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Gem Minerals, Mica And Charcoal Based Water Filter For Heavy Metal Removal

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Abstract:
The present study relates to a manufacture of simple water filters using inferior quality gem minerals to trap heavy metal ions such as As, Cd, Cr, Pb found within drinking water. Since the gem minerals are of inferior quality they can be bought for a paltry sum. In Sri Lanka it is found that most drinking water sources are contaminated with high concentrations of heavy metals. As such, a variety of minerals, each having the capability to trap a certain type of heavy metal ions at different levels, were carefully chosen for this filter. This filter is manufactured in such a way that it can be used in small hamlets or in a common household. Within households it is possible to buy an inexpensive commonly available water filter and fill the compartments with the said gem minerals removing already available filter media except activated charcoal. The filter also has the ability to reuse the filter media after a certain period of use by subjecting it to a simple cleaning process, which could be performed by any layman. The filter comprising several compartments filled with tourmaline, hessonite garnet, biotite mica and activated charcoal is subjected to a retarded water flow, allowing the water to be in contact with the filter media for a longer period. These minerals/charcoal do not dissolve in water, therefore the water passing through them is not harmful to humans; the formulas of each mineral testify to this effect. During the study the adsorption and desorption capability of gem minerals in relation to several types of heavy metal ions was analyzed.

Key Words: *tourmaline, hessonite garnet, biotite mica, activated charcoal, adsorption, desorption*

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I. Introduction

In Sri Lanka most people lack access to clean drinking water. On the other hand some researchers found out that groundwater within Northern areas of the country were contaminated with heavy metals such as As, Cd, Pb, Cr etc. Most researchers' suspect anthropogenic activities, such as pesticides, modern fertilizers and soil/sewage are the potential contributors in high concentration of heavy metals within drinking water but some have different opinions [1]. In case of heavy metals like arsenic, drinking water is the prime source for inorganic arsenic and there is a higher probability to contaminate groundwater than the surface water [2]. Dug wells are the primary source of drinking water especially in North and North East areas (90% households) in addition to some tube wells [3]. Geology and climatic variation directly control heavy metal concentration in ground water. Although most areas record acceptable limits some areas record high levels of arsenic, cadmium and lead [4]. It was found out that some areas like 'Nagadeepa' arsenic levels were up to 15.5 µg/l and this exceeds WHO maximum permissible levels of arsenic 10 µg/l [5]. Inflow of high levels of heavy metal ions such as As, Cd, Pb within blood may affect the filtration process of kidneys and this can lead to kidney failure [6]. On the other hand, in addition to Arsenic, Cadmium affects human health because of its half-life (15-20 years) [7]. This also resulted in kidney failures [8]. On the other hand, Some researchers have pointed out there is a relationship between high intake of heavy metal ions and the spread of CKDu but some are not in agreement with this theory [9]. Whatever the case, there is an outbreak of chronic kidney disease of unknown etiology (CKDu) in numerous districts in the dry zone of Sri Lanka. Recently the number of CKDu patents has been increasing at a rapid pace within the North Central Province of Sri Lanka [10].

According to one research findings 'Wewelketiya' area (CKDu prone area) Cd concentrations recorded 60% and Pb concentrations recorded 40% within drinking water and this exceeded maximum permissible limits [11]. Several decades back anthropogenic activities were limited and people used to filter drinking water using indigenous methods. As such there is no record for the spreading of CKDu. At that time noble families used water filters made of tourmaline bearing garnet biotite gneiss (Figure 1) whereas ordinary people used locally known "mee" seeds (Madhuca longifoliato seeds) and several other types of seeds to filter the drinking water. The first types of filters are still available in ancestral homes of noble families and these inspired the author to carry out research using the same minerals.

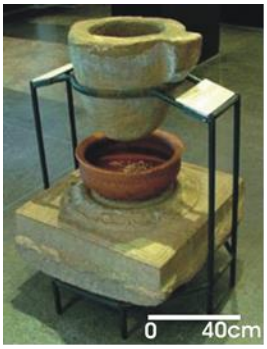

Figure 1: 200 year old water filter made of tourmaline bearing garnet biotite gneiss (Old photograph own by Author's family)

Anyhow in order to provide safe drinking water to these areas having higher concentration of heavy metals, the government mainly relies on the Reverse Osmosis (RO) water. As such RO plants have been introduced to provide drinking water to CKDu affected areas [6]. Yet maintenance of RO plant is costly and needs to be replaced with cartridges at least twice a year. This also needs electricity to operate and routine maintenance incurring high cost is really necessary to keep the machines in good health [6]. Although RO water is safe for drinking it can have harmful effects due to total removal of essential minerals like calcium, magnesium and potassium. This can lead to mineral deficiencies and also affect the smooth functioning of the body. On the other hand if the RO plant is not regularly serviced there is a probability to grow bacteria within the plant [12].

Since installation of RO filters needs huge capital, people sought portable and inexpensive water filters. Most of these water filtering systems introduced during the last couple of years addressed the common water problems like smell, colour and turbidity; also, the removal of fecal matter. But these were not capable of providing a permanent solution for the total removal of heavy metal ions found in the water. Most water filters available today cannot completely trap heavy elements and after some time it is necessary to replace the filter cartridge with a new one incurring some expenditure. In some cases, it is difficult to find the filter cartridge that exactly matches the particular water filter; hence, the necessity arises to replace the whole unit. As such there is an increasing demand for sustainable water filtration systems that do not rely on addition of chemicals or extensive maintenance and the capability to be re-used after a simple purification process of the filter media. The same problem is faced by some industries, even though; they spend a lot of money for the treatment of effluent water before discharging it to the environment. In most cases, the so called treated water of industries still contains harmful levels of heavy metal ions especially Cd and Pb. As a result the author came up with the filter inspiring the filter depicted in Figure 1. Hence it is really necessary to understand properties of the minerals used in this study.

In the case of tourmaline (Figure 2a), considered as fine adsorption material and increasingly used in the treatment of heavy-metal polluted water. Tourmaline's specific properties such as piezoelectricity and spontaneous polarization, instrumental in the removal of heavy metals in water [13][14][15][16][17].

Historically hessonite garnet (Figure 2b) was used as filter media in water purification in some parts of India. Its inertness, resistance to chemical attack and its adsorption/desorption make them suitable as water purification media [18].

Mica, especially biotite mica (Figure 2c), is used to purify water in many countries. Since it has large surface area due to its layered structure it can act as efficient adsorption media. As such it can remove pollutants like pesticides, insecticides and especially heavy metals [19][20].

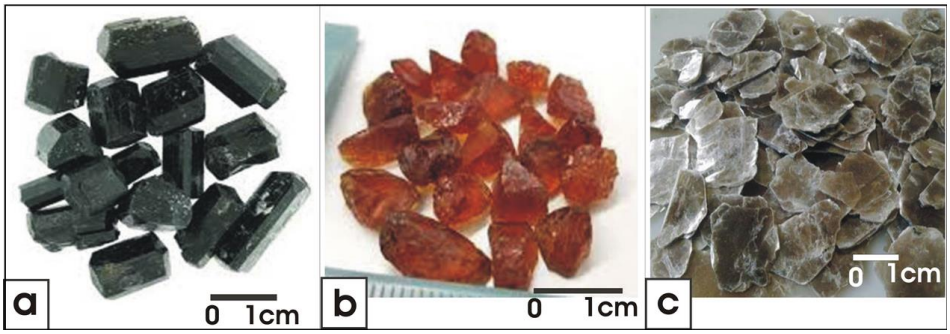

Figure 2a: Tourmaline - Figure 2b: hessonite garnet - Figure 2c: biotite mica

Activated charcoal is used in water purification to remove coloring elements, organic chemicals, taste, and odor. The process is called adsorption, where the particles bind to the large surface area of the activated charcoal as water passes through the material or when contact with the material for certain duration of time. In this case adsorption chemically binds impurities on the large surface area of the activated charcoal [21][22][23].

II. Materials And Methodology

Compartments of the water filters (Figure 1 and Figure 2) are filled with particles of natural minerals such as tourmaline, hessonite garnet and biotite mica in addition to activated charcoal. This sort of filter media combination had not been used in any other water filter yet. Activated charcoal had already been tested by many laboratories and had determined that it is capable of absorbing coloring elements, organic chemicals, taste, and odor. On the other hand, it is available in almost all commercially available water filters. As such no evaluation has been carried out to ascertain its filtering capability. The natural minerals mentioned have pyroelectric and piezoelectric properties, especially; the mineral tourmaline's pyroelectric property is quite significant and is capable of adsorbing heavy metals. This fact is ascertained by filtering water that is saturated with heavy metals through these minerals and subsequently analyzing the filtered water with the use of analytical instruments such as Energy Dispersive X-ray Fluorescence Analyzers (EDXRF). The tests provided promising results. On the other hand, these minerals do not dissolve in water. Therefore, the water coming in contact with these minerals is not harmful to humans; the formula of each mineral testifies to this effect. Finally, the filters are made in such a way that water could keep in contact with the filter media for a longer duration.

Water filter made of stainless steel for the use of small hamlets

Figure 3a depicts the external view of the water filter whereas Figure 3b depicts the detailed view of the filter along with filter media. Figure 3c depicts the internal view of a single compartment, bottom sieve plate and 'O' ring which provide the filter with water tight arrangement. Water comes through the supply pipe and goes through the one way valve followed by particle filter compartments. Basement compartment is filled with activated charcoal of 0.2mm to 0.3mm size. Thereafter biotite mica (Particle Size: 350µm to 850µm) Followed by Tourmaline (Particle Size: 250 µm to 850 µm) and Hessonite Garnet (Particle Size: 400µm to 900 µm). Water coming through the supply line goes through each chamber and gets collected to the storage tank at top. The dimension of the water filter can decide according to the water requirement and size of the hamlet.

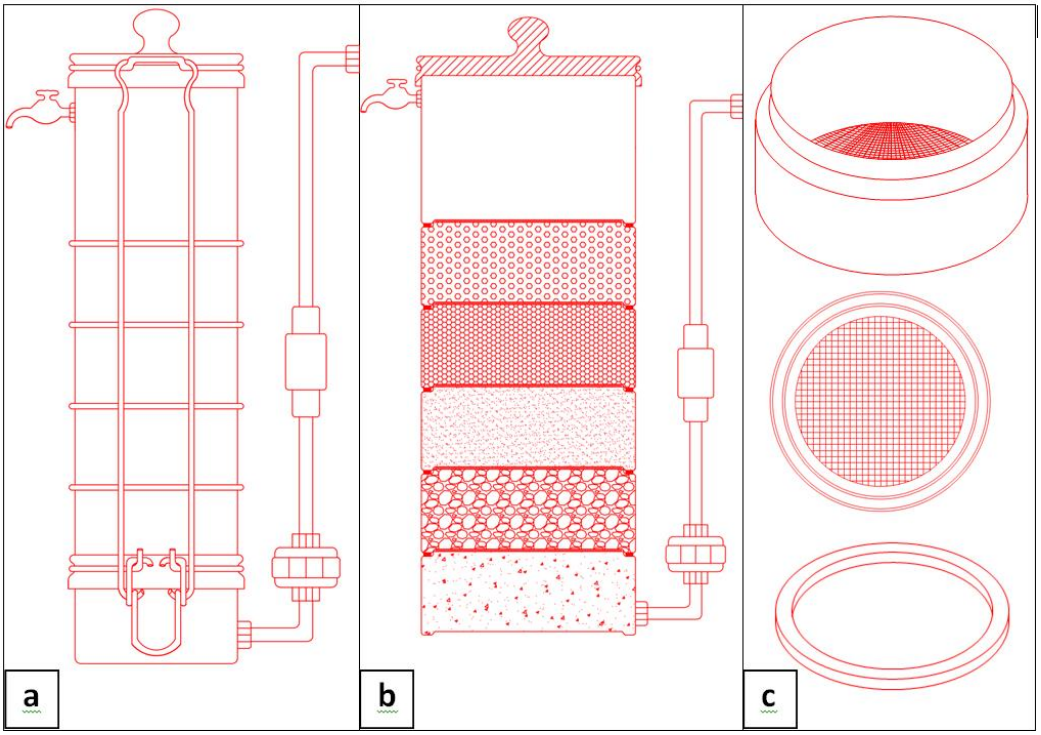

Figure 3: Water filter made of stainless steel for the use of small hamlets

Water filter assembled from commercially available low priced water filter for domestic use

Figure 4a depicts the external view of the water filter whereas Figure 4b depicts the Perspective view of the filter cartridge with its sliding door closed and Figure 4c depicts the Perspective view of the filter

cartridge with its sliding door open. Figure 4d illustrates the sliding door of the filter cartridge and Figure 4e depicts the changing of filter media whereas Figure 4f illustrates re-filled bottom cartridge top view and side view. The sliding door is the new addition made by the author and this eases the cleaning and refilling of minerals. The bottom cartridge is also refilled with 250µm to 1000µm size particles of tourmaline, hessonite garnet, and mica accordingly keeping the activated charcoal as it is. The most important case is that the original water filter illustrated in Figure 4a can be bought for a petty price. This type of mineral re-filled filter is ideal as a domestic water filter in areas having high concentration of heavy metals.

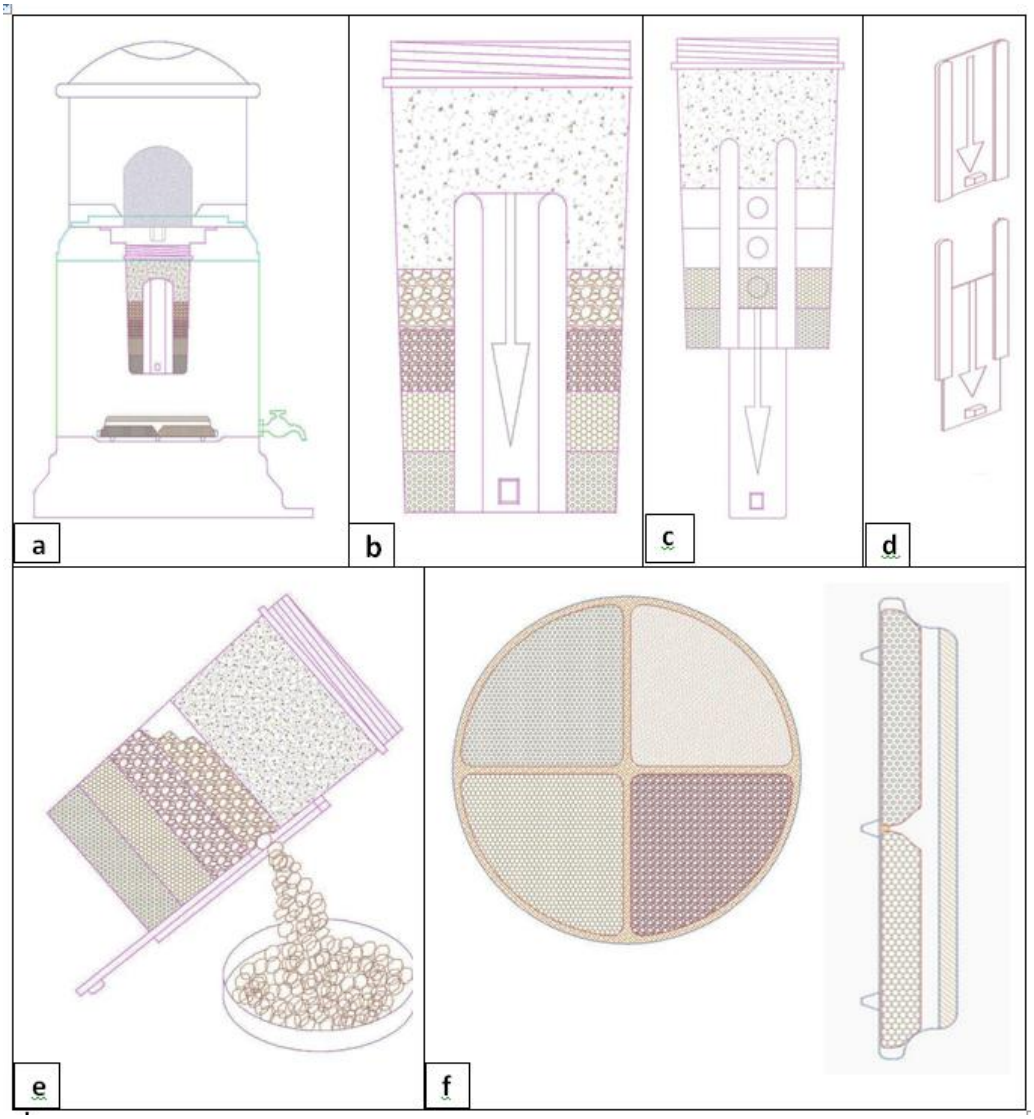

Figure 4: Water filter assembled from commercially available inexpensive water filter for domestic use

III. Results

The primary filter material tourmaline is a naturally occurring mineral with the general formula as follows.

$XY_3Z_6(BO_3)_3Si_6O_{18}(O,OH,F)_4$ where X=Na, Ca or vacancy, Y=Al, Li, Fe^{2+}, Fe^{3+} and other cations, Z=Al, Mg and Fe^{3+}.

Tourmaline possesses piezoelectric properties, pyroelectric properties and heavy metal ion adsorption properties. As such Heavy metal ions can either sneak into vacant sites or/and replace the existing metal ions.

$$Pb^{2+} + XY_3Z_6(BO_3)_3Si_6O_{18}(O,OH,F)_4 \longrightarrow Pb_xX_{1-x}Y_3Z_6(BO_3)_3Si_6O_{18}(O,OH,F)_4$$

(X=Na, Ca or vacancy, Y=Al, Li, Fe^{2+}, Fe^{3+} and other cations, Z=Al, Mg and Fe^{3+})

Tourmaline gravel of 2 mm and finer sand can remove Cd^{2+}, Hg^{2+} and Pb^{2+} ions

The same type of results was shown by hessonite garnet and biotite mica.

Table 1: Shows time course studies of heavy metal exchange kinetics

Time (min)	Element Concentration (in mg/L)			
	As	**Cd**	**Cr**	**Pb**
Initial concentration	41.77	45.41	46.73	41.68
5	34.05	37.56	43.96	28.88
10	33.90	36.86	41.99	27.49
20	33.93	36.69	40.90	27.42
30	33.47	35.79	38.91	26.52
60	33.12	33.87	39.11	26.38
120	30.41	31.57	36.71	24.11

(When As, Cd, Cr, Pb saturated water in contact with the filter media for longer duration more adsorption takes place)

Table 2: Particle size of the materials used

Tourmaline	850 µm – 2 mm
Hessonite Garnet	850 µm – 2 mm
Mica	850 µm – 2 mm
Activated Charcoal	0.2 - 0.3 mm

Initial Treatment:
All the materials were initially treated with 6 M NaOH for 2 hours at 100^{o} C temperature.

Heavy Metal Treatment:
In order to identify the heavy metal adsorption capability, each material was treated with 100 mg/ l Cd^{2+} and Pb^{2+} solutions for 3 hours.

Desorption Treatment:
Desorption was carried out by mixing with 1 M HCl for 24 hours.

Table 3: Results of the ED-XRF Analysis (unit: mass %)

Material	After Initial Treatment (NaOH)		After Treatment with heavy metals(adsorption)		After Treatment with acid (desorption)	
	Pb	**Cd**	**Pb**	**Cd**	**Pb**	**Cd**
Tourmaline	0.0002	<0.0001	0.0725	0.0219	<0.0001	<0.0001
Hessonite Garnet	<0.0001	<0.0001	0.0448	0.0022	<0.0001	<0.0001
Mica	<0.0001	<0.0001	0.2970	0.0827	<0.0001	<0.0001

As to table 3 Filter media (tourmaline, hessonite Garnet, and biotite mica) could be regenerate for multiple uses (desorption)

Industrial Applicability
Some industries spend a lot of money for the treatment of effluent water before discharging it to the environment. In most cases, the so called treated water of industries still contains harmful levels of heavy metal ions. As such the same filter (Figure 3) could be used in industries for waste water treatment (Removal of heavy metal ions) by simply scaling it up.

IV. Conclusion

The filter exclusively uses natural minerals compared to the existing filters: the filter media (natural mineral) of this study adsorbs heavy metal ions present in water during the process of filtering. Thus, the filtered water once the heavy metal ions are trapped would be quite safe for human consumption. These water filters are extremely portable and quite simple to operate.

This filter system is very inexpensive compared to various other endeavors made to supply drinking water for human consumption and it requires neither chemicals nor energy for its operation.

The filter media of most water filters has a short life span but the filter media of this study, once its life span is over, could be re-used after a simple process of purification (washing with a household acid source or washing with a 10% acid solution followed by a wash down of ordinary water)

This is only a preliminary study conducted with only limited budget, limited facilities and during the summer holiday of the university (two and half months). As such further research and modifications are necessary to ascertain the suitability of this filter to be used in areas where water is contaminated with high concentrations of heavy metals.

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