Ceramic Water Filters as a Response Technology to Geo-Hazards

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Abstract: Geo-hazards, a collective term for earthquakes, floods, windstorms, famine and drought, are intensifying with time and are obstacles to attainment of sustainable development. In particular, issues of availability of safe water are major disruptive elements causing the spread of diarrheal diseases during, and post, these geo-hazard events. Given that ceramic water filters (CWFs) have been shown to effectively remove *E.-coli* (and, by similar attributes, is effective in the removal of cholera), CWFs as a Point-of-Use (POU) technology are described as an effective option for the post-disaster phase of geo-hazards. As described herein, important dimensions of CWFs are provided, showing they can be stored effectively without suffering deterioration, are inexpensive, and are an easy technology to explain to users. Pertinent rationale for serious consideration of CWFs as a post-disaster POU is provided.

Keywords: *E.-coli*, Cholera, Point-of-Use, geo-hazards.

1. INTRODUCTION

'Geo-hazards' is a collective term for events such as earthquakes, floods, windstorms, famine and drought. Since the world is facing geo-hazard disasters at an unprecedented scale, more consideration needs to be given to potential options to decrease the obstacles for sustainable post-disaster recovery. Literature sources help to put the needs into perspective, reflecting the numbers of people displaced and death rates (e.g. CRED, 2015).

Unfortunately, geo-hazard disasters are intensifying over time for reasons including climate change and population increases, where people are increasingly living in precarious locations. While geo-hazards are attributable to many causes, climate change and environmental degradation are exacerbating the intensity and frequency of weather-related hazards, resulting in escalating economic and human losses.

Issues of geo-hazards are clearly huge and intensifying. However, a single dimension which is common to virtually all, is the disruption of water supply. Given the above evidence of widespread and intensifying impacts of geo-hazards, the world community needs to be preparing for onset of geo-hazard events. This includes the need to be prepared, to use appropriate and inexpensive water treatment technologies.

In particular, the available literature on disasters indicates that epidemics of communicable diseases do not always occur after geo-hazards but, if they do, it is usually not the geo-hazard itself, but the secondary effects of the disasters. The destruction of water, sanitation and health care services, overcrowding and population displacement into artificial, crowded refugee communities with limited water and sanitation facilities, that lead to infectious disease outbreaks (Wilder-Smith, 2005; Howard *et al*., 1996; Watson *et al*., 2007).

Overcrowding of displaced people and lack of availability of healthcare services, along with limited water supplies and inadequate hygiene and sanitation, are all contributing factors known to increase the incidence of diarrhea, respiratory infections, and other communicable diseases. All of these interact within the context of the local disease ecology to influence the risk of spread of communicable diseases and death in the affected populations.

The need for immediate action to provide a reliable system of safe water supply is apparent. Adequate quantities of safe water are preferable to small amounts of very high quality water. Each person must receive a minimum of 15 to 20 L of safe water per day for their domestic needs (WHO, 2011; Sphere, 2011). Unfortunately, it has been demonstrated that it is frequently difficult to provide even these minimum quantities of water to disaster-affected populations. One of the response options is to implement an effective Point-of-Use (POU) technology, implemented quickly, along with the necessary training needed for the users.

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2. THE MERIT OF POINT-OF-USE (POU) WATER TREATMENT TECHNOLOGIES

The most frequently observed increases in communicable diseases post geo-hazards are directly attributable to faecal contamination of water. Examples of microbial pathogen sources include (i) sediments due to erosion of soils; (ii) nutrients from animal wastes and sewage-treatment plants; (iii) animal wastes from livestock husbandry and septic systems; and, (iv) human wastes. Geo-hazards (e.g., storm, flooding and landslides) bring about not only gravitational movements, but also intense and concentrated erosion along streams and slopes denuded of their vegetative cover; it follows that this process causes an over-accumulation of sediment and pollutants into the water body.

Displaced populations in camp settings are at high risk of infectious diseases due to the secondary effects of the geo-hazards indicated above. Death rates of over 60 times the baseline have been recorded in refugee camps and internally-displaced people, with over three-quarters of these deaths caused by communicable diseases (Wilder-Smith, 2005). Epidemic-prone diseases in refugee settings are diarrheal diseases, respiratory infections, measles, meningitis and possibly, malaria. In refugee camp situations, diarrheal diseases have accounted for more than 40% of these deaths in the acute phase of an emergency, with over 80% of these deaths occurring in children aged less than two years (Wilder-Smith, 2005).

Table **1** lists a number of waterborne communicable diseases that are common, as followup to geo-hazards. Outbreak investigations have shown that common sources of infections include polluted water sources (by faecal contamination of surface water entering incompletely sealed wells), contamination of water during transport and storage (through contact with hands soiled by faeces), shared water containers and cooking pots, scarcity of soap, and contaminated foods (Wilder-Smith, 2005). The growing number of pollutants and/or toxicants entering the environment through point and nonpoint sources has led to increasing health impact concerns; nevertheless, many harmful effects are unexplored due mainly to the lack of effective detection capabilities. Lack of safe water, overcrowding, insufficient understanding of personal and domestic hygiene, nutritional deficiency, and overall poor sanitation are the major contributing factors for the spread of diarrheal diseases.

As evident from the preceding, elapsed time is key. Access to safe water, most notably through availability of POU treatment may be fundamentally important to controlling microbial illnesses.

3. CHOLERA IS ONE OF THE WORST AFTERMATHS OF GEO-HAZARD EVENTS

A waterborne disease which is particularly relevant in post geo-hazard events is cholera. *Vibrio cholerae* (*VC)* infections result from ingestion of the organism. Cholera is an acute intestinal disease caused by the bacterium *VC O1* or *O139* (the two pathogenic strains are abbreviated henceforth together as '*VC*'). Depending on the vulnerability of the person who has been exposed, the incubation period for *VC* infection can range from 12 to 72 hours (Naidoo and Patric, 2002). The small intestine is the primary site of infection with *VC* and is the source of the secretory diarrhea during cholera. In patients with severe *VC* infection, the volume of small intestine fluid reaching the colon far exceeds the maximum re-sorptive capacity of the colon, which is six liters/day. This causes profuse watery diarrhea (Cash *et al*., 1974).

Table 1: Waterborne Communicable Diseases in Natural Disasters

Disease	Transmission	Agent	Clinical Features	Incubation Period
Cholera	Fecal/Oral, contaminated water or food	*Vibrio cholerae serogroups O1 or O13*	Profuse water diarrhea, vomiting	2 hours to 5 days
Leptospirosis	Fecal/Oral, contaminated water	*Leptospira spp*	Sudden onset fever, headache, chills, vomiting, severe myalgia	2-28 days
Hepatitis	Fecal/Oral, contaminated water or food	*Hepatitis A & E virus*	Jaundice, abdominal pain, nausea, diarrhea, fever, fatigue and loss of appetite	15-50 days
Bacillary Dysentery	Fecal/Oral, contaminated water or food	*Shigella dysenteriae type 1*	Malaise, fever, vomiting, blood & mucous in stool	12 - 96 hours
Typhoid Fever	Fecal/Oral, contaminated water or food	*Salmonella typhi*	Sustained fever, headache, constipation	3 - 14 days

During cholera outbreaks, people of all ages may contract the disease, although cholera is a more severe disease in pregnant women, causing high rates of fetal loss even in women who receive adequate rehydration (Bennish, 1994). Vomiting commonly accompanies the diarrhea, especially early in the illness (Naidoo and Patric, 2002). This purging causes severe dehydration in patients recognizable by: increases in pulse rate and decreases in pulse volume; hypotension; an increase in respiratory rate; sunken eyes and cheeks; dry mucous membranes; decrease in skin turgor; a decrease in urine output; lethargy; weakness; irritability; and thirst. Some of these symptoms are also observed in malnourished children (skin turgor, sunken eyes, lethargy) making diagnosis of dehydration sometimes unreliable in poor areas (Bennish, 1994).

VC exist as natural inhabitants of aquatic ecosystems, thus making them facultative human pathogens (Lobitz *et al*., 2000; Reidl and Klose, 2002). The quantities of *VC* suspended in water are generally low (<50 CFU/L for *O1*); however, *VC* multiplies rapidly in poorly stored drinking water containers and may be found in large numbers attached to aquatic species such as cyanobacteria, algae, zooplankton, with up to 10^5 *VC* organisms measured as attached to their surfaces). The prevalence of *VC* historically is partly due to its ability to re-emerge with significant genetic variation, giving rise to new clones such as *01 El Tor* in 1994 and *O139* in 1995 and 2002 (Gubala, 2006). It causes disease by colonizing, proliferating and secreting toxins in the intestine of the infected person (Wang *et al*., 2010). Epstein (1993) has demonstrated how VC populations grew exponentially, as a result of consumption of algae and *VC* by fish, mollusks, and crustacea, such that a heavy inoculum of carriers infected with *VC* was generated.

The *VC* toxin causes watery diarrhea of such exceptional volume that hypotensive shock (abnormally low blood pressure) and death can occur within 12 hours of the first symptom. The toxigenic *O1* and *O139* strains survive in water by entering into a resting state known as 'viable but not culturable' (VBNC). Cells in the VBNC state can retain their viability and infective potential in the environment for over a year while also maintaining their associated pathogenic genes along with the integrity of their chromosomes (Chomvarin *et al*., 2007).

According to the WHO (1994), there is no substitute for drinking only potable water, practicing good personal hygiene, and preparing food safely and hence, access to potable water is a basic requirement for health. Although typically absent from wealthy countries, the impact of cholera remains significant at the global level. The world is currently experiencing its 7th cholera pandemic and has been since 1961. With unstable refugee and internally-displaced persons, geo-hazards, and lack of safe water and sanitation, cholera has reached epidemic proportions on six continents (Colwell, 2000). In 2006, 52 countries officially reported to the WHO a total of 236,896 cholera cases including 6,311 deaths; however, these numbers do not reflect the true burden of cholera due to limitations in the surveillance and notification systems of many countries where the disease is endemic, as well as having widespread underreporting due to fear of travel and trade-related sanctions (Deen *et al*., 2008).

Cholera remains a global threat to public health and an indicator of inequity and lack of social development. Researchers have estimated that every year, there are roughly 1.3 to 4.0 million cases, and 21 000 to 143 000 deaths worldwide due to cholera (WHO, 2017; Ali *et al*., 2015).

4. CERAMIC WATER FILTER AS AN EFFECTIVE POU

As referred to above, the provision of adequate quantities of safe water is a key prevention strategy to reduce the spread of cholera. When normal water supplies are interrupted or compromised due to geo-hazards, affected populations are often encouraged to boil or disinfect their drinking water to ensure its microbiological integrity. While chlorine can be very effective, its availability in times of geo-hazards makes the potential for chlorine use rather limited. The result is that treatment must be done at the POU level by one or more of boiling, disinfecting, filtering, etc.

The result is important merit for considering POU as an effective measure to protect against bacterial diseases in the post geo-hazard situation. POU water treatment technologies include any of a range of devices or methods used for the purposes of treating water in the home or at the POU in other settings. A number of POUs are available as emergency options, including sodium hypochlorite, flocculant/disinfection powder, solar disinfection (SODIS), ceramic water filter (CWF), and biosand filtration. Criteria for determining the most effective POU include:

4.1. Effectiveness in Removing Pertinent Microorganisms

Key biological contaminants, as per above, are *E-coli* and *VC*. POU filtration technologies include membrane filters, porous ceramic filters and granular media filters. Traditional membrane technology (Tchobanoglous *et al*., 2003) is generally expensive and therefore largely unknown for small-scale drinking water treatment systems in developing countries. Cloth filters such as those using sari cloth, have been recommended for reducing *VC* in water when these are associated with copepods or other eukaryotes in water (Colwell *et al*., 2003). However, these cloths will not significantly retain dispersed bacteria not associated with copepods, other crustaceans, suspended sediment, or large eukaryotes because the pores of the cloth fabric (>20 μm) are sufficiently small to exclude high percentages of bacteria. Based on the discovery that *VC* is frequently associated with zooplankton, Colwell *et al*. (2000) showed a simple filtration method involving a sari cloth folded four to eight times is capable of removing zooplankton and particulates >20 μm, effectively achieving 99% removal (2 log) of *VC*. This study was completed in 65 rural villages in Bangladesh involving approximately 133,000 individuals from September 1999 through July 2002 and a 48% reduction in cholera was observed. Hence, this technology will work in theory but it is somewhat elaborate and not feasible in many locations due to the availability of saris. Consequently, sari cloth filtration can have significant beneficial health impacts but not universally.

A study by Berney *et al*. (2006) determined the efficacy of SODIS for enteric pathogens, including *VC,* finding that bacteria are very susceptible to SODIS. *VC* were measured to be not resistant to sunlight and highly susceptible to mild water temperatures (above 40°C) of the entero-pathogenic strains studied. Nevertheless, the most interesting POU is the ceramic water filter (CWF) because of its many advantages. One of a number of designs of CWFs is depicted in Figure **1**. This type of CWF is typically constructed of clay and milled rice husk; the mixture is separated into 7-8 kg balls and pressed into cylindrical pot form (24cm x 34cm) (height X diameter) as demonstrated in Figure **2**, where the CWF is shown as inserted into a plastic receptacle which serves as a reservoir for the safe (filtered) water. Upon forming the cylindrical pot form, the CWF is then fired at 830°C to burn out the rice husk resulting in a product with a controlled porosity, thus allowing adequate transmittance of water (1- 3 L/h). Lantagne (2001) reported pore diameters ranging from 0.6 to 3 μm while van Halem (2006) reported a pore size distribution ranging from 0.02-200 μm, with a predominant pore size of 14 μm.

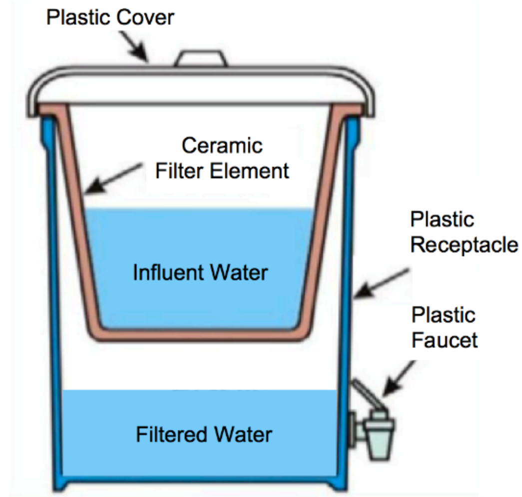

Figure 1: Ceramic Water Filter Schematic.

Figure 2: Ceramic Filter Retained in a Plastic Receptacle, Outlet Spigot from the Receptacle at Bottom.

CWFs have been shown to effectively remove *E.-coli* from drinking water (Murphy *et al*., 2010a, b). Bacteria generally range in length from 1-50 μm and rod-shaped bacteria (including *E.-coli*) are 0.3-1.5 μm in diameter and 1-10 μm in length (Tchobanoglous *et al*., 2003). *E.-coli* is gram-negative, flagellated, facultative bacillus about 2-4 μm long and 0.6-1.0 μm in diameter (Zaritsky and Woldringh 1978). As a result, the considerable majority of *E.-coli* are filtered from the source water during CWF operation.

In addition to filtration, the development of a biofilm on the surface of the CWF during operation of the filtration device, aids in the removal of pathogens. Silver nitrate and/or silver nanoparticles have also been utilized as disinfectants in some cases (Mittelman, *et al*., 2015). Hence, the combination of filtration, disinfection and biofilm development result in significant removals of microorganisms from source water during CWF operation.

In field studies, as apparent from Figure **3**, the *E.-coli* removal efficiency associated with individual CWFs studied during field trials in Longhai, China. Farrow *et al*. (2017) reported field removal (i.e. by the villagers in Longhai), efficiencies of *E.-coli* ranging from 75-100% (as opposed to laboratory studies where removal efficiency was observed to range from 97.7-99.9%), with average *E.-coli* removal efficiencies in the field, and lab *E- coli* observed to be 94.7% and 99.5% respectively. The differences (field versus lab) in removal efficiency are attributed to contamination of the filter element and receptacle when employed in the field (as would be expected also in post geo-hazard conditions) indicating the importance of technology training, to ensure adequate performance during field use by end-users. Even at these reported levels, the field-level removal effectiveness of *E.-coli* is decidedly different from the raw water and hence, would be very helpful in reducing the *E.-coli* exposure under emergency conditions. One or two log removal would be enormously helpful. Given the similar sizes of *E.-coli* and *VC*, the merit of the CWF is evident. *VC* is a comma-shaped, gram-negative, flagellated, aerobic bacillus whose size varies from 1-3 μm in length by 0.5-0.8 μm in diameter (Handa, 2010) which, due to the similarity of *E.-coli* and *VC*, the CWFs are able to effectively remove much of the *VC* from drinking water. As well, due to size exclusion, CWFs can easily filter out zooplankton from water further adding to the probability that *VC* is significantly attenuated by CWFs.

Given that CWFs have been shown to effectively remove *E.-coli* (and bacteria in general), CWFs as a POU technology have great potential; however, they have not been widely considered for use in geo-hazard recovery in emergencies. Three situations involving CWF interventions in emergencies include, from the Dominican Republic after flooding in 2003 (Clasen and Boisson, 2006), from Haiti after flooding in 2003 (Caens, 2005), and from Sri Lanka after the tsunami in 2004 (Palmer, 2005). The microbiological improvement of water documented in the Dominican Republic intervention indicates that these improvements can also be available in emergency and post-emergency contexts (Clasen and Boisson, 2006). These POU technologies may be especially effective during the initial phase of an emergency when responders cannot yet reach the affected population with longer-term solutions (Lantagne and Clasen, 2009). However, research on POU technologies has primarily occurred in the development context, not the emergency context.

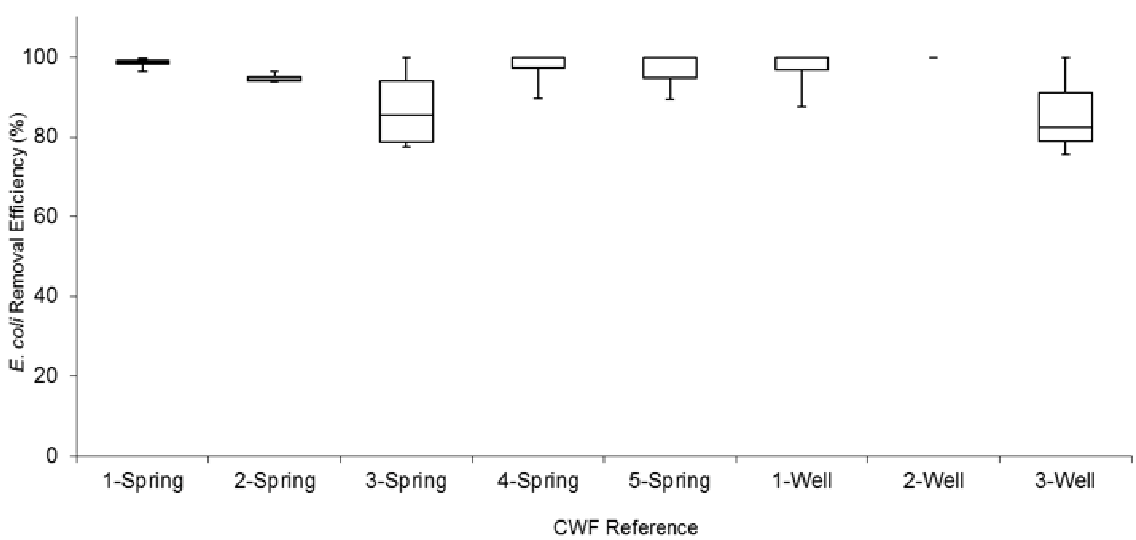

Figure 3: Removal efficiency of *E. Coli* during field studies in Longhai, China. Box represents 25^{th} and 75^{th} percentiles; lines extending vertically from the boxes (whiskers) represent maximum/minimum values.

4.2. Cost Is Important to the Selection of the POU

There are a number of such POU options, with prices that vary from a few dollars to substantial amounts. For example, Lifestraw is also possible but the technology is expensive (175$) (Thomas, 2016). The purchase price of the clay water filter is typically around 6 $.

4.3. Ease of Technology Transfer

There is also the issue of technology transfer, meaning the training of users to properly use the technology. While it can be more difficult to conduct in emergencies, training is a necessary component of the emergency implementation strategy. User preference and transfer of technology should be considered when deciding which POU technology to implement. User acceptance and training have been identified as one of the most difficult factors in implementation of a POU (Murphy *et al*., 2010c). Equally important, it is straightforward to train a user in the use of the CWF. Cleaning is accomplished by a simple brushing of the surface of the filter to remove sediments.

In the development context, the higher levels of user adoption have been documented when POU technologies are promoted in schools or health clinics and when motivational interviewing and social marketing are employed as "behavior change communications strategies" (Lantagne and Clasen, 2009). Training was identified as a factor contributing to the high usage of CWFs in both the Sri Lanka tsunami and Dominican Republic flooding interventions. Although the training was not extensive, and follow-up visits were not needed to ensure continued usage, some training at the outset on operation and maintenance of the CWFs was identified as "vital" (Palmer, 2005; Clasen and Boisson, 2006). It is necessary that all recipients be provided with all the materials necessary to use and maintain the CWFs including the filter element, plastic receptacle, brush for cleaning the element, etc. In the development context, POU water treatment technology interventions need to select culturally appropriate options, distribute the products reliably and work with trusted local community educators to encourage healthy water practices. It appears that these factors translate into the emergency context, and it is recommended that materials be developed specifically for the emergency context to assist organizations in conducting the training necessary to ensure project success (Lantagne and Clasen, 2009). Continued use of CWFs post-emergency as well as beyond, may occur (where villagers in Longhai specifically requested to be allowed to continue to use the CWFs (Farrow *et al*., 2017).

Additionally, the importance of access to replacement CWF parts for recipients in post-emergency situations depends on the project goals of the organization and the type of emergency, and therefore may be considered either unimportant or vital. In the instances where the goal is to provide emergency relief that translates into long-term development interventions, establishing a replacement part supply chain is necessary for the sustainability of such a project. In these cases CWFs should only be implemented if the necessary materials to manufacture replacement parts are locally or readily available. A benefit of products that are locally available prior to emergencies is that if adequate stocks are maintained, the filters can be deployed quickly and efficiently. Further, the CWF performance does not deteriorate over time and hence are highly adaptable for the emergency situation and are not expensive.

If the above-mentioned factors are implemented in emergency interventions, continued use of the POU technology can occur post-emergency. In follow-up studies conducted in communities where CWFs were distributed, it was found that in one Sri Lankan tsunami response community, 23% of people were using the ceramic filter three months after distribution, in the Dominican Republic, 48.7% of households were correctly operating filters 16 months after distribution with 54% of water samples from operating filters (26.1% of total) free of thermo-tolerant coliform (Palmer, 2005; Clasen and Boisson, 2006). In Haiti, users expressed a desire to continue using the filter (Caens, 2005). These studies highlight that a one-time distribution of CWF accompanied with training may lead to the long-term usage of POU water treatment.

4.4. No Deterioration in Effectiveness Occurs During Storage

The CWF technology doesn't deteriorate with time i.e. could be stored in an as-ready condition and be distributed at times of emergency. The weight of the CWF is approximately 6 kg, ensuring availability for manufacturing and storage (see Figure **4**), available for use in the event of an emergency as the CWF is based primarily upon the physical removal mechanism (although removal effectiveness will improve over time with continued use due to the development of the biofilm). Products that can be locally made and hence locally available prior to emergencies is that if adequate stocks are maintained, the filters can be deployed quickly and efficiently.

Figure 4: Ease of Storage of CWFs.

CWFs can be highly effective after the acute emergency has passed when recipients are moving from transitional to more permanent living structures. A sense of permanency allows for more time and receptivity to training on the operation and maintenance of the filters. In the Sri Lanka tsunami intervention, lack of living space was identified as a barrier to their use, and recipients living in an emergency shelter type were associated with having a greater number of problems with the filter (Palmer, 2005).

CONCLUSIONS

Concerns with geo-hazards are increasing as they are increasingly disruptive. One of the most important consequences of geo-hazards is the displacement of people and the circumstances of water needs, post geo-hazard. Disease burden arising from exposure to being without safe water, and developing illness may be profound, post geo-hazard.

POU water treatment technologies structured around use of a ceramic filter is an effective strategy in response to a geo-hazard emergency. The filters are inexpensive, able to be stored without deterioration and hence easily available for distribution in post-emergency situations, and easily introduced to recipient populations for their effective use. Further, the technology assessment shows that CWFs will be effective at removal of *E.-coli H157O7* and *VC*.

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