in Angola is diamond while the main mineral in Ghana is Gold (Fritz et al., 2018).

2.2 Gold Mining Operations in Ghana

Ghana is known for its long history of gold mining and its significant portion of the world's total gold production. During its colonial period, Ghana was known as the Gold Coast Colony. (Chuhan-Pole, 2015) Currently, Ghana holds the top spot as Africa's largest gold producer. (B.Stewart, 2019)

2.2.1 History of Gold Mining Operations

Ghana's first gold rush happened in the last decade of the 18th century followed by its second gold rush after World War I (Chuhan-Pole, 2015). The total gold production of Ghana had decreased and remained low until the 1980s. However, Ghana's annual gold production has skyrocketed by 700% in the past 20 years. The high international price of gold is believed to have contributed to the expansion of small-scale mining (Chuhan-Pole, 2015). In 2014, Ghana was found to be one of the four countries to have an average of more than 1 million miners in Africa (Fritz et al., 2018). By 2016, Ghana had 1.1 million operators directly working in ASM and had 4.4 million estimated number of dependents (Fritz et al., 2018). Among the main minerals mined in ASM in Ghana are Gold and Diamond (Fritz et al., 2018). Ghanian ASM contributed to 9% of the world's total gold production in 2000 and by 2010 it had risen to 23% with more than a million miners engaging directly in ASM (Benkenstein, 2012).

ASM in Ghana is administered by formal ASM policy and its ASM legislation that has an incentive-based approach. The policies are regulated to avoid child labor and support miners to get a fair trade for the minerals and the equipment they use, etc (Fritz et al., 2018). In 2010, the Ghanian government released a 'Draft National Mining Policy of Ghana' to recognize economic benefits and employment opportunities created by ASM as well as tensions with large scale mining (O'Faircheallaigh et al., 2016). The policy encourages large scale mining companies to support small scale miners and form a symbiotic relationship benefiting both parties (Government of Ghana, 2014). However, this contradicts the usual approach by senior Ghanaian government officials who condemn and call for the eradication of the illegal ASM also commonly known as galamsay (Srem, 2014). While most of the Ghanian ASM is viewed as an illegal activity by the National Government, this is often not the situation with Galamsey miners being granted rights to mine under customary laws from the local perspective (O'Faircheallaigh et al., 2016).

ASM is characterized by a significant migration of the workforce within countries and between neighboring or other countries and this makes it difficult to generate accurate estimates. (Fritz et al., 2018). Over the past decade, an estimated 50,000 Chinese people had relocated to rural Ghana to pursue mostly illegal mining activities (Hilson et al, 2014). This has sparked the interests of the global public and the media's attention. The government of Ghana has responded by assembling a National Task Force to pursue illegal mining and serve them justice. (Hilson et al, 2014). However, it can be argued that this is only a short term relief as the increasing number of illegal involvement of Chinese people is the latest 'symptom' of ASM (Hilson et al, 2014). To tackle the inflow of Chinese immigrants into the rural mining sector, it is essential to address the root causes of the informality and bureaucracy (Hilson et al., 2014).

2.2.2 Current Gold Mining Operations

The process of mining constitutes exploration, development, exploitation, and transportation. ASM miners are usually not involved in the exploration part of the mining process (Emmanuel, 2011). This section of the mining process is predominated with large scale miners (LSM) who are financially capable and have larger means of getting around. Unlike ASM, LSM usually uses sophisticated mining machinery including but not limited to excavators, drilling machines, dozers, and dump trucks. At the end of the LSM process, the site is usually disturbed and exhibits environmental issues. The environmental issues may include land degradation, water contamination, flora depletion, destruction of arable lands, and mercury contamination. These safety concerns have and may lead to some fatalities and injuries (Bansah et al., 2016).

The Kibi district is a gold enriched region in the Eastern Region of Southern Ghana. (Srem, 2014) In Osino, Kibi district, there are three widely known large mining companies. These are:

1. Kibi Goldfields Limited (KGL) (Ghanaian origin) is Located in Osino, Volta, Ghana. It obtained a recognizance license from the Minerals Commission in 1986 and its environmental permits in 1994 and 2002 from Environmental Impact Statement (EIS) and Environmental Protection Agency (EPA) respectively ("Kibigoldfields," n.d.).
2. Xtra-Gold Resources Corporation (Canadian origin) is located in the Kibi Gold Belt region and owned concessions which are secured by 5 mining leases (Xtragold, n.d.).
3. Narawa Mining Company LTD (Israeli origin) is located in Osino, Volta, Ghana (Otieku, 2020).

The artisanal small scale miners (ASM) work on sites that were once owned and operated by the large scale mining. The left behind sites look like the one in Figure 1.

Figure 1: ASGM Site in Osino, Ghana

The process of ASM to recover gold from the mining site is as follows:

1. Excavation of mineral-rich bedrock and unconsolidated materials using rudimentary tools such as picks, shovels, etc…
2. Transfer of excavated materials into a crusher and grind up the soil material into finer particles. This crusher is also attached to a machine known as a chan fan. The chan fan also serves as a motor to run the crusher. Finally, both machines are attached to a plate of wood that receives the outflowing material.
3. The chan fan and crusher are also attached to a water pump that pressurizes and pushes underground water into the fine particles coming out of the crusher. The goal of this step is to wash away any irrelevant dirt and material from the fine particles. Since gold is a heavy metal, it will sink to the bottom of the plate of wood also known as a sluice board.
4. The sluice board is covered with two consecutive mats that have the ability to trap the fine particles of gold. The second mat has finer strands that can trap any gold that has not been trapped by the first mat. These mats are continuously washed into a rubber bowl of water to transfer the trapped gold.
5. After every 8 hours of nonstop mining shifts, the rubber bowl is carefully drained while making sure that the gold has sedimented to the bottom.
6. The ASM operators then use their hands and liquid mercury to create an amalgam by gently mixing and rubbing the rubber bowl content. They also use water to rinse out the amalgam to washout any unwanted contaminants.
7. The ASM operators, next, use a handkerchief to squeeze out and remove any remaining mercury.
8. The amalgam in the handkerchief is then heated with a blow torch to evaporate mercury. This will produce gold that is then sold to Precious Minerals Marketing Company (PMMC). PMMC is the sole organization responsible for buying and selling Ghana's precious minerals (PMMC, n.d)

2.3 Socioeconomic Impact of Gold Mining

ASM provides support to the livelihoods of over 1 million people in Ghana, especially for those living in poor rural areas. Men, women, and even children participate in the ASM sector. Mining contributes a large amount to GPD and to fiscal revenue. Despite its contribution to economic growth, ASM has negative impacts on the health of those involved, the education of children, the livelihoods of those in the agriculture sector and more. A large factor of this is due to the use of harsh chemicals such as mercury that are detrimental to the health and safety of people and the surrounding environment.

2.3.1 Influence on Job Availability

Most miners in the artisanal small-scale gold mining (ASGM) sector support not only himself but three to five other family members which is why the mining sector has become so economically important to rural Ghanaians (Teschner, B. A. 2012). Small-scale miners in Ghana are unique to informal sector employment in that wage labor is absent, though workers are not paid poorly. Small-scale miners are largely attracted to the sector by the opportunity to earn relatively high wages (which is equivalent to $5-$10 per day) (Teschner, B. A. 2012).

Many youths frequently become involved in this type of mining. Globally, there are more than 1 million children working in ASM (O'Driscoll, 2017). Due to the illegal nature and practices of ASM, it is difficult to estimate how many children in Ghana are involved in this sector. According to Thorsen (2012), poverty is the main reason why children of school-going age enter into mining work. In cases of extreme poverty, children's contribution may be important for household food security, especially if alternative opportunities exist. According to the International Labour Organisation, mining falls under section D of Article 3 of the ILO's Worst Forms of Child Labour Recommendations of 1999. The types of work referred under this article include:

A. Work which exposes children to physical, psychological or sexual abuse;
B. Work underground, underwater, at dangerous heights or in confined spaces;
C. Work with dangerous machinery, equipment, and tools, or which involves the manual handling or transport of heavy loads;
D. Work in an unhealthy environment which may, for example, expose children to hazardous substances, agents or processes, or to temperatures, noise levels, or vibrations damaging to their health;
E. Work under particularly difficult conditions such as work for long hours or during the night or work where the child is unreasonably confined to the premises of the employer (ILO 2002)

Young boys between the ages of 10-16 are often used to explore deep holes of about 40-70 feet down, are used as errand boys, and for sieving gold dust (Gold Fields Ghana and Opportunities Industrialization Centers International, 2005). There are both short term and long term health effects for all miners, but especially for children in this sector. Children in gold mining may be exposed to lead or mercury poisoning, as confirmed by Mwami (2002), that mercury contamination caused by the amalgamation of gold in gold mining is an environmental problem of increasing concern and the exposure to mercury could have adverse effects on children. These conditions predispose children to a variety of health risks such as lung-related diseases, fever and bilharzia, headaches, pneumonia, stomach aches, dysentery, and malaria (Mwami (2002).

There is also a growing issue of female participation in the artisanal small-scale mining sector. Nearly 50% of those employed in small-small scale mining are women (Yakovleva, N.

2007). Female participation can either be direct (primary engagement in mining operations) or indirect (servicing mine sites). Direct roles include panning, sluicing, and separation of gold. As a result, women receive lower pay. There are sites where women are organized in groups of 10-15 people and load trucks with gravel and sand (Yakovleva, N. 2007). More hazardous activities, such as underground work and the burning of amalgam, are conducted by men (Yakovleva, N. 2007). At some points, health authorities in the Birim North District reported and increasing number of respiratory diseases in children and linked it to the effects of mercury from gold mines (Yakovleva, N. 2007). The main drive for increased female employment in galamsey mines is the need to bring income to households as well as the lack of employment opportunities.

2.3.2 Economic features of small scale gold mining

It is common for developing countries with high poverty rates to also have an abundance of mineral resources. This mineral wealth is usually extracted through large scale mines, which are high capital intensive and therefore provide few employment opportunities for locals (Guenther, 2018). Migrant miners continue to fuel the economically significant ASM sector through much of sub-Saharan Africa. Mining is a major industry in ghana. It contributes 8% to GDP and 16% to fiscal revenue (Guenther, 2018). Gold accounts for 97% of this revenue and makes up 23% of all exports (Guenther, 2018). Up until 2006, most of Ghana's gold production originated from large-scale mining. ASM began to grow as a result of an influx of foreign capital, technology and labor, as well as the value of gold increasing (Guenther, 2018). ASM in Ghana has developed into a major industry and it accounts for more than one million jobs directly and over four million indirectly through downstream industries. It has been estimated that there is a higher per-capita income for areas with high ASM activity. In addition to this, more households have access to electricity, more people are literate, and fewer individuals work in agriculture. (Guenther, 2018).

The negative impacts of ASM have led to a decline in capital resources or investments in the agriculture sector. Ghana is endowed with valuable minerals such as gold. Due to the increasing price of gold, there has been an expansion of exploration and exploitation of gold into agricultural lands, which are sometimes forceful and destructive of farmlands and the livelihoods of some communities (ACET 2017). The ASM sector is comprised of individuals who are trapped in a cycle of poverty, lacking means to improve their standard of living (Hilson 2006). Miners are burdened with the costs associated with the deterioration of their health. In addition to this, these small scale miners are often forced to sell their gold at discounted prices to monopsonistic middlemen who quote below-market rates for gold (Fritz 2018). Miners face considerable challenges in their efforts to improve the mining process; they find themselves unable to mobilize the funds needed to purchase sophisticated equipment (Fritz 2018). One large factor fueling poverty within the ASM sector is the use of mercury to create an amalgam with gold. Mercury is an environmental pollutant and is toxic to a wide range of animal species, including humans

(Tchounwou 2012). Individuals working within, or downstream of ASM regions can become readily exposed to metallic mercury.

2.3.3 Social features of small scale gold mining

Public perception of ASM is largely driven by reports on social issues such as child labor, prostitution, drug abuse, corruption, and violence. As a result, ASM operations are often associated with and blamed to cause extreme poverty (Hilson 2006). Gold prices have witnessed a substantial increase over the past decade, rising from an average of USD 270 per ounce in 2001 to nearly USD 1800 per ounce in early 2012 (Nyame, 2014). As a result, many migrants have joined the ASM sector in Ghana. Activities often begin small, but within a short period of time, areas will become more populated. For example, in Kuii, which is in the northern region of Ghana "there was not even a single hut or house a few decades ago…[has] become so big that it is now probably the largest illegal mining site in West Africa with people from Ghana, Burkina [Faso], and other countries operating at the place" (Nyame, 2014).

Small scale surface mining is considered one of the greatest agents of land degradation and destruction, destroying about 13% of the total forested land in Ghana. A study revealed that surface mining resulted in about 58% deforestation and a substantial 45% loss of farmland within mining concessions in the western region of Ghana (Arah, I. K. 2015). The majority of the mining concessions are found in and around forests, agricultural lands, and human settlements resulting in competition for land and depriving farmers of access to farming land. In Ghana, many communities have been displaced totally as a result of mineral deposits found in those communities (Owusu, 2012). The relocation of communities leads to loss of social ties, psychological problems, and disturbance to the communities' way of life. For example, 14 communities with about 30,000 inhabitants were displaced between 1990 to 1998 as a result of mining activities in Tarkwa in the western region. There was increased pressure for accommodation and an increase in unemployed youth, and as a result, engaged themselves in illegal mining. Often times, these circumstances could generate other social issues such as drug trafficking, prostitution, and high high-school dropout rates (Owusu, 2012).

2.4 The Effect of Mining on Human Health and the Environment

ASGM is an illegal form of gold mining that involves the use of elemental mercury to extract gold from the ore through the process of amalgamation. The amalgamation process is ideally done in enclosed equipment with vapors being captured prior to the release into the environment. In ASGM, however, the precautions that should be taken are often overlooked and miners handle the mercury directly. The exposure to elemental mercury to the environment has put miners, miners' families, the ecosystem and the river at high risk for mercury poisoning.

2.4.1 The Use of Mercury

ASGM in Ghana has created an environmental and human health crisis due to the use of elemental mercury. The use of mercury is prevalent due to the cheap cost, accessibility, and efficiency of the chemical within the mining industry (Rajaee 2015). The drastic effects on the people and the environment have taken a great toll on the 5 million women and children that work directly in ASGM operations (Bush 2009). The evaporation of methylmercury when miners burn the amalgam of gold and mercury creates a dangerous environmental and human health problem. The elemental mercury that is used is not readily soluble in water but the methylmercury that recondenses does bioaccumulate in the environment. The methylmercury that is vaporized recondenses quickly and therefore can be hard to trace the level of contamination of a particular area. Winds can easily transport the methylmercury far from the mining site but also the surrounding streams can have droplets condense in the water. The contamination, therefore, spreads to surrounding communities and infiltrates the reservoir of water. The contamination can then bioaccumulate in fish which then biomagnifies the mercury when bigger fish ingest the smaller ones. The allowable level of mercury in drinking water is ideally zero. Therefore the mercury that is in the environment even at seemingly low levels is still high in comparison. The majority of the mercury burning is also done at the home site of the miners. The current disposal method of mercury is simply burning off the mercury from the amalgam. There is currently no particular disposal method of the bottles that mercury comes in either so most are just thrown at the sides of the mining site. The mercury is treated with care in the sense that the miners try to limit the amount that they use due to the high cost. The mercury, however, is mostly burned off and disposed of into the air.

Inorganic mercury is lost to the environment during the ASGM process which contaminates the water (Esdaile, 2018). Mercury is an endocrine-disrupting chemical that binds to the central nervous system and causes brain and nerve damage. The form of mercury found in the water, methylmercury, poses a great risk to fetal development and the potential for mental and physical disabilities (Dzigbodi 2014). Mercury readily crosses the walls of the gastrointestinal tract through biological membranes, where it accumulates in the envelopes of nerve cells and can cause neurological damage. The proliferation of the mercury within the environment and the bioaccumulation within human organs have caused kidney failure due to mercury poisoning to be the highest cause of death in Ghana (Davor 2019). Signs of acute mercury poisoning include neuromuscular malfunctions such as loss of eyesight, tremors and paralysis, depression and other behavioral disturbances (Fernandes 2012). Individuals working within, or downstream of, ASM regions can become readily exposed to metallic mercury through the amalgamation process itself, during which it is mixed atop wet sluices containing gold-aggregated sediments, and through inhalation of vapor produced when amalgam is burned to purify gold (Hilson, 2006). The transferring of mercury from the mother to fetus can also affect multiple generations of the populations living next to the ASGM operations.

Wildlife and plant life are greatly affected by mercury contamination due to the direct impact on biodiversity (Bonzongo 2004). ASGM operations are often located in diverse areas in the world such as the Amazon Rainforest and comparable places in Africa, Asia and other areas of South America. The people that live near these areas often depend on fish as the main resource for food which exposes the population to mercury at a concentrated level as the mercury is stored in animal tissue (Junaidi 2019). Coastal Lagoons in Ghana serve as prime commercial fishing areas and the rise of mercury accumulation is compromising food security. In 2016, a study of 45 fish specimens from the top two consumed fish in Ghana found that 5% contained mercury levels 2-4 folds higher than the allowable amount of mercury in fish (Gbogbo 2018). The cyanide-mercury water is often sent back into the environment where it contaminates the drinking water. The water is used to irrigate food, contaminating rice and food security. The health and ecological impact is drastic and destroys the productivity of many ASGM communities in areas outside of the mining (Esdaile, 2018). Elemental mercury can cross the blood-brain barrier and blood-placenta barrier creating neurological damage and hindering fetal development. Women of childbearing age in these communities have high levels of mercury in their bloodstream. Children born in these areas are born with brain damage, limb deformities and a variety of deformities (Colvin 2016). The exposure through direct interaction with the mercury and then the derivatives of mercury exposure within the drinking and food sources create a complex situation that requires multiple approaches for mitigation.

2.4.2 Degradation of Land

Mining has a significantly destructive impact on the environment. The destruction is analogous to the Superfund sites that have major chemical spills and environmental disasters. Ghana became the top producer of gold in Africa in 2019 surpassing long-standing South Africa with the production of 180 tonnes of gold (Njini 2019). Ghana also became the top country in the world to be losing rainforests due to the clearing of land to mine for gold (Asiedu 2019). In a statement from a 2016 report by the Forestry Commission, it was stated that a combination of logging to sell timber and forest removal for mining has resulted in 80% of Ghana's forest resources under state management to have been lost since 1989 (Status 2016). Galamsey is the local name for the ASGM operations and has been attributed to degrading 2.5 square kilometers (4.4%) of the Offin shelterbelt reserve in 5 years (Boadi 2016). At the beginning of the 20th century the original reserve contained 8.2 million hectares but from mining and logging the total has decreased to only an estimated 1.6 million hectares (Boadi 2016). Loss of vegetation and shrub variety has resulted in lesser tree densities that are contributing to desertification as trees are disappearing at an expedited rate (Tom-Dery 2012). The tripartite approach of addressing deforestation requires management, development, and the environment to create a complex problem that requires all three to work harmoniously (Tindan 2013). The Ghanaian Environmental Protection Agency has now been tasked with simultaneously preventing illegal gold mining operations while remediating the devastating effects of mercury (Christenson 2019).

2.4.3 Water and Air Pollution

The mercury that is used within the ASGM operations is not often recovered and leaves tailings that end up downstream from the sites and can contaminate areas far from the mines. Many rivers have been diverted for the mining process and have turned crystal clear drinking water into contaminated opaque brown water (Kusi-Ampofo 2012). It is estimated that 650-1000 tonnes of mercury are deliberately released each year into the environment and ASGM is the main culprit (UNEP, 2008). The chemicals used throughout the process seep into the soil and through the water cycle is then evaporated into clouds and affect places far from the site of conception (Emmanuel 2013). The contaminated rivers provide water to the surrounding villages in Ghana despite their use within the galamsey sector. Due to this water not being safe some have turned to buy sachet or bottled water. The increase in people using sachet water has changed the drinking water landscape and rapidly increased plastic pollution (Stoler 2012). The cost of buying bottled water is a recent phenomenon as well and has caused part of the tight income to be allocated to bottled water (Wardrop 2017). The current involvement within the mining sector to disband the mercury pollution has up until this point been purely technical which completely avoids the socio-political reality of the mining industry. The evaporation of mercury and other chemicals used in mining provides another pathway, air, for pollution to spread and disease to be rampant (Armah 2013). In a study done in 2016, with 1,001 miners, 47.55% were found to have asthma as a result of working within the mining industry (Ayaaba 2017). The task of miners' health being traded to provide for their families has created a delicate problem. An appropriate approach to addressing mercury pollution would need to include a design that involves the community affected to create a solution. In order to create a successful solution, a co-design approach that involves the local community, the miners and the environmental foundation is the next course of action needed to address the mercury pollution effectively.

2.5 Co-design Approach to Reduce Impact of Mercury Pollution

The approach to creating a sustainable filter design that is used within the community needs to involve the community within the research design. The co-design approach defines the issues and creates the context of the problem by involving the locals affected by the problem throughout the whole process. Through this design method, the problem and solution are created with the community so that the filter can be known about and used when the facilitators leave to go back.

2.5.1 The Implementation of Co-design

The mercury pollution in Ghana involves intervention from the aspect of the government, the miners, and the local community. The key role that our team played within this intricate situation is to provide possible solutions using local resources while simultaneously working with each stakeholder. The basis of human-centered design, and in particular with this project, begins with the definition of the sociological problem that is presented within Kyebi, Ghana (Smith 2010). A sociological problem is often started from an idea or more often from a personal experience that was indicated by seeing or hearing of a situation that needed to be addressed, hence the problem of the mercury pollution from the mining operations. The elusiveness of the social world regarding mining as it is an illegal practice creates difficulties due to the dependence on the perception of a problem from each stakeholder (Sanders 2008). In order to remedy such difficulties, the inclusion of each perspective to scale the depth of the complex problem is essential in order to prevent the mistakes of failed development projects.

The importance of a co-design approach comes from an overview of past development projects that have created more harm than successful solutions. The reason many development projects have failed in Africa is due to the distorted narrative created to interpret the situation (Aronson 2017), The oversimplification of entire communities such as in, The End of Poverty by Jeffrey Sachs, where he attempts to lift poverty through targeted assistance in his Millenium Villages Project, more problems were created than solutions (Munk 2014). The Millennium Villages were spread across 10 countries in Africa that were stocked with malaria nets and pesticides to remake the African village (Sachs 2005). The project was documented by Munk in her 6-year journey to explore the Millenium Village and she wrote a cautionary tale about the damage that was done when aid was dropped onto the villages which then destroyed the local infrastructure (Munk 2014). Unfortunately, the Millenium Village is only one of many failed attempts to comprehend the complexity of development. The approach of co-design to create an understanding of the situation as well as guiding the solution attempts to address the problems presented in previous approaches.

The fieldwork is of great importance as one is to be guided by experience and an essential aspect that has often been missing in other approaches (Sanders 2008). Within the field, however, the ethnographer is not free of theory or previous thought as meaning is interpreted from the experience, the narrative of the field, the theory and the perspectives of the locals as well as those exploring the field for the first time (Anzul 2003). Co-design involves the blending of two frames of thinking where each side is equally as valuable in the end result (Sanders 2008). The importance of a diverse approach adds inherent value to the sustainability of the project as the project is braided into the framework that is valued to the villagers. Ownership of the work is therefore multi-faceted as it includes the time and effort of everyone who is affected by the project (Daynes 2018). This approach fundamentally changes the projects upon arrival which then allows for consistent involvement and ownership from the locals who will continue the project once we have left.

2.5.2 Activated Carbon

Activated carbon is a porous carbon material that has been treated with a combination of heat and pressure followed by carbonation to make a highly porous and large functional surface area (Dalefield, 2017). Activated carbon uses adsorption which is a surface process that leads to the transfer of a molecule from fluid bulk to a solid surface to absorb heavy metals. Physical adsorption is a common way by which activated carbon is used to remove contaminants from liquid and vapor streams (Ekpete, 2017). Activated carbon can be made from a variety of sources that are cellulosic based. The carbon-based material can be converted to activated carbon through physical modification and thermal decomposition in a furnace under a controlled atmosphere and temperature. It has a large surface area to a unit volume and a network of submicroscopic pores where adsorption takes place (Hina, 2018).

There are two types of basic methods of making activated carbon-steam activation and chemical activation. Steam-activated charcoal is produced in a furnace at a high temperature of 1700 to 1800F with steam in the absence of oxygen. However, this method is limited to industrial technology because of its high temperature required for steam activation. Therefore, we resorted to making chemically activated charcoal. Chemical-Activated charcoal uses a chemical solution to activate the carbon and ultimately produce the same end result as the steam activation with lower activation energy and temperature. Typically, wood-based activated charcoal is activated at 842 F to 1652 F (450-900 C) with various chemicals such as lemon juice or bleach. In the chemical activation charcoal production process, the wood is first pyrolyzed and then the char is saturated with the chemical acid, followed by a controlled reheating to enhance the chemical erosion of the carbon atoms. Different methods suggest the use of various chemicals to the activation of carbon. Among these suggested chemicals are battery acid (sulphuric acid), hydrochloric acid, nitric acid, potassium or sodium hydroxide, etc. However, this can be dangerous to use in the backyard scale and additionally these materials are difficult to find in the rural areas.

2.5.3 Clay-Sawdust Filter

In 1981, Dr. Fernand Mazaeiegod, a researcher at the Central America Industrial Research Institute (ICAITI), in Guatemala, developed a low-cost clay pot water filter (CPWF). The goal was to make contaminated water potable for the poor living in underdeveloped countries (Varkey 2012). Currently, there are many countries worldwide that advocate the use of CPWF's in rural communities and many other studies have been done on various forms of this filter. Our team has decided to implement a version of the clay-sawdust filter into our design. The purpose of adding this concept to our design was to make any water going through the filter potentially potable. The conventional water treatment plants being adopted in high-income countries are neither cost-effective nor technically adaptable to low-income countries such as Ghana (Osumanu 2010). Various point-of-use water treatment methods, which include ceramic filtration, have been reported to improve the quality of drinking water as well as decrease the incidence of endemic diarrhea caused by waterborne pathogens (Clasen 2015). Having such an addition to our filter would allow us to tackle the issue of mercury contamination in two areas: as the source as well as the end. Some versions of the pot call for rice husk, diatomite, etc, though as this is just a preliminary prototype, we have decided to just use those materials. The drawbacks have also been identified as lower effectiveness against removal of viruses; lack of residual protection that can lead to recontamination of treated water is stored unsafely; variability in quality control of locally produced filters; filter breakage over time, and need for spare parts; the need to regularly keep the filter and receptacle clean, especially when using turbid waters; and, a low flow rate.

2.6 Summary

ASM plays a crucial role in poverty alleviation and rural development (Hentschel, 2002). Most people involved in ASM are poor and mining provided promising income. Despite this, the sector is also known for its negative environment, health and safety impacts. Many continue to view it as dirty, unprofitable and fundamentally unsustainable. ASM is extremely prevalent in three regions: Asia, Latin America, and Africa (Fritz, 2018). ASM plays a significant role in the economies in at least 23 sub-Saharan African countries. The mining sector in Africa is growing rapidly and is the main recipient of foreign direct investment (Chuhan-Pole, 2015). Ghana is known for its long history of gold mining and its significant portion of the world's total gold production (Chuhan-Pole, 2015). ASM provides support to the livelihoods of over 1 million people in Ghana, especially for those living in poor rural areas. Men, women, and even children participate in the ASM sector. Mining contributes a large amount to GPD and to fiscal revenue. Despite its contribution to economic growth, ASM has negative impacts on the health of those involved, the education of children, the livelihoods of those in the agriculture sector and more. The environmental issues may include land degradation, water contamination, flora depletion, destruction of arable lands, and mercury contamination. These safety concerns have and may lead to some fatalities and injuries (Bansah et al., 2016). The amalgamation process is ideally done in enclosed equipment with vapors being captured prior to the release into the environment. In ASGM, however, the precautions that should be taken are often overlooked and miners handle the mercury directly. The exposure to elemental mercury to the environment has put miners, miners' families, the ecosystem and the river at high risk for mercury poisoning.

3.0 Methodology

3.1 Production of Activated Carbon

Since charcoal is a commonly utilized source of energy in Ghana, for our project, we purchased a bag of charcoal from a local charcoal store. We took the charcoal and laid them on a wood surface and gently pound it with stone until they were small as rock pebbles. Next, we took a flat wood to grind the charcoal up to a very fine powder which was next sieved into a bucket. The process was repeated as necessary to produce the fine powder of charcoal. This process could take from a few minutes to a couple of hours depending on the method used for crushing the charcoal and the amount of charcoal crushed. For the scope of this project, we focused on producing a locally sourced powdered activated carbon.

Our chemicals of choice are lemon juice and bleach. We used lemon juice and bleach separately to create two batches of chemically-activated carbon. These chemicals are commonly available for the rural general public in Kyebi, Ghana. Next, we heated the two batches of powdered carbon to activate the carbon. We did this through three means namely an LPG (Liquefied Petroleum Gas) bunsen burner, LPG (Liquefied Petroleum Gas) oven, and Pit fire. LPG has a flame temperature near 1970 C when burned in air. However, the bunsen burner has a smaller flame and the pot used loses more heat as compared to the LPG stove. The LPG stove has a semi-insulated body that preserves the heat. The pit fire's temperature ranges at approximately 1100 C. The high temperature and the chemical added (in this case the bleach and lemon juice) erodes the powdered charcoal's internal surface. This will increase the adsorption capacity by increasing the surface area to volume ratio.

In this project, we explored the adsorption capacity of the various powdered activated carbon created using local resources in Kyebi, Ghana. We compared the bleach activated carbon, lemon activated carbon and the control unactivated carbon. We also researched the influence of the source of heat (LPG oven, LPG bunsen burner or pit fire) on the level of activation on the powdered carbon.

3.1.1 Carbon Analysis

The physical and chemical analysis of the activated carbon was analyzed with various methods as shown below. The physical properties are weight and bulk density. The chemical properties are pH and iodine value.

3.1.1.1 Iodine number (IN)

Iodine number is the amount of iodine absorbed (in milligrams) by 1g of carbon. It determines the relative activation level of carbon by adsorption of iodine from aqueous solution.

3.1.1.2. Preliminary Visual Iodine Test

The experiment consists of adding equal mass of activated carbon to test tubes and added 2M HCl. The test tubes were heated for approximately 30 seconds. Next, 25 mL of 4 g/ml Iodine solution (with alcohol) is added to the test tube. This was left to settle for approximately 24 hours. The sample was visually analyzed to understand the adsorption capabilities of the activated carbons. In some samples, 10mL of the test tube samples were titrated with 0.01M sodium thiosulfate to calculate the amount of iodine adsorbed by the activated carbon. The powdered and unactivated carbon was used as a control in this experiment.

3.1.1.3. Altered ASTM D4607-94

In this method, the iodine number is determined using an altered version of the ASTM D4607-94 method. The experiment consists of treating the activated carbon sample with 10 mL of 5% HCl. Next, the sample is boiled for 30 seconds and cooled to room temperature. Thirdly, 100 mL of 0.1 N (0.1 mol L^{-1}) iodine solution is added to the mixture and stirred for 30 seconds. The resulting mixture is then filtered and 10 ml of the filtrate is titrated with 0.1 N (0.1 mol L^{-1}) solution of sodium thiosulfate using a starch indicator. The iodine amount adsorbed per gram of carbon (X/M).

$$X/M = \{(N_I * 126.93 * V_I) - [(V_I + V_{HCl})/V_F] * (N_{Na_2S_2O_3} * 126.93) * V_{Na_2S_2O_3}\}/M_c \quad (1)$$

where N_I is the iodine solution normality, V_I is the volume of the iodine solution added, V_{HCl} is the volume of the 5% HCl added, V_F is the volume of the filtrate added and used in the titration, $N_{Na_wS_2O_3}$ is the normality of the sodium thiosulfate solution used, $V_{Na_wS_2O_3}$ is the volume of the 0.1 N sodium thiosulfate solution and M_C is the mass of the activated carbon used.

3.1.1.4 Weight and Bulk Test

A 50 ml measuring cylinder was first zeroed on the weighing balance. The lump-free activated carbon was poured into the cylinder to the 50 ml mark. The measuring cylinder was gently tapped to ensure no void was created. The weight was measured and recorded. The bulk density was calculated using equation 2.

$$Bulk\ Density = \frac{Mass\ (g)\ of\ carbon}{Volume\ (ml)\ of\ Carbon} \quad (2)$$

3.2 Filter Creation and Local Community Involvement

The ideal implementation method for the filter is within the community through the locals who take ownership of the creation of filters. The process to create the filters needs to be tested through different firing methods for both parts as well as various ratios for the clay-sawdust. The process needs to be simplified and then replicated. The major part of the current project is primarily the testing phase whereas the next groups may focus on further implementation within the community.

3.2.1 Production of Clay-Sawdust Filter

The materials used include clay, sawdust, and water. The fractions of sawdust used in preparing the pots were 50%, 60% and 80% by volume. The dry clay and sawdust were mixed together, then water was added in incremental volumes until the clay was easily moldable. The clay was then molded into a bowl-like-shape and placed outside to dry in the sun for at least 24 hours. Once the pot was dry, the pots were then ready to be fired. A challenge arose once it came to firing the pots. We had no access to a kiln in Kyebi, nor in any nearby area. As a result, different methods of firing techniques were approached. We tried firing the pots with a bunsen burner found in the chemistry lab of Kibi High Technical Secondary School. For this method, the pots were placed in an aluminum pan and this plan was placed on a stand with the bunsen burner directly beneath. The pots were fired for approximately 4 hours. The second method we tried was to create a pit fire. For this method, we created a pit fire. We then heated up some charcoal on a charcoal grate until the charcoal became red hot. As the charcoals were burning, we set up the placement for our clay pot. We purchase a ceramic pot from a local market. This pot was filled with about 2 inches of sawdust. Our clay piece was placed on this layer of sawdust, then covered with another layer of sawdust. Once the charcoal was red hot, the charcoal was placed on top of the second layer of sawdust and allowed to burn entirely as well as cool down. This process took at least 4 hours. Once the system was cool down, the clay piece was removed from the system. The final method of firing our clay pieces was to place our clay pieces in an oven fueled by liquid petroleum gas. The clay was left in the oven for 4-6 hours.

Once the clay pieces were fired and cooled, they were allowed to be submerged in water to visually see if the clay would dissolve in water. This was a preliminary test that would tell us if the clay was fired properly. Clay becomes pottery at temperatures at about 540 C. The heat converts clay molecules to molecules that are insoluble in water (Riccardi 1999). Very slight pressure was added to the filters to see if any immediate cracks would appear. If they did not break, a qualitative test was done on the filters to determine if water was able to pass through the filter as well as detecting if the filter was able to remove sediment from the water that was being filtered. This was done by mixing some sand found outside with water. The filter was placed over a beaker and the sand-water mixture was poured over the filter. The beaker under would be used to catch the filtered water.

3.2.2 Using Local Resources

The local technical secondary high school provided the location for experiments. The goal of the filter was it needed to be made with local materials therefore everything was bought in the town we worked in. The use of any materials from the United States was counterintuitive and therefore only gloves and mercury testing strips were brought. The reason for these two items to be brought was that testing for mercury is not a prominent practice and the gloves were required to handle the tests. All the other sources whether they be chemicals or a pan were bought within the town and within walking distance. The replicability of this filter was one of the most important parts and the materials reflected the requirement. The school has chemistry and sculpture classes that provided materials that could at least be replicated at the school. The testing of the activated carbon was conducted in order to understand the adsorption capacity. The chemicals were found in a chemistry lab since they are fairly commonly used in laboratories. The clay-sawdust pot needed a kiln in order to fire but there were issues with using a kiln as a firing method.

3.2.3 Local High School Engagement

Kibi Senior High Technical School provided us with lab space to produce and conduct all of our tests for the filter. While working, there were often students in the lab space studying. Since they had free time, we had the opportunity to explain to the students exactly what we were doing.

The students became very intrigued throughout the process so much of our time spent with them involved letting them conduct experiments, explaining to them how our filter works, and even bounce back ideas with them on how to scale up our project. Many of the students communicated to us how they would like to work with the WPI students that come next year. The students also expressed their concerns about their drinking water. They were passionate about making their drinking water safe in general. After completing our prototype, we had many of the resources that we acquired, leftovers. Some of the students stated how they were willing to take the materials home so that they could try making filters as well. Therefore, we were also able to acquire more of the chemicals we used to give to them for their convenience.

4.0 Results and Discussion

4.1 Limitations to Testing for Mercury

The ability to test for the levels of Mercury that are present in the water requires sensitive equipment to test low concentrations of mercury. The equipment that we had access to were strips that were able to detect much higher amounts and not in between levels which we suspect where the concentration levels would have fallen. This posed issues for testing as detecting levels of the mercury with test strips resulted in the strips detecting zero although the color was slightly pink which indicates a presence of mercury.

4.2 Tests for Level of Activation

The activated carbon can be made through various bio starters that in turn provide various levels of activation. In order to provide the community with the best filter design, the carbon activation needs to be tested. The testing indicates how much can be absorbed through how many pores are able to be created within the carbon. The following section looks into the testing methods of bulk density, pH and iodine.

4.2.1 Analysis of the Bulk Density of Activated Carbon

The bulk density of activated carbon samples are listed below in Table 1. The batches include Unactivated Carbon (UC), Bunsen-burner Bleach Activated Carbon (BBAC), Bunsen-burner Lemon Activated Carbon (BLAC), LPG-stove Lemon Activated Carbon (LLAC), and LPG-stove Bleach Activated Carbon (LBAC).

Table 1: Bulk Density of Activated Carbon

Samples	**Density (g/cm^3)**	**Activation Conditions**
(B^1BAC)	0.69	4 hours

(B^2BAC)	0.53	2 hours
(B^1LAC)	0.51	4 hours
(B^2LAC)	0.54	2 hours
(LBAC)	0.56	2 hours
(LLAC)	0.53	2 hours
(UC)	0.51	_

In Table 1, it was observed that all the activated carbon samples in the exception of Bunsen-burner Lemon Activated Carbon (B^1LAC) were activated and this was reflected in their densities. We observed an increase in density in the activated carbon samples which implies that it has an enhanced adsorption capability. However, the Bunsen-burner Lemon Activated Carbon (B^1LAC) was observed to have the same value of density when compared to the Unactivated Carbon (UC), which indicated little to no activation. We believe that this was as a result of an insufficient amount of lemon juice utilized in the process of batch production. We were able to improve this and result in a better production by increasing the lemon juice during the saturation phase of the second batch of Bunsen-burner Lemon Activated Carbon (B^2LAC). The density of B^1LAC, 0.51 g/cm3, increased to 0.54 g/m3 in the B^2LAC batch production despite the latter being activated by heat for 2 hours less than the former.

It also was observed that the highest bulk density was obtained by the first batch of the Bunsen-burner Bleach Activated Carbon (B^1BAC) which was heated to activation for approximately 4 hours followed by LPG-stove Bleach Activated Carbon (LBAC) heated for 2 hours. The second batch of Bunsen-burner Lemon Activated Carbon (B^2LAC) had the third-highest bulk density. This implies that the bleach activated carbons will filter better than those from lemon activated carbons.

The LPG-stove batches were also noticed to have slightly higher bulk densities in the bleach activated carbons. The LPG-stove Bleach Activated Carbon (LBAC) gave better densities than the second batch of Bunsen-burner Bleach Activated Carbon (B^2BAC) counterpart that was heat-activated for the same amount of time. However, this wasn’t the case with lemon activated carbon batches. This may be attributed to the natural formation of lumps in the lemon juice activated carbon which affects the measurement of bulk density.

The effect of time of heat activation on the adsorption capacity of bleach activated carbon was found to be positive. An increase in the length of time spent for heat activation showed a huge increase in the bleach activated carbon. We weren’t able to compare the effect of time in the lemon activated bleaches due to the batch being not activated as a result of insufficient lemon juice used during production. We observed that the 4-hour heat-activated bleach carbon (B^1BAC) had a higher density of 0.69 g/cm3 as compared to a 2-hour heat activated carbon which gave a bulk density of 0.56 g/cm3 and 0.53 g/cm3 in LBAC and B^{1}BAC respectively.

4.2.2 Analysis of Iodine Test for Activated Carbons

In this test, we started our experiment with a burgundy-colored solution in our test tubes which was attributed to the 4mg/ ml iodine solution (with alcohol) in them. As time progresses, the burgundy color will start to fade away which indicates the adsorption of iodine solution by the carbon. During our preliminary visual iodine test analysis, we noticed that the unactivated carbon would start clearing up faster than the activated carbons. Soon, the pace would be reversed and the activated carbons would clear up faster. Unlike activated carbons, unactivated carbon was noticed to float on the top of the test tubes.

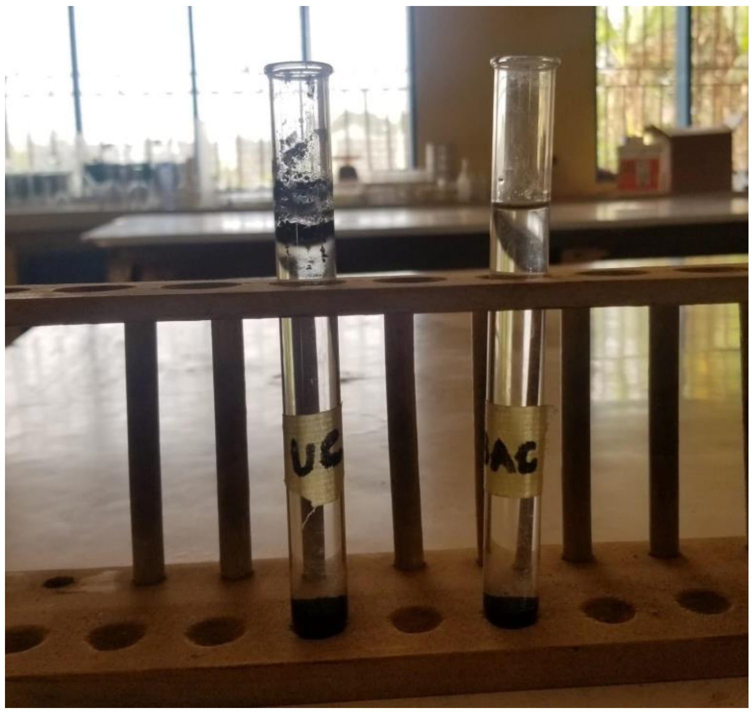

Figure 2: Images of test tubes containing UC on the left and B^{1}BAC on the right on Day 5

For our first test, we set up an experiment with the unactivated carbon with the first batch of the Bunsen-burner Bleach Activated Carbon (B^{1}BAC). These samples were left for 5 days and both samples were noticed to be completely clear indicating the complete adsorption of the iodine solution. This was also proved by titrating the samples with 0.5 M, 0.1M, and 0.01M sodium thiosulfate. We suspected that the unactivated carbon didn't have the same adsorption capabilities as the first batch of the Bunsen-burner Bleach Activated Carbon (B^{1}BAC). On day 5, the unactivated carbon sample had a visible growth in it while the first batch of the Bunsen-burner Bleach Activated Carbon (B^{1}BAC) was found to be remaining clear without any growth as shown in figure 1. This indicated that the first batch of the Bunsen-burner Bleach Activated Carbon (B^{1}BAC) was purified resulting in clean water without visible growth while the unactivated filter had growth. This was later supported by both the bulk density test presented above and the altered ASTM method shown below. We believe the false results in the unactivated carbon were as a result of the ashy nature of the powdered un-activated carbon used in this experiment. Since ash is alkaline in nature, we suspect that it was reacting with the iodine instead of iodine being adsorbed. In the following experiments, we bypassed this issue by increasing the volume of HCl added from 2mL to 4mL to ensure the complete reaction of the ash and neutralize the samples. The next experiments indicated a tint reddish yellow on the un-activated carbons indicating residual iodine.

In all the experiments involving the 1g of the first batch of Bunsen-burner Lemon Activated Carbon (B^1LAC), we noticed that it was still heavily burgundy colored after the 24 hours period. This indicated it had a low adsorption capacity. This was further verified by the other tests conducted. We also conducted a 2g of the first batch of Bunsen-burner Lemon Activated Carbon (B^1LAC) and we noticed the sample to have a lighter color of Iodine indicating a higher amount of iodine adsorbed. In the second batches of the Bunsen-burner Lemon Activated Carbon (B^2LAC) and LPG-stove Lemon Activated Carbon (LLAC) used in this test, we observed the samples to have a yellow tint in the samples after the iodine cleared up. We suspected and verified that it was as a result of the lemon juice remaining after its activation.

In order to avoid the qualitative analysis of the preliminary iodine test, we resorted to an altered American Standard Testing Method. This method produced quantitative data to analyze the adsorption capabilities of the activated carbon. We were able to compare the iodine adsorbed per gram of carbon (mg/g) to the other tests we have conducted.

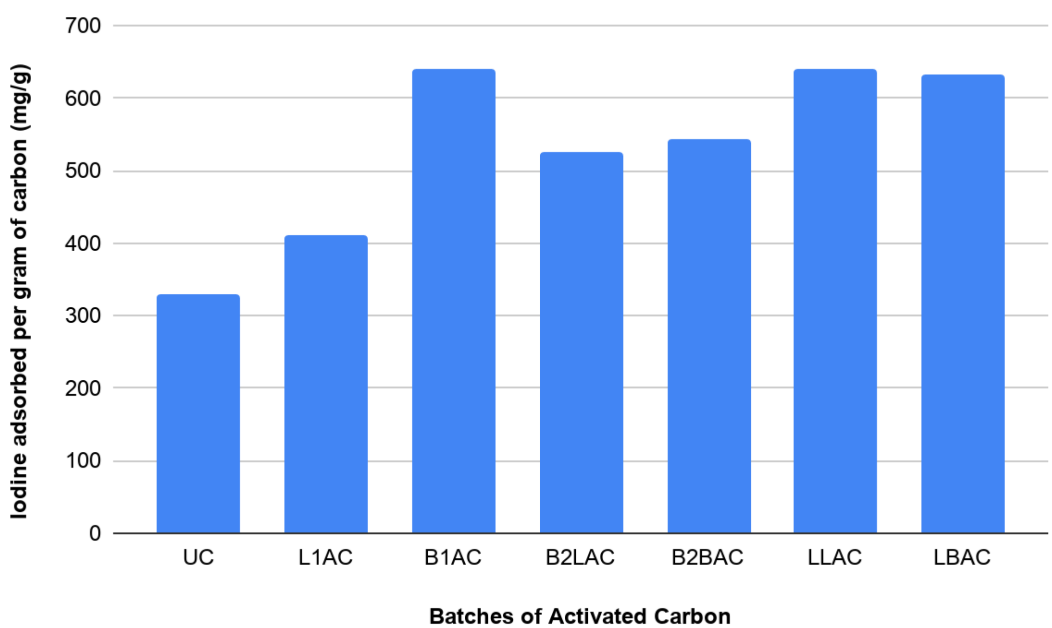

Figure 3: Adsorption Capacity of Various Activated Carbon Batches

In the figure above, we can notice that the first batch of the Bunsen-burner Bleach Activated Carbon (B^1BAC) and LPG-stove Lemon Activated Carbon (LLAC))were found to have the highest adsorption of iodine at 640.6 mg iodine/g carbon. While we expected the results from the first batch of the Bunsen-burner Bleach Activated Carbon (B^1BAC), the ASTM D4607-94 results of the LPG-stove Lemon Activated Carbon (LLAC) was not supported by the bulk density and preliminary iodine tests. Secondly, the LPG-stove Bleach Activated Carbon (LBAC) has the second-highest adsorption capacity at a close 631.6 mg iodine/g carbon. The first batch of the Bunsen-burner Lemon Activated Carbon (BLAC) and the un-activated carbon (UC) were found to have the lowest adsorption capacity. This was corroborated by the other tests as well.

Table 2: Comparison of Adsorption Capacity of Activated Carbons by Rank

Samples	Bulk Density (g/ml)	Rank (by Density)	Iodine absorbed per gram carbon (mg/g)	Rank (by Iodine adsorbed per gram carbon)
(B^1BAC)	0.69	1	640.9	1
(B^2BAC)	0.53	4	543.9	3
(B^1LAC)	0.51	5	410.6	5
(B^2LAC)	0.54	3	524.6	4
(LBAC)	0.56	2	631.6	2
(LLAC)	0.53	4	640.9	1
(UC)	0.51	5	329.1	6

Overall, with the exception of the ASTM D4607-94 results of the LPG-stove Lemon Activated Carbon (LLAC), all the data collected from the density and preliminary iodine test supported and verified each other as shown in table 2.

4.2.4 Activated Carbon Filter Creation

After our production of the clay-sawdust filter and various batches of the activated carbon, we were able to produce a triple-layer water filter. We used a locally sourced small bucket to contain the different layers which included a clay-sawdust filter, activated carbon and cloth from bottom to top. However, due to the limitation of time, we weren't able to investigate the overall efficiency of the whole filter.

4.2.5 Cost of Filter

The cost of the filters was calculated based on how much material was used within the filter itself. The cost of the materials is in Table 3 and also includes the size.

Table 3: The Cost of Local Materials for Activated Carbon Filter

Material	Size	Cost (1 Dollar= 5 Cedies)
Clay	10 kg Bag	10 Cedis
Sawdust	10 kg Bag	10 Cedis
Charcoal	1 Bag (~1 kg)	1 Cedis
Bleach	500 mL	6 Cedis
Lemons	5 lemons	3 Cedis

The estimated price of the filter is 3 cedis. The cost of the filters based on the ratios is about 3 cedis. The filter can be used up to 4 weeks depending on the water consumption of the family. The cost of bottled water is about 2 cedis and there has to be multiple bought for a family every day. The cost in comparison is significantly more affordable as 3 cedis can be used for up to 4 weeks of water compared to 5 cedis a day approximately. The use of the filter design also eliminates the creation of plastic waste and reduces the amount of plastic exposure. The health impact of constantly drinking out of plastic is also fairly significant and reducing the amount of plastic being used is a big benefit.

4.3 Accessibility to Locals and Resources

The resources to create the filters were all sourced locally due to the replicability of the filter. The sources to find these items often came from walking on the street and stopping by a shop or asking where it could be found. Since all the sources needed to be local there were some issues in not being able to find everything that was needed. Difficulties in finding all the resources we needed were expected and adaptations to the project needed to be made. The following section explains some of the challenges and remedies for the problems that arose.

4.3.1 Clay-Sawdust Disk

When testing different ratios of clay to sawdust, we found that a 1:1 ratio of clay to sawdust worked best. It cooked the best and could withstand slight pressure after being soaked in water. The finished filter can be found in Figure 4.

Figure 4: Clay-Sawdust Filter Made from 1:1 Ratio of Clay and Sawdust After Being Fired

Water was able to pass through this filter and even collect some sediment from the water. The other two ratios did not work out. The filter that was made with 20% clay and 80% sawdust was extremely difficult to mold and it fell apart soon after being submerged in water. The 40/60 filter could withstand a little more pressure as compared to the 20.80 filters, although it did not do better than the 50/50 filter. One of the greatest challenges that came with creating the clay-sawdust filter was the lack of a kiln. In order for clay to be fired properly, it needs to experience extreme heat for a long period of time. First, we attempted to locate a kiln. The nearest kiln was more than two hours away and would not be easily accessible to the local community of Kyebi. As a result, we attempted various firing methods. The firing method that was most successful was placing the clay-sawdust filters in an LPG oven for several hours. This testing was extremely preliminary, but it allows us to understand what processes can be used to create the filter.

4.3.2 Access to People

The local technical secondary high school provided material and the location of most of our experimentation. The pottery class and chemistry class provided space to perform experiments as well as to prepare the clay and charcoal. The clay, charcoal, lemons, bleach, and sawdust were all used to create the actual filter. Small shops were located right next to the school as well as our lodging that provided all the organic materials needed. The experimentation required a pot and pan as well which were also located within a five-minute walking distance from the school. The chemistry class provided essential chemicals that were needed to conduct testing. The chemicals were iodine, sodium thiosulfate, starch and potassium iodine among other chemicals that were needed in smaller amounts. The school was fundamental in gaining access to chemicals and to people who helped the project. The high school students were engaged throughout the entire process and helped through bringing water as well as preparing materials.

5.0 Conclusion and Recommendations

5.1 Activated Carbon Filter

The creation of the activated carbon filter required effort from the local community, the high school, and our previous research. The relationship that was created with the community has created a foundation that can continue to be utilized throughout the next phases of the filtration process. The activated carbon filter was proven successful as it can be created and that local materials are able to be used.

5.1.1 Established Relationship with Locals

The two months spent in Kyebi, Ghana created connections to the locals that were pivotal in the development of the activated carbon filter. Working with the local community established a sense of trust between the students from America and the citizens of Kyebi. The success of the filter is completely based on the integration of such a filter within everyday life. The local high school was instrumental in the design iterations and idea culmination. The chemistry and sculpture teacher provided information about the town that we could not have found in any research from what materials are easily accessible, to sources of drinking water and insight into the environmental situation. The interest from the high school students is also an invaluable part of the project that creates an actual possibility for the interest to not only continue in the following year with new MQP students but also with the high school students for the year prior to WPI coming back. The connection to the locals is preparation for the next year but also an insight into the potential for participation within a scaled-up version of the filter design

5.1.2 Prototype Creation

The activated carbon filtration system was developed over the past 7 weeks in Kyebi, Ghana. The timeline to create a functioning clay-sawdust disk and an activated carbon filter layer was successful in certain regards. Activated carbon is able to be created using both common household items, lemon, and bleach. The effectiveness of both varied but the ability to be able to create activated carbon using fairly common items on an open flame which could be easily replicated is an important development. The clay-sawdust disks were still able to filter water even if the end result was not completely clear water. The first step in being able to make all parts of the system in conventional ways is an insight that the next approach may be successful in and of its own right. The next group of students have a basis of people and past results to use as they continue to work on these filters. The resources that are available are now known and therefore will provide the next group of students with a foundation to start their project.

5.1.3 Community Infrastructure

The tap water of Kyebi, Ghana is polluted and the locals have protested that the government should clean the water. The locals are then forced to find an alternative whether that be using a well or buying bottled water. The water sources that people have used for a long time have recently become polluted. The change in the water has created the need to find an alternative and the filter is potentially the best approach. The locals do not like the mining operations and disagree with their use of mercury. The impact that we created was working with both sides and meeting on common ground. The miners understood we only wanted to know how we can help them in their current situation and get to a place that has less exposure. The students understood that we wanted to create a filter that would help clean their water as they knew they could not just drink their water. A mapping of the water that is used and who gets that type of water could have further informed where the disparities are and who is affected by them in an easier manner.

5.2 Recommendations for Future Projects

The success of the project in creating a foundation for the implementation plan for the next five years will allow these next outlined steps to happen. The next phases of the project will need to be done through calculated step by step approaches that continue to expand the reach and influence of the design each year. The steps will go from finding the best-activated carbon to a scale-up design that can be implemented in Kyebi but also possibly be adapted within other mining-affected areas.

5.2.1 Sources of Carbon

The source of carbon for this iteration of the activated carbon filter simply came from grinded charcoal as the base. The main focus was to figure out if activation was possible through any carbon source. However, throughout our stay, we were able to explore the cellulosic sources that are available and that could be used to create activated carbon. Heaps of scrap coconut husks and rinds from various starches were scattered in many areas. The husks and rinds are primarily a waste product and collect on the streets. The waste that could be found on the street potentially creates a continuous source of carbon that would further reduce the cost of the filters. The testing phase would, however, need to be more in-depth in order to find out which source is more effective or if possibly it does not create a large difference. This testing phase would need to be done the following year in order to completely understand the situation of the carbon-based sources. The tests would need to look at efficiency, time to create the product, length of product viability along with accessibility and price to optimize the potential of all of the carbon sources. The testing could happen in part with another team that continues the focus of the clay sawdust part of the filter. The following recommendation will further address the clay-sawdust aspect of the filter but could be done later on in the next phases.

5.2.2 Activated Carbon for Mercury Vapor

The activated carbon when created correctly has the potential to remove mercury from both the air and water. The team that worked with us during our project worked on a retort design for the mercury amalgam that is burned during the mining process to reduce the exposure to mercury vapors. The use of activated carbon as a substance to absorb mercury vapor is a process often done to extract contaminants from flue gas in many factories. One of the professors at WPI, Jennifer Wilcox, works on carbon capture and has studied activated carbon for air filtration methods for her research at WPI. A prototype has been created for use in the amalgam burning that could be added to through the use of activated carbon. The materials that would be available to create the activated carbon are currently known and once the best carbon source is discovered it could be tested for the ability to extract vapors. The cost of a retort could decrease significantly if the original and cheapest prototype design was fitted with activated carbon. The multiple applications of the carbon increase the value while the cost is still fairly low. The project could also be conducted as a three-term MQP at WPI or partial testing done the term before the student leaves for Ghana. The collaboration with research currently happening at WPI could combine multiple projects into one which would expand the range of impact.

5.2.3 Testing of Mercury Sources and Deposits

The mercury that is released within the environment is scattered as the mining process and amalgam of gold-mercury is done at the homes of the miners. With each site having possibly 70 miners and if each mining group consists of 4 people, then about 17 unknown neighborhoods are being exposed to mercury in a more direct way than say people who did not live near the mines. Mapping the mercury sources could begin to explain where the mercury goes and to what extent each area is being exposed. Testing the water in these areas could provide a deeper understanding of what differences exist in the exposure level throughout the community. The mapping would also help predict where the mercury is moving and further investigations could be done into the health records of these areas to see if there is any indication of mercury exposure. Mapping mercury within the environment is also a well-designed process that could inform the steps that would need to be taken within the mining areas of Ghana. The mapping of the mines would also create a clearer image of where mining is done and what kind of mining. The impact on the environment could be scaled as well which would create an outline of which areas would need immediate action and possibly multiple points of intervention.

5.2.4 Clay-Sawdust Filter Collaboration

The clay-sawdust pot filter is an established and working implementation in the northern region of Ghana (Murcott, 2005). The attempt to create our own filter was not successful which could be an indication that there is an opportunity for a collaboration that would deem more fruitful. The addition of an activated carbon layer could expand the use of the filter pots to regions that are contaminated by mercury and heavy metal pollution. The current pot system is ideal for turning river water into drinkable water but not contaminated water. The next few years could be taken to establish contact with the northern region. The community that currently uses the project, as well as the researcher who facilitated the implementation of the pot, would be the greatest help. The activated carbon at this point would have to be perfected and easily replicable within any region. However, establishing contact both in Ghana and in the United States would take a while especially if collaboration on both continents would need to happen. If contact was made in the US, the researchers could communicate over email and skype, with both sides being able to add to the filter with the various experiences that they have. Once the filter design would be proposed to the mining communities, the design could then be altered and implemented.

5.2.5 Establishing Infrastructure to Manufacture Filters

Once both filters are designed and can be made together, the next major step would be implementation through a scale-up design. The goal of the water filter system is to be able to be created by locals and that when filters need to be changed the ability to do so exists. The fundamental filter design is fairly simple but the process to be reiterated correctly each time is a much more tricky process. The best approach to the filters would be to have trained individuals in the community who are able to become entrepreneurs and facilitate the filter business. Ideally, the filters could be created by stay at home mothers who already have a great deal of access to the materials that are needed in particular for the activated carbon. While the developments for the filter are created, the community will continue to be involved throughout the entire time. The hope is that members of the community will begin to take ownership and want to be a bigger part of the filter being used to clean their tap water. The students that worked with us from the local high school took a deep interest in the filter and how it could help their community. If the students are able to work on the filter and develop their own design, then that is a development that we could not have foreseen but is an ideal one. The students' understanding of the problem and being given the guidance to make a difference for themselves would progress the plan quickly. The students could then be the first facilitators of the filters as they had developed their own design. With the knowledge they have of the area and how this could be done, they could guide the process with help from those who could give them access to people who have higher say in government. The collaboration would work in a way that involves multiple stakeholders and the problem is addressed with multiple perspectives.

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Appendices

Appendix A: MSDS Sheet for Mercury

Material Safety Data Sheet
Mercury, 99.999%

ACC# 96252

Section 1 - Chemical Product and Company Identification

MSDS Name: Mercury, 99.999%
Catalog Numbers: AC193480000, AC193480500
Synonyms: Colloidal mercury; Hydrargyrum; Metallic mercury; Quick silver; Liquid silver
Company Identification:
Acros Organics N.V.
One Reagent Lane
Fair Lawn, NJ 07410
For information in North America, call: 800-ACROS-01
For emergencies in the US, call CHEMTREC: 800-424-9300

Section 2 - Composition, Information on Ingredients

CAS#	Chemical Name	Percent	EINECS/ELINCS
7439-97-6	Mercury	99.999	231-106-7

Section 3 - Hazards Identification

EMERGENCY OVERVIEW

Appearance: silver liquid.
Danger! Corrosive. Harmful if inhaled. May be absorbed through intact skin. Causes eye and skin irritation and possible burns. May cause severe respiratory tract irritation with possible burns. May cause severe digestive tract irritation with possible burns. May cause liver and kidney damage. May cause central nervous system effects. This substance has caused adverse reproductive and fetal effects in animals. Inhalation of fumes may cause metal-fume fever. Possible sensitizer.
Target Organs: Blood, kidneys, central nervous system, liver, brain.

Potential Health Effects
Eye: Exposure to mercury or mercury compounds can cause discoloration on the front surface of the lens, which does not interfere with vision. Causes eye irritation and possible burns. Contact with mercury or mercury compounds can cause ulceration of the conjunctiva and cornea.
Skin: May be absorbed through the skin in harmful amounts. May cause skin sensitization, an allergic reaction, which becomes evident upon re-exposure to this material. Causes skin irritation and possible burns. May cause skin rash (in milder cases), and cold and clammy skin with cyanosis or pale color.
Ingestion: May cause severe and permanent damage to the digestive tract. May cause perforation of the digestive tract. May cause effects similar to those for inhalation exposure. May cause systemic effects.
Inhalation: Causes chemical burns to the respiratory tract. Inhalation of fumes may cause metal fume fever, which is characterized by flu-like symptoms with metallic taste, fever, chills, cough, weakness, chest pain, muscle pain and increased white blood cell count. May cause central nervous system effects including vertigo, anxiety, depression, muscle incoordination, and emotional instability. Aspiration may lead to pulmonary edema. May cause systemic effects. May cause respiratory sensitization.
Chronic: May cause liver and kidney damage. May cause reproductive and fetal effects. Effects may be delayed. Chronic exposure to mercury may cause permanent central nervous system damage, fatigue, weight loss, tremors, personality changes. Chronic ingestion may cause accumulation of mercury in body tissues. Prolonged or repeated exposure may cause inflammation of the mouth and gums, excessive salivation, and loosening of the teeth.

Section 4 - First Aid Measures

Eyes: Get medical aid immediately. Do NOT allow victim to rub eyes or keep eyes closed. Extensive irrigation with water is required (at least 30 minutes).
Skin: Get medical aid immediately. Immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Wash clothing before reuse. Destroy contaminated shoes.
Ingestion: Do not induce vomiting. If victim is conscious and alert, give 2-4 cupfuls of milk or water. Never give anything by mouth to an unconscious person. Get medical aid immediately. Wash mouth out with water.
Inhalation: Get medical aid immediately. Remove from exposure and move to fresh air immediately. If breathing is difficult, give oxygen. Do NOT use mouth-to-mouth resuscitation. If breathing has ceased apply artificial respiration using oxygen and a suitable mechanical device such as a bag and a mask.
Notes to Physician: The concentration of mercury in whole blood is a reasonable measure of the body-burden of mercury and thus is used for monitoring purposes. Treat symptomatically and supportively. Persons with kidney disease, chronic respiratory disease, liver disease, or skin disease may be at increased risk from exposure to this substance.
Antidote: The use of d-Penicillamine as a chelating agent should be determined by qualified medical personnel. The use of Dimercaprol or BAL (British Anti-Lewisite) as a chelating agent should be determined by qualified medical personnel.

Section 5 - Fire Fighting Measures

General Information: As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear. Water runoff can cause environmental damage. Dike and collect water used to fight fire. During a fire, irritating and highly toxic gases may be generated by thermal decomposition or combustion.
Extinguishing Media: Substance is nonflammable; use agent most appropriate to extinguish surrounding fire. Use water spray, dry chemical, carbon dioxide, or appropriate foam.
Flash Point: Not applicable.
Autoignition Temperature: Not applicable.
Explosion Limits, Lower: Not available.
Upper: Not available.
NFPA Rating: (estimated) Health: 3; Flammability: 0; Instability: 0

Section 6 - Accidental Release Measures

General Information: Use proper personal protective equipment as indicated in Section 8.
Spills/Leaks: Absorb spill with inert material (e.g. vermiculite, sand or earth), then place in suitable container. Avoid runoff into storm sewers and ditches which lead to waterways. Clean up spills immediately, observing precautions in the Protective Equipment section. Provide ventilation.

Section 7 - Handling and Storage

Handling: Wash thoroughly after handling. Remove contaminated clothing and wash before reuse. Minimize dust generation and accumulation. Keep container tightly closed. Do not get on skin or in eyes. Do not ingest or inhale. Use only in a chemical fume hood. Discard contaminated shoes. Do not breathe vapor.
Storage: Keep container closed when not in use. Store in a tightly closed container. Store in a cool, dry, well-ventilated area away from incompatible substances. Keep away from metals. Store protected from azides.

Section 8 - Exposure Controls, Personal Protection

Engineering Controls: Facilities storing or utilizing this material should be equipped with an eyewash facility and a safety shower. Use only under a chemical fume hood.

Exposure Limits

Chemical Name	ACGIH	NIOSH	OSHA - Final PELs
Mercury	0.025 mg/m3 TWA; Skin - potential significant contribution to overall exposure by the cutaneous route	0.05 mg/m3 TWA (vapor) 10 mg/m3 IDLH	0.1 mg/m3 Ceiling

OSHA Vacated PELs: Mercury: 0.05 mg/m3 TWA (vapor)

Personal Protective Equipment

Eyes: Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166.

Skin: Wear appropriate protective gloves to prevent skin exposure.

Clothing: Wear appropriate protective clothing to prevent skin exposure.

Respirators: A respiratory protection program that meets OSHA's 29 CFR 1910.134 and ANSI Z88.2 requirements or European Standard EN 149 must be followed whenever workplace conditions warrant respirator use.

Section 9 - Physical and Chemical Properties

Physical State: Liquid
Appearance: silver
Odor: odorless
pH: Not available.
Vapor Pressure: 0.002 mm Hg @ 25C
Vapor Density: 7.0
Evaporation Rate: Not available.
Viscosity: 15.5 mP @ 25 deg C
Boiling Point: 356.72 deg C
Freezing/Melting Point:-38.87 deg C
Decomposition Temperature: Not available.
Solubility: Insoluble.
Specific Gravity/Density:13.59 (water=1)
Molecular Formula: Hg
Molecular Weight:200.59

Section 10 - Stability and Reactivity

Chemical Stability: Stable under normal temperatures and pressures.

Conditions to Avoid: High temperatures, incompatible materials.

Incompatibilities with Other Materials: Metals, aluminum, ammonia, chlorates, copper, copper alloys, ethylene oxide, halogens, iron, nitrates, sulfur, sulfuric acid, oxygen, acetylene, lithium, rubidium, sodium carbide, lead, nitromethane, peroxyformic acid, calcium, chlorine dioxide, metal oxides, azides, 3-bromopropyne, alkynes + silver perchlorate, methylsilane + oxygen, tetracarbonylnickel + oxygen, boron diiodophosphide.

Hazardous Decomposition Products: Mercury/mercury oxides.

Hazardous Polymerization: Will not occur.

Section 11 - Toxicological Information

RTECS#:
CAS# 7439-97-6: OV4550000
LD50/LC50:
Not available.

Carcinogenicity:
CAS# 7439-97-6: Not listed by ACGIH, IARC, NTP, or CA Prop 65.

Epidemiology: Intraperitoneal, rat: TDLo = 400 mg/kg/14D-I (Tumorigenic - equivocal tumorigenic agent by RTECS criteria - tumors at site of application).
Teratogenicity: Inhalation, rat: TCLo = 1 mg/m3/24H (female 1-20 day(s) after conception) Effects on Embryo or Fetus - fetotoxicity (except death, e.g., stunted fetus).
Reproductive Effects: Inhalation, rat: TCLo = 890 ng/m3/24H (male 16 week(s) pre-mating) Paternal Effects - spermatogenesis (incl. genetic material, sperm morphology, motility, and count).; Inhalation, rat: TCLo = 7440 ng/m3/24H (male 16 week(s) pre-mating) Fertility - post-implantation mortality (e.g. dead and/or resorbed implants per total number of implants).
Mutagenicity: Cytogenetic Analysis: Unreported, man = 150 ug/m3.
Neurotoxicity: The brain is the critical organ in humans for chronic vapor exposure; in severe cases, spontaneous degeneration of the brain cortex can occur as a late sequela to past exposure.
Other Studies:

Section 12 - Ecological Information

Ecotoxicity: Fish: Rainbow trout: LC50 = 0.16-0.90 mg/L; 96 Hr; UnspecifiedFish: Bluegill/Sunfish: LC50 = 0.16-0.90 mg/L; 96 Hr; UnspecifiedFish: Channel catfish: LC50 = 0.35 mg/L; 96 Hr; UnspecifiedWater flea Daphnia: EC50 = 0.01 mg/L; 48 Hr; Unspecified In aquatic systems, mercury appears to bind to dissolved matter or fine particulates, while the transport of mercury bound to dust particles in the atmosphere or bed sediment particles in rivers and lakes is generally less substantial. The conversion, in aquatic environments, of inorganic mercury cmpd to methyl mercury implies that recycling of mercury from sediment to water to air and back could be a rapid process.
Environmental: Mercury bioaccumulates and concentrates in food chain (concentration may be as much as 10,000 times that of water). Bioconcentration factors of 63,000 for freshwater fish and 10,000 for salt water fish have been found. Much of the mercury deposited on land, appears to revaporize within a day or two, at least in areas substantially heated by sunlight.
Physical: All forms of mercury (Hg) (metal, vapor, inorganic, or organic) are converted to methyl mercury. Inorganic forms are converted by microbial action in the atmosphere to methyl mercury.
Other: No information available.

Section 13 - Disposal Considerations

Chemical waste generators must determine whether a discarded chemical is classified as a hazardous waste. US EPA guidelines for the classification determination are listed in 40 CFR Parts 261.3. Additionally, waste generators must consult state and local hazardous waste regulations to ensure complete and accurate classification.
RCRA P-Series: None listed.
RCRA U-Series:
CAS# 7439-97-6: waste number U151.

Section 14 - Transport Information

	US DOT	Canada TDG
Shipping Name:	DOT regulated - small quantity provisions apply (see 49CFR173.4)	MERCURY

Hazard Class:		8
UN Number:		UN2809
Packing Group:		III

Section 15 - Regulatory Information

US FEDERAL

TSCA
CAS# 7439-97-6 is listed on the TSCA inventory.
Health & Safety Reporting List
None of the chemicals are on the Health & Safety Reporting List.
Chemical Test Rules
None of the chemicals in this product are under a Chemical Test Rule.
Section 12b
CAS# 7439-97-6: Section 5
TSCA Significant New Use Rule
None of the chemicals in this material have a SNUR under TSCA.
CERCLA Hazardous Substances and corresponding RQs
CAS# 7439-97-6: 1 lb final RQ; 0.454 kg final RQ
SARA Section 302 Extremely Hazardous Substances
None of the chemicals in this product have a TPQ.
SARA Codes
CAS # 7439-97-6: immediate, delayed.
Section 313
This material contains Mercury (CAS# 7439-97-6, 99.999%),which is subject to the reporting requirements of Section 313 of SARA Title III and 40 CFR Part 373.
Clean Air Act:
CAS# 7439-97-6 (listed as Mercury compounds) is listed as a hazardous air pollutant (HAP).
This material does not contain any Class 1 Ozone depletors.
This material does not contain any Class 2 Ozone depletors.
Clean Water Act:
None of the chemicals in this product are listed as Hazardous Substances under the CWA. CAS# 7439-97-6 is listed as a Priority Pollutant under the Clean Water Act. CAS# 7439-97-6 is listed as a Toxic Pollutant under the Clean Water Act.
OSHA:
None of the chemicals in this product are considered highly hazardous by OSHA.
STATE
CAS# 7439-97-6 can be found on the following state right to know lists: California, New Jersey, Pennsylvania, Minnesota, Massachusetts.

California Prop 65
WARNING: This product contains Mercury, a chemical known to the state of California to cause developmental reproductive toxicity.
California No Significant Risk Level: None of the chemicals in this product are listed.

European/International Regulations

European Labeling in Accordance with EC Directives
Hazard Symbols:
T
Risk Phrases:
R 23 Toxic by inhalation.
R 33 Danger of cumulative effects.

Safety Phrases:
S 45 In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).

S 7 Keep container tightly closed.

WGK (Water Danger/Protection)
CAS# 7439-97-6: 3
Canada - DSL/NDSL
CAS# 7439-97-6 is listed on Canada's DSL List.
Canada - WHMIS
This product has a WHMIS classification of D2A, E.
This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations and the MSDS contains all of the information required by those regulations.
Canadian Ingredient Disclosure List
CAS# 7439-97-6 is listed on the Canadian Ingredient Disclosure List.

Section 16 - Additional Information

MSDS Creation Date: 6/15/1999
Revision #5 Date: 3/16/2007

Appendix B: Raw Data for Weight and Bulk Density

Batch 1	LAC Weight	LAC Density (g/cm^3)	BAC Weight	BAC Density (g/cm^3)	UC Weight	UC Density (g/cm^3)
Trial 1	25.24	0.50	34.71	0.69	24.57	0.49
Trial 2	25.61	0.51	33.65	0.67	25.93	0.52
Trial 3	25.63	0.51	34.89	0.70	25.69	0.51
Average	25.49	0.51	34.42	0.69	25.40	0.51
Batch 2	BLAC Weight	BLAC Density	BBAC Weight	BBAC Density		
Trial 1	26.78	0.54	25.97	0.52		
Trial 2	27.55	0.55	25.69	0.51		
Trial 3	26.39	0.53	27.29	0.55		
Average	26.91	0.54	26.32	0.53		
Batch 3	LLAC Weight	LLAC Density	LBAC Weight	LBAC Density		
Trial 1	27.02	0.54	26.69	0.53		
Trial 2	25.67	0.51	29.56	0.59		
Trial 3	26.37	0.53	28.48	0.57		
Average	26.35	0.53	28.24	0.56		

Appendix C: Raw Data for Altered ASTM D4607-94

Batch 1	Iodine Solution Filtrate Beaker (mL)	Na2S2O3 used (mL)	Iodine Left (mmol)	Per 10 ml	Iodine Solution Added to carbon (mL)	Iodine Adsorbed (mmol)	Carbon amount (g)	X/M
BLAC 1	10	5.4	0.54		100	9.46	1	515.3358
BLAC 2	10	5	0.5		100	9.5	Iodine solution (M)	571.185
BLAC 4	10	5.7	0.57		100	9.43	0.1	473.4489
BLAC 5	10	5.4	0.54		100	9.46		515.3358
BBAC 1	10	4.5	0.45		100	9.55		640.9965
BBAC 2	10	3.5	0.35		100	9.65		780.6195
BBAC 3	10	5.5	0.55		100	9.45		501.3735
UC 1	10	6.2	0.62		100	9.38		403.6374
UC 2	10	7.1	0.71		100	9.29		277.9767
UC 3	10	6.9	0.69		100	9.31		305.9013
Batch 2						0		
BLAC 1	10	5.3	0.53		100	9.47		529.2981
BLAC 2	10	5.5	0.55		100	9.45		501.3735
BLAC 3	10	5.2	0.52		100	9.48		543.2604
BBAC 1	10	5	0.5		100	9.5		571.185
BBAC 2	10	5.4	0.54		100	9.46		515.3358
BBAC 3	10	5.2	0.52		100	9.48		543.2604
Batch 3								
LLAC 1	10	4.5	0.45		100	9.55		640.9965
LLAC 2	10	4.2	0.42		100	9.58		682.8834
LLAC 3	10	4.8	0.48		100	9.52		599.1096
LBAC 1	10	5.3	0.53		100	9.47		529.2981
LBAC 2	10	4.1	0.41		100	9.59		696.8457
LBAC 3	10	4.3	0.43		100	9.57		668.9211